Ergonomic redesign of hand-held floor-polishing device for reducing the occupational exposure to vibration and improvement of usability

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Submitted by

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Under the supervision of

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February 2020

Dedicated to my family

Declaration Certificate

28th February 2020

I hereby declare that the thesis entitled “Ergonomic redesign of hand-held floor-polishing device for reducing the occupational exposure to vibration and improvement of usability” being submitted in the partial fulfillment for the award of Ph.D. degree, is an authentic work of my research work carried out during the period from July 2015 to December 2019 in the Department of Design, Indian Institute of Technology Guwahati under the supervision of Dr. Sougata Karmakar. The thesis has not been submitted by me earlier for any other degree or diploma.

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The thesis entitled “Ergonomic redesign of hand-held floor-polishing device for reducing the occupational exposure to vibration and improvement of usability “presented herein by Mrs. Susmita Nath (Roll No. 156105008) was undertaken under my supervision. The volume of work submitted for the degree of Doctor of Philosophy of the Indian Institute of Technology (IIT) Guwahati has not been submitted by her earlier for any other degree or diploma.

She has undergone six specified courses and fulfilled all the requirements as mentioned in the rules and regulations for submitting the thesis for the Ph.D. degree of the Indian Institute of Technology Guwahati.

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Abstract

Globally, a large workforce contribute their skills in different informal sectors viz. construction, transportation, agriculture, etc. In many instances, they are exposed to vibration transmitting equipment/ hand-tools (powered and non-powered) and workstations as a part of their daily work. Depending on the intensity and duration, vibrating tools can cause work-related disorders like hand-arm vibration syndrome (HAVS), vibration white finger (VWF), and carpal tunnel syndrome (CTS). Frequency related symptoms include damage to blood vessels and nerves (40 to 500 Hz), back and neck ache (8 to 12 Hz), chest and abdominal pain (4 to 10 Hz), headache and muscular tension (10 to 20 Hz) (Mansfield, 2004). Among different unorganized sectors, stone / floor polishing is one such occupation where the workers are prone to hand-arm vibration (HAV) and the handheld vibrating polishing devices are being used in the construction process for the finishing of the floors/ stairs made up of stone/ mosaic. Usages of these vibrating devices may lead to irreversible hand injuries.

In Indian, 90% of the total workforce is employed in informal sectors (IBEF, 2016). The Government of India has introduced a smart city mission in the year 2015 to develop a hundred cities to make them citizen -friendly and self-sustainable. Among the hundred cities nominated, one is Guwahati city. With the initiation of smart city project, the manifold increase in construction work all over the Guwahati city has motivated the present researcher to select Guwahati city as the study location.

Floor polishing is an integral part of the construction sector. Therefore, stone polishing workers have been undergone prolonged working. Thus, from occupational point of view, they are exposed to a higher dose of daily vibration. While research and development activities related to occupational vibration are in full swing in the developed countries, it is not very promising in the Indian scenario.

The literature on the impact of occupational vibration (especially on floor polishing sector) on human health and subsequent design intervention is scantly reported from Indian unorganized or informal sectors. From the literature review, in the Indian context, it was evident that the impact of HAV on the health of workers involved in various occupational set up (specifically in construction sectors) lacks attention among researchers. Moreover, applied research targeted about design interventions to reduce vibration content in machines/ tools

has been rarely carried out. Based on the literature survey and initial field visits, mainly four **research questions** were raised.

1. What is the level of vibration to which the workers are exposed while working with floor polishing device in the unorganized sector?
2. What are the possible ways to reduce biomechanical stress associated with the hand and arm of the operators involved with hand-held floor polishing device in the unorganized sector?
3. Can a supportive mechanism for avoiding load holding during use of hand-held floor polishing device significantly reduce the muscular effort required to perform polishing activities?
4. Can design intervention of hand-held floor polishing device ameliorate vibration exposure of the workers in the unorganized sector working with vibrating tool/equipment/device enhance work performance of the workers?

Following the pilot study, various **problems** have been noticed as described below.

i) High level of transmission of vibration from the polishing device to the hands and arms of the operator.
ii) Using of the polishing device for a prolonged duration (8 to 10 hr) during a shift.
iii) Awkward posture and sustained load holding for around 30-45 minutes at a stretch.
iv) Repetitive and strenuous manual actions.
v) Lack of ergonomic considerations in the design of the polishing device.

Therefore, the present research **aimed** to study the occupational exposure to HAV during the use of hand-held floor polishing device and come up with ergonomic design intervention to curtail vibration content while maintaining the usability. To achieve the aim and based on problem statements, the following **objectives** were framed.

1. To study the health hazards among the floor polishing workers.
2. To quantify vibration exposure level among the workers while using hand-held floor polishing machine.
3. To understand the effectiveness of specific of vibration reduction interventions and their practicability.
4. To introduce ergonomically designed intervention of hand-held floor polishing device to reduce vibration content.
5. Validation of redesigned hand-tools and evaluating their effectiveness in terms of reduction of vibration exposure and improvement of usability.

Three hypotheses were conceived for ensuring a proper direction to the research work. They are as follows:

H1: Design Interventions of the polishing device by modifying the gear train mechanism and using vibration dampening material would significantly reduce vibration generation and transmission and thereby exposure to vibration.

H2: Supportive/weight-bearing mechanism for avoiding sustained load holding during use of hand-held floor polishing device can significantly reduce muscular effort.

H3: Proper anthropometric and biomechanical compatibility of hand-held floor polishing device can significantly improve the usability of the device.

Following a questionnaire study, it was found that the occurrence of pain/ discomfort among the polishing workers was prevalent. Perceived vibrational discomfort while operating the polishing device was another factor that significantly affected the prevalence of body parts discomforts, mainly in the wrist, elbow, and shoulder of the workers. A high proportion of workers reported discomforts at the neck (48.9%), shoulder (51.1%), wrist (84.4%), elbow (83%), feet (53.3%) and knee (31.1%).

During the polishing work, various awkward postures like forward bending of the trunk, forward and side bending of the neck; chin kept on the knee, forward side bending, hands supported on the knee along with frequent forceful arm movements were noticed irrespective of working location (floor, wall, staircase). To estimate the ergonomic risks related to the polishing workers' adopted postures, postural load was analysed using the REBA method. The analysis showed that the REBA grand score was high (floor=9, wall base 7, staircase=10) in all cases of polishing activities. It indicated high risk leading to further investigations and changes of the working tool/ equipment/ device, the introduction of the proper work-rest cycle, etc. at the earliest.

The existing device has an improper handle design. Earlier reported studies mentioned that the perceived discomfort and fatigue are associated with involvement of localized forces at the handle interface (Gurram et al., 1995; Singh and Khan, 2012). There is no dampening material on the system. There is sustained load holding during the use of the existing device as the workers hold the device by both hands. A systematic product development process was adopted for redesigning the existing hand-held floor-polishing device. A user and market survey was carried out to gain information regarding the type of device used for stone polishing activities. After getting information on the design fallout of the existing device, brainstorming was performed to generate ideas focusing on the functional needs of the floor-polishing device. The Morphological chart was prepared to combine all the essential functions of the floor-polishing device along with the possible solutions. The concept created based on the functions of the floor-polishing device was screened by using the Pugh Chart. Before developing the final prototype, digital mock-ups (CAD model) was drafted to figure out all the fine details of the product. The final prototype was fabricated in the department workshop of IITG.

In the redesign polishing device, a supportive frame has been provided to withstand the load of the whole device and to minimize the vibration occurring due to the planetary gear trains from compound gear trains to reduce the external shock, which makes the device moves away from the polishing-surface. Due to this modification in the gear system, less force is required in case of the redesigned device for smooth movement on the surface. The redesigned device was tested in real working conditions. It was given to the workers to work for seven days for habituation with the redesigned device.

To check the effectiveness of the new design in comparison to the existing one, the magnitude of vibration was measured at the handled of the device and right wrist of the polishing workers. The vibration intensity was found beyond the exposure action value (2.5m/s^2). Average daily vibration exposure A(8) value of 3.11 m/s^2 at the handle and 2.79 m/s^2 at the operator's wrist were found in case of the existing floor-polishing device whereas 1.06 m/s^2 at the handle and 0.95 m/s^2 at the operator's wrist were noticed in case of redesigned polishing device. The Wilcoxon signed-rank test exhibited a significant difference in the scores of daily exposure value A (8) (in m/s^2) at the handles between the existing and redesigned polishing devices ($Z = -3.408$, $p =<0.00$). This result indicated that there was a reduction in vibration transmission from the handle to the operator's hand while operating redesigned polishing device.

There was also significant difference in requirement muscular effort during operation of the existing and redesigned polishing device. The muscular effort were recorded using EMG system mainly for four muscles which include Deltoid, Bicep, Flexor Digitorum Superficialis (FDS) and Extensor Carpi Radialis (ECR) showed that there were decrease in the requirement of muscular strength/effort (%MVC) for the redesign polishing device. The strength required for the redesigned device was lower than the existing device by 62.73% for Deltoid, 79.72% for Bicep, 12.77% for FDS, and 82.25 % for ECR. The Wilcoxon signed-test showed a significant difference in muscular strength requirements for Deltoid muscle ($Z = - 3.180$, $p<0.001$), Bicep muscle ($Z= - 3.180$, $p< 0.001$), ECR ($Z= -3.180$, $p<0.001$) while operating existing and redesigned polishing device.

According to the feedback, the polishing workers who participated in testing and feedback of the redesigned device were satisfied in terms of the quality of polishing on the floor surface. System Usability Scale (SUS) was administered for evaluating the usability of both the existing and redesign floor-polishing devices involving 15 polishing workers. An average score of all the respondents was calculated after each question of the SUS questionnaire was rated by the polishing workers for both existing and redesign floor polishing devices. The average SUS score for the existing floor polishing device was 13.45, which meant ‘awful’, and ‘unacceptable’ usability ratings. Similarly, the average SUS score for the redesign floor polishing device was 86.8, which meant ‘excellent’ and ‘acceptable’ level of usability (Bangor et al., 2008, 2009).

The hypotheses formulated at the commencement of the research work have been tested by fulfilling various objectives. The gear mechanism of the fabricated polishing device was changed from compound to planetary gear to bring the motor axle and output shaft (attached with polishing stone) on the same vertical axis to avoid jerk and reduction of vibration. Direct transmission of vibration energy to the operator’s hand-arm was reduced due to the developed supportive frame around the polishing device to withstand the load of the whole device and stabilizing the load on three legs connected with the frame. Moreover, vibration dampening coating material provided on the handle of the redesigned device reduces the vibration transmission to the hand- arm system during polishing work. The data collected using hand-arm vibration meter revealed that the eight-hour energy equivalent frequency-weighted acceleration magnitude [A (8)] for each of the participant was more than the recommended daily average vibrational exposure (action value = 2.5 m/s^2 and exposure limit = 5 m/s^2) for the existing device. Average daily vibration exposure A(8) value of 2.84 m/s^2 at the handle and 2.79 m/s^2 at the operator’s wrist were found in case of the existing floor-polishing device whereas 1.06 m/s^2 at the handle and 0.95 m/s^2 at the operator’s wrist were noticed in case of redesigned polishing device. There was a significant difference ($p< 0.001$) in vibration generation and transmission between the existing and redesigned polishing device as evident Wilcoxon paired test. Thus, it can be stated that **hypothesis H1 is accepted**.

Workers used to undergo sustained load holding (2.8 kg without sanding stone) of the existing polishing device for a prolonged duration (8 to 10 hr) during a shift. In case of redesigned polishing device, the weight (3.9 kg without sanding stone) of device is borne by the supportive structure on the ground. Thus, there is no requirement of sustained load holding during manoeuvrability of the device. It has distinct provision for easy assembling and dissembling of the polishing device with the supportive frame. The former device did not have any spring mechanism where the variation of applied pressure was controlled by muscles of the hand and arm. However, in the redesigned device, there is a provision to adjust the pressure with the help of spring mechanisms at the legs of the polishing device as per the requirement of the floor/ polishing surface.

Due to the supportive structure for load -bearing, there were significant reduction of muscular effort (% MVC) for polishing activities in case of redesigned device. The strength required for the redesigned device was lower than the existing device by 62.73% (Deltoid), 79.72% (Bicep), 12.77% (FDS), and 82.25 %(ECR). The Wilcoxon signed-test showed a statistically significant change in muscle strength levels for Deltoid muscle (Z = - 3.180, p<0.001), Bicep muscle (Z= - 3.180, p< 0.001), ECR (Z= -3.180, p<0.001) while operating existing and redesign polishing device. This proves that the supportive/ weight-bearing mechanism is helpful for avoiding sustained load holding during the use of hand-held floor polishing device and thereby significantly reduce the muscular effort for polishing activities (**Hypothesis H2 is accepted**).

Handles of the existing polishing machine was not properly designed by due consideration of anthropometric and biomechanical compatibility of the targeted user population. The Grip diameter of the existing device was 35 mm and it was hard plastic coated. In the redesigned device, handle grip diameter (42 mm) and length were designed as per hand anthropometry of the Indian male population and there was soft-rubber coating on the handle for a comfortable grip. The addition of roller ball caster unit at the bottom of the 3 supportive legs along with the provision of two hand manoeuvrability helps in smooth movement of the redesigned device on the floor-surface. The redesigned polishing device has the provision of attaching the handle on both the right and left side of the frame as per the requirement of the hand-dominance of the workers. The Redesigned handle of the device improved the wrist posture during the polishing activities, as was evident from the postural score of the wrist from the REBA score table. Following usability evaluation using the System Usability Scale (SUS), was observed that the average SUS score for the redesign floor polishing device was 86.8 which meant ‘excellent’ and ‘acceptable’ level of usability. This was a great improvement is SUS score in comparison to existing device with the average score of 13.45. Thus, it could be stated that the **hypothesis- 3**: ‘Proper anthropometric and biomechanical compatibility of hand-held floor polishing device can significantly improve the usability of the device’ is accepted. It implies that

designers/engineers should concentrate on anthropometric and biomechanical data during the design of the hand-held vibrating tool/equipment/device.

The current research has demonstrated how to come up with appropriate ergonomic design solution against a given problem. The detail methodology of product design innovation has been followed here. It involves user study and market study for design limits selection; generation of product concepts following brain storming and using Morphological chart; screening of final concept using Pugh chart; mock-ups development, prototype development; and user trial and feedback from real field condition. The intervention strategies to address each of the identified problems such as (a) use of planetary gear mechanism (by replacing compound gear) to reduce jerk and vibration; (b)use of supportive structure and vibration dampening material towards diminishing vibration transmission to hand-arm of the workers; (c) provision for the vertical adjustment of the device to accommodate polishing stone of different thickness; (d) proper casing of the device to ensure electrical safety; (e) changing the dimension and design of the handle for anthropometric and biomechanical compatibility; (f) provision of attaching the handle on both left and right side of the device for facilitate as per workers hand dominance and operational requirement; (g) supportive frame with 3 legs on the ground to avoid sustained load holding by hands; and (h) use of roller ball caster unit at the bottom of the 3 supportive legs for the smooth movement of the redesigned device on the floor-surface.

The research work notably imparted to the existing knowledge base of occupational health evaluation in the context of the industrially developing countries like India in the field of occupational vibrations in construction sectors. Current research also demonstrated innovative design intervention as mitigation strategy to adverse impact of ergonomic stressors on workers' health. Research outcome of the thesis could be able to ameliorate the vibration exposure of the workers during the use of vibrating device (hand held floor polishing device) and this would also facilitate the improvement in quality and efficiency of the system as well as life of the polishing workers in the unorganised construction sectors.

Keywords: Ergonomics; Product design; Occupational vibration; Electromyography; Usability; Unorganised sector

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1. Introduction

In India, 92% of the total workforce is employed in the informal sectors like construction, transportation, agriculture, etc. International Labor Organization (ILO) has defined the informal sector, where various economic activities take place outside the system of the private, corporate, and public establishments. It is characterized by small-scale operations, labor intensiveness, low technology involvement, low capital endowments, unregulated market, unskilled workforce, and learning of skills outside the formal education system. The informal sector does not obey the established regulations of governing labor practices, taxes, and licensing (ILO, 2016). According to the report of the 66th round of NSS (from July 2009 to June 2010), among all the workers in India engaged in agriculture-related (AGEGC) and non-agricultural sectors, nearly 71 % were in the informal sectors. Out of this, 74% in the rural areas and 67 % were found in the urban areas. It is worthy to mention that the share of non-agricultural workers who are engaged in the informal sectors, was 71% in rural areas and 67% in urban areas (NSS, 2012).

The workers engaged in these informal sectors are victims of different occupational hazards and psychological stresses. Workers use varieties of equipment/ devices (air hammer, drilling machine, floor polishing machine, earth tamper, pavement breaker, etc.) for a period of 8 – 10 hours during a shift. The wide use of these tools leads to physical, physiological, and musculoskeletal disorders among the workers (McCallig et al., 2010). Vibration can affect human health negatively and cause irreversible hand injuries in terms of neurological, vascular, and musculoskeletal disorders (Dewangan and Tewari, 2009). Due to repetitive and manual long-term usages of vibrating devices, workers suffer from vibration-triggered diseases like ‘vibration-induced white finger (VWF)’ or ‘hand-arm vibration syndrome (HAVS). Thus, various health disorders may happen in the workplace due to vibrational exposure that leads to a reduction of work efficiency and productivity among the worker.worker.

Occupational vibration arises from a wide variety of processes and operations of power tools performed in various sectors e.g., construction, agriculture, and mining. Whole-body vibration (WBV) occurs when the human body is supported on a surface that is vibrating, e.g., in all forms of transport and when working near some industrial machinery. WBV is transmitted to a person’s body through exposure with a vibration source, mainly through sitting or standing on a vibration source (seat and floor). The transmission of vibration is greater in the vertical sitting position to the lower spine than in standing posture

(Matsumoto and Griffin, 2002). There is strong epidemiological documentation that the prolonged subjection to WBV is related to a high risk of low back pain, lumbar-vertebral disc disorders, and deterioration changes in the spinal system (Bovenzi and Hulsh, 1999). Vibration exposure affects different parts of the body, and it mainly depends on the factors like the intensity of vibration, dispersal of the movement within the body, body postures, the vibration frequency, direction, and time-span. The common consequences of ride vibration are impaired activities; diminish natural ease and motion sickness. The international standard for whole-body vibration has set three standards to evaluate vibration in various circumstances These include conservation of performance planning, conservation of health/safety, and conservation of comfort (Mehta et al., 1997).

Hand-transmitted vibration (HAV) occurs when the vibration enters the body through the hands, e.g., in various work processes where hands or fingers hold percussive power tools or vibrating workpieces. HAV is a considerable threat to many employees in many industries and occupations. Regular exposure to vibration for prolonged duration can affect the operator's health. However, the chance of ill health caused by vibration can be possibly controlled through regulation and proper assessment of risk factors. Depending upon the intensity of generated vibration, vibrating tools cause health impairment like hand-arm vibration syndrome, carpal tunnel syndrome, damage to blood vessels and nerves (40 to 500 Hz), back and neck ache (8 to 12 Hz), chest and abdominal pain (4 to 10 Hz), headache and muscular tension (10 to 20 Hz) (Mansfield, 2004).

Many studies had mentioned that the continuous subjection to the hand-transmitted vibration from any vibrating tool had the highest chances of disorders in arteries, veins, capillaries, spine, nerve, bones, and joints. The composite of previously mentioned disorders is known as hand-arm vibration syndrome (Bovenzi, 1990; Dewangan and Tewari, 2009; Mandal and Srivastava, 2006). The vascular section of the hand-arm syndrome characterized by a low form of Raynaud's phenomenon is known as a vibration-induced white finger. Some studies investigated the association between white finger and vibration exposure. Vibration induced white finger has been included in the European Schedule of recognized occupational disease (Commission of the European Communities, 1990). The Government of India has recognized exposure to vibration as the crucial factor that influences productivity, economic as well as on social development, health, and safety of the workers. Ministry of Labour and Employment, 2009 has mentioned that the prevention of white fingers and vibration exposure is equally important for safety and health standard at work. Two distinct procedures mainly evaluate hand-transmitted vibration i.e. establishment of hand-arm vibration exposure limits with safe working conditions and evaluation of characteristics of vibration transmissibility in the hand-arm system. The first procedure directly evaluated the vibration transmissibility at hand and arm while the second procedure evaluates force at the driving point of hand that indirectly assesses the vibration power absorption (Saha and Kalra, 2016). The number of workers affected by vibration exposure during working with vibrating tools depends upon the number of workers performing jobs involving exposure to vibration and the types of operational machine/ equipment/ device.

Occupational histories of the operators of the vibrating tools are not kept in the record in unorganized sectors, thus the nature of vibration exposure and thereby complications of the workers is difficult to ascertain. Most of the vibrational equipment/ devices used in occupational purposes exceed the exposure limit of ISO standard (Singh and Khan, 2014; Mandal and Srivastava, 2006; Tewari and Dewangan, 2004). There is also no quantifiable data from which one can estimate the extent of harmful vibration levels generated from various machines/ equipment used in the various informal sectors. There is a lack of awareness about the ill hazards of vibration among the workers, and most of them are not aware of the proper implementation of engineering control of equipment/device as well as a change in work practices that can also contribute towards the reduction in health risks. In the mining industry average of 18% of employees are found to be exposed to vibration at work (Mandal and Srivastava, 2006). The construction industry is one of the most hazardous industries where the average fatal Accident Frequency Rate (FAFR) was 15.8% employees/ year (Tiwary and Gangopadhyay, 2011). Similarly, in the agricultural sector exposure to WBV and HAV is the primary concern. It is reported that vibration transmitted to the hands and arms of the operators through the handle of the hand tractor causes discomfort and early fatigue and reduces the efficiency of their work.

In the workplace, workers generally use vibratory tools discontinuously. Assessing exposure to a different level of vibration intensities of the vibrating tool is immensely difficult as data recording is generally not possible throughout the working day. The measurements can be obtained only for a few minutes. Thus, the real exposure time to vibration varies from the calculated one. The significant variation in the vibration acceleration of the vibratory tools is another source of uncertainty of the measured value. Moreover, the grip strength can alter the result of vibration measurement on the handle, the condition of machines/devices, and the working state. The measurements of vibration for vibratory tools should be accomplished several times to get the most accurate value of measurement vibration.

Hand-held floor vibrating polishing devices are used in floor polishing activities of the construction process to control the surface finish and quality of the stone/mosaic. Polishing activities require prolonged repetitive and manual usage of vibrating devices that led to significant health disorders like ‘Vibration-induced white finger (VWF)’ or ‘hand-arm vibration syndrome (HAVS)’. While research and development activities related to occupational vibration are in full swing in the developed countries, it is not very promising in the Indian scenario. Literature about the impact of occupational vibration (especially on floor polishing sector) on human health and subsequent design intervention is scantily reported from Indian unorganized or informal sectors. Theoretical and applied researches on vibration are happening all around the globe including India. However, applied research targeting design interventions to reduce vibration transmission from vibrating machines/ tools to human body parts is rarely carried out in India. Hence, in the present research, an attempt has been made to go for design modification of existing floor polishing hand tools to reduce the impact of occupational vibration on the physical well-being of the floor polishing workers.

1.1 Ergonomic stressors in work place

One of the crucial ergonomic stressors is exposure to WBV and HAV vibration in various occupational sectors. Work-related injuries and diseases cause persistent damage to the health and wellbeing of the workers around the globe. WBV is a serious health concern, which exists in various sectors including transportation, construction , and industrial shop floor. The WBV harmful impacts are generated by a compound force distribution consequence because of the oscillatory movement of the body (ISO 2631-1, 1997). Exposure to WBV is one of the common problems in the TWU sector. Around 22.3% of all workers in the TWU (Transportation, warehousing and utilities) missed the number of days of work because of injury and diseases caused by vibration (Bureau of Labour Statistics, 2006; Krajnak, 2018). There was also confirmation that WBV may increase the risk of workers developing specific cancers (Young et al., 2009; Nadalin et al., 2012; Jones et al., 2014; Waugh et al., 2016). Similarly, BLS (2006) had mentioned that around 8% of the labor force is engaged in the agriculture sector, workers doing crop production and animal husbandry and in the forestry sector are likely at the risk of subjection to both HAV and WBV. Around 15.35% of workers in these sectors incur an injury or illness that results in absence of work.

Again, millions of the workers in the developing countries working with hand-held vibrating equipment/devices frequently are subjected to hand transmitted vibration in their work. The employee in the fishing industry are subjected to WBV and HAV vibration produced by the motor and lift equipment/ device on boats or by the movement of the boat mainly in rough waters. A worker who cleans fishing vessels in large bodies of water and who perform water rescues may be subjected to impact or shock vibration when moving through rough water (Ye at al., 2012; Howarth and Griffin, 2015; Zhou and Griffin, 2017). Johnson et al. (2017), reported that about 79% of workers employed in the manufacturing sectors are exposed to extreme vibration. About 12.5% of such people missed days of work due to illness or injury and this finally led to technical difficulties and reduced quality of life.

1.2 Health disorders due to occupational exposure to vibration

Extensive use of vibrating equipment/ devices is a significant cause for transmitting vibration from that equipment/device to the hands, arms, and shoulders of the operator. Vibration transmission leads to discomfort to the operator of the vibrating machine/ device and causes early fatigue (Singh and Khan, 2014). It is also noticed that patients diagnosed with HAV syndrome either are normalized or continue to degrade more. It affects the self-perceived health and workability, difficulties in performing the day-to-day activities that were strongly associated with reduced grip strength and pain of the workers. The identification of HAVS is difficult and requires proper recording, skilled examination and the use of a variety of experiments like the thermal and vibration perception, nerve conduction tests and vascular imaging of the hand to confirm diagnosis (Harada and Mauro, 2008). In many studies, it has been mentioned that the workers were not aware of the level of the vibration transmitted to the hand-arm system (Singh and Khan, 2014; Margarita et al., 2008), and in some studies, it was mentioned that self-reported exposure time evaluation was found to be more than the real observation evaluation (McCallig et al., 2010).

The human reaction to vibration depends mainly on the magnitude, frequency, and direction of the vibration signal (Griffin, 1996). The harmful health effects of whole-body vibration can occur in the low-frequency range from 0.5 to 80 Hz. For hand-transmitted vibration, frequencies from 6.3 to 12.50 Hz can provoke disorders in the hand-arm system. Apart from the physical characteristics of vibration, some other factors are believed to be related to the injurious caused by vibration e.g., the duration of exposure (daily, yearly and lifetime cumulative exposures), the pattern of exposures (continuous, intermittent, rest periods), the type of tools, processes or vehicles which produce vibration, the environmental conditions (ambient temperature, airflow, humidity, noise), and the dynamic response of the human body (mechanical impedance, vibration transmissibility, absorbed energy and individual characteristics) (Bovenzi, 2011).

The factors that influence the human response to vibrations can be classified into two groups of variables. First is the intrinsic variables, which include component of population type (fitness, size, sex, age) developmental trait (motivation, experience), posture and activities straight related to the operator. Secondly, the external variables that include components like vibration duration, vibration frequency, vibration input position, vibration magnitude and some other environmental components (acceleration, noise, heat, light) which do not have a direct influence on the operator. Exposure to harmful vibration at the workplace can induce several complaints at the upper limbs and the lower back. Epidemiologic surveys of hand-arm vibration have shown that the prevalence of external sensory neural disorders varies from a few percents to more than 80% and that symptoms and signs of sensory loss can affect users of a wide range of tool types (Bovenzi, 1998; Bovenzi et al., 2011). Studies have pointed out that the workers involved in the informal sector like mining, construction sector, agriculture sector, stone polishing sector, are the victims of the occupational vibration. Extensive use of vibrating equipment/device is a regular part of the workers in these informal sectors.

The Construction sector, which is one of the most hazardous sectors, plays a vital role in the development of infrastructures. About 340 million workforces are engaged in the unorganized sectors in India and around half of this workforce belongs to the construction sector (Tiwari and Gangopadhyay, 2011). The Indian construction labour force is 7.5%, and it contributes to 16.4% of fatal global occupational accidents (Kulkarni, 2007). Depending on their function, construction machinery could be classified into the following primary groups: excavating, drilling, pile-driving, reinforcement, roofing and finishing machinery for working with concrete and machinery for carrying out preparatory work. Equipment like rippers, brush cutters and stump pullers are used for preparatory work like loosening the soil and clearing the area of underground trees and rocks. For earthwork vibration, rollers with metal rolls and pneumatic tires are used. Different types of drilling machines are used in earth drill, setting pipe and laying explosive charges. Literature indicates that the operators of the equipment mentioned above generally suffer from health hazards like whole body vibration, awkward postural requirements (including static sitting), dust, noise, temperature extreme and shift work, which produces systematic effects on their entire body. However, the information on vibration transmission to the hand-arm system during the operation of vibrating equipment/ devices is relatively less reported.

1.3 Exposure to vibration: Scenario in construction sectors in Northeast, India

The socio-economic status of the workers in unorganized/ informal sectors is impoverished and they are exposed to various chemicals, biological, physical problems that include respiratory problems, injuries, musculoskeletal disorders (Jang et al., 2002; Jayakrishnan et al., 2013). The nature of their work is hard physical labor, usually in a problematic state like poor weather conditions and poor living conditions, long working duration, the absence of job security with absence of essential amenities. In this period of globalization, construction is a fast-growing industry but very little research has been carried upon the occupational health hazards and psychosocial problems of the workers. Among the unorganized sectors, the construction industry has been identified historically as one of the sectors that have a higher amount of injury, casualty, and diseases than other industries (Bureau of Labor Statistics, 1995).

In India, the construction sector is one of the steady growing sectors and it is the most significant profitable occupation after agriculture that consists of 44% of all unorganized urban workers. North-East India, which constitute of eight states, Arunachal Pradesh, Assam, Meghalaya, Mizoram, Manipur, Nagaland, Tripura, and Sikkim, is geographically linked to the rest of the country, by a narrow corridor of land, surrounded by Nepal and Bangladesh. For a long period, the socio-economic growth of these states had hindered due to poor infrastructure and limited connectivity of roads. The Northeast Council (NEC) has developed a new plan called the North East Road Sector Development scheme that focuses on building roads covering 10, 5000 kilometers that include inter-state roads connectivity for economic importance (Das,P. 2008).

Guwahati city the largest city in Assam and Northeast India and it is the second biggest cosmopolitan region in eastern India after Kolkata. The smart city mission introduced by the Government of India in the year 2015 helped the country to develop a hundred cities enabling them citizen-friendly and self-sustainable. As per the plan, a total number of hundred cities were selected which also featured Guwahati city. Guwahati city is the gateway to the northeastern belt of the country, has considerably witnessed an upsurge of various infrastructural facilities in recent times in terms of development (Hemani and Das, 2016). Under the smart city projects as initiated by the Government of Assam, the Guwahati Metropolitan Development Authority (GMDA) is working on revising the master plan of the city. As such, a major part of constructional work is underway. Therefore, this city is witnessing a significant number of construction works. These construction works require a large work-force of informal workers like a plumber, carpenter, floor polishing workers, and unskilled laborers like helpers. Polishing of mosaic floors, stairs, etc. and various stones used for flooring and decoration is an integral part of the construction activities where hand-held floor-polishing devices are being used frequently for a prolonged duration. With the initiation of the smart city projects, the manifold increase in construction work all over the city has motivated the present researcher to select Guwahati; city as the study location.

1.4 Design Intervention of vibrating equipment/ device

The overall market of the power tools had 56000 numbers approximately in India during the financial year 2013-2014 (Mehta et al., 2014; Chaturvedi et al., 2016). The adverse effects of the occupational vibration on human health is known all over the globe for a long time, and the prevalence of exposure to vibration was found to be dominated in construction (63%), manufacturing and mining (44%) and agricultural sectors (Eashew, 2008). Extensive use of vibrating equipment/ device in these sectors is the main reason for the highest sufferers from occupational vibration. It is essential to have some design intervention of the vibrating equipment/ devices to reduce the risk factor associated with occupational vibration. There are some design modifications and interventions suggested by many researchers depending upon the type of equipment/device used. The handle is the central part of the equipment/device as vibration transmission happens to the human body through handles of the vibrating equipment/ device. It is usually suggested that the surface of the handle should be smooth and somewhat compressible as it is beneficial for even distribution of surface pressure in hand and it minimizes the vibration transmission (Bjoring et al., 1999).

Gloves are generally being used while operating any hand tool (Chang et al., 1999). Earlier studies reported that vibration attenuating glove materials e.g. foam, rubber, silica gel etc. were found to be more potent in shielding the palm than the fingers from vibration (Xu et al., 2019; Almagirby et al., 2017). It was also mentioned that anti-vibration gloves could minimize vibration constituent at very excessive frequencies (>500HZ), mainly when a low hand coupling force is registered. Researchers also stated that vibration-attenuating gloves could minimize vibration transmission from tool handle to the palm from 5% to 20% depending on the tool types (Hewitt et al., 2016; Yao et al., 2018). However, the use of gloves demonstrated both effective and gloomy impact on hand exertion (Chang et al., 1999). Wearing gloves reduces the hand motion and ability, which increases the amount of work duration and reduces the grip force (Bensal, 1993; Hallbeck and McMullin, 1993; Muralidhar and Bishu, 1994; Shih et al., 1995). In some studies, gloves have been suggested as an alternative measure to reduce vibration exposure but it is not useful in bringing down the vibration transferred to fingers (Paddan and Griffin, 2001; Dong et al., 2008; Dong et al., 2012; Welcome et al., 2014). The effectiveness of anti-vibrational gloves is determined by both the material properties of the glove and the mass of the hand-arm system (Dong et al., 2009). The glove materials should differ significantly according to the natural dynamic properties of the hand-arm system, which cannot not be significantly changed (Hewitt et al., 2016). Wide gloves are effective at minimizing vibration transmission but might maximize the grip forces required to operate the machine and reduce the manual dexterity safely.

Vibration transmission from handles to the hand-arm system can be reduced through coating material of rubber sheet, rexene, jute, polyurethane, rubber, an amalgamation of both rubber and cotton on the handle (Chaturvedi et al., 2016; Singh and Khan, 2014). Rubber mounts are also used to separate vehicle structure from engine vibration. Its flexible hardness determines the accomplishment of an isolator and dampening absorption that decides the transmissivity attributes of the isolators (Dewangan and Tiwari, 2009). However, under compelling circumstances, the isolation attributes differ from the frequency of innervations and amplitude (Swanson, 1993; Yu et al., 2001; Dewangan and Tiwari, 2009). In designing the mounts, the challenge is to make them stiff in a static condition and soft in a dynamic conditions (Ahn et al., 2003).

Agriculture is the pillar of the Indian economy, which contributes about 16% of total GDP and 10% of total exports (Bose, 2015). In the agriculture sector, a vast number of traditional hand tools and animal-drawn equipment/ device were being used but with the progress of time, various mechanical, as well as electrical powered hand tools, tractors, power tillers, and other power machines, are being extensively used for various farming activities. One of the significant safety concerns of these farm equipment/ devices is the exposure to a high intensity vibration of the hand-arm while operating them (Salokhe et al., 1995; Ying et al., 1998; Tewari et al., 2004; Sam and Kathirvel 2006; Goglia et al., 2006, Chaturvedi et al., 2012). Hand tractors and power tillers have very complex vibration characteristics, and at any location, several dominant frequencies are observed (Salokhe et al., 1995; Tewari et al., 2004). The operation of agricultural equipment in various environmental circumstances causes extreme physiological demand on the operators (Tewari et al., 2004). During the use of hand tractors, excessive vibration is felt at the handle grip. Vibration is transmitted to the hands, arms and shoulders of the operator through the handle of the hand tractor, causing discomfort and pain that results in early fatigue (Tewari et al., 2004). In a tractor, vibration can be attenuated up to 35% through pliable handgrips and inserting rubber sleeves near the handle grip of the hand tractor (Ragn, 1994; Xu et al., 1995, Ying et al., 1998). Dewangan and Tiwari, (2009) reported that the installation of isolator on handle grip had an excellent effect on reducing the level of transmission of hand-arm vibration and eventually reduced the pain at the shoulder, forearm, upper arm, elbow, hand and wrist. The handle of the power tiller is a cantilever beam, and power is acquired from a single cylinder diesel engine, for which the transmission of HTV is very much severe (Ying et al., 1998; Chaturvedi et al., 2016). The existing problem was solved by developing an operator's seat, which was manufactured at the Central Institute of Agricultural Engineering, Bhopal based on Anthropometric data of Indian farm workers (Mehta et al., 1997; Gupta et al., 1983). The use of vibration isolators for the engine, handle and the handlebar of a power tiller can minimize handle vibration by 50-60% (Sam and Kathirvel, 2009). Similarly, engine mounts were installed to lessen the engine vibrations and the inclusion of the intervention at specific interfaces vibration reduction happened up to 70% in both stationary mode and transportation mode of the power tiller (Chaturvedi et al., 2016).

In Indian mining legislation/ standards are not sufficient to develop a particular approach for assessment and control of occupational vibration. In Indian scenario, there is no specific methodology to investigate the population suffering from vibration exposure above safe limits (Mandal and Srivastava, 2006). Automation of the mining industry is very much necessary for growth and modification of the work environment to avoid health risks caused by exposure to whole body vibration. Even from the limited information available, it is evident that the risk of injury from excessive exposure to vibration across Indian mines is prevalent. All these facts indicate that there is a requirement of a specific regulation to develop a strategy for evaluation and control of occupational vibration in the mining sector of India (Mandal and Srivastava, 2006).

Like many other informal sectors, stone polishing sector is also one of those sectors where a hand-held floor-polishing device is used. Vibrating hand-held floor polishing devices are being used in the production process to control the surface finish and quality of the stone for a very long time. The device used for polishing activity is a customized drill with a polishing stone fitted in place of the drill bit, which is more convenient for a horizontal surface and involves repetitive actions. However, there is rarely any research reporting the impact of transmitted vibration from hand-held floor/ stone polishing machine to worker's hand-arm system due to occupational exposure to vibration.

1.5 Research Gap and justification of the present research

A sufficient amount of work is available all over the world on occupational vibration but it is not promising in the Indian scenario. In India, the majority of these studies predominantly focus on theoretical and applied aspects of vibration generation; its types and characteristics;3D form and material of vibrating machine parts/tools; mechanism of vibration control or suppression, etc (Roy et al., 2016; Sharma et al., 2005; Veeramuthuvel et al., 2016). Studies related to the use of vibrating machines/ tools; the transmission of vibration to the human body, and its effect on human health are scantily reported in Indian scenario (Mandal and Srivastava, 2006; Dasgupta and Harrison, 1996; Tewari et al., 2004, Dewangan and Tewari, 2009).

In the Indian scenario, some literature is available on agriculture, forestry and mining sectors. The available literature mainly described the characteristics and health hazards of occupational vibration. For example, Tewari et al. (2004) and Salokhe et al. (1995) had mentioned that hand tractor and power tiller had very complex vibration characteristics and extreme vibration is felt at the handle grip. Dewangan and Tewari, 2009 carried out an experiment on hand-transmitted vibration in field conditions and emphasized the need to provide intervention for the reduction of hand-transmitted vibration for increased comfort and safety of the operators. Mandal and Srivastava (2006) had suggested that monitoring should be made mandatory for all the semi-mechanized and mechanized mines to reduce vibrational exposure. Chen et al. (2015) and Sutinen et al., (2006) had mentioned that forestry machinery made progress in terms of product range and functionality, but some problems remained in ergonomics and other human aspects. The types of machinery used in construction work were explored by Maiti (2008) and Kittusamy and Buchholz (2004) and they mentioned that the data on vibration transmission to the hand-arm system during the operating of construction machinery was very less. There is an ample amount of information regarding subjective responses to the vibration that mainly performed in laboratory settings. Not much data representing real-life conditions to characterize the vibration exposure and to better understand the health outcomes of the operators of construction equipment is reported.

In the floor polishing activities, which is an integral part of the construction, the adoption of awkward working posture, repetitive forceful movement, prolonged work duration, and improper working tool are some of the ergonomic stressors associated with the floor polishing work. There is no single literature, which deals with the ergonomic risk factors, thereby occupational health issues and their corresponding remedial measures including ergonomic design intervention. Hence, in the present research, an attempt has been made to go for design modification of existing hand-held floor polishing device used by floor polishing workers to reduce the impact of occupational vibration on their physical well-being. The research gap identified for the current research has been schematically presented in Fig. 1.1.

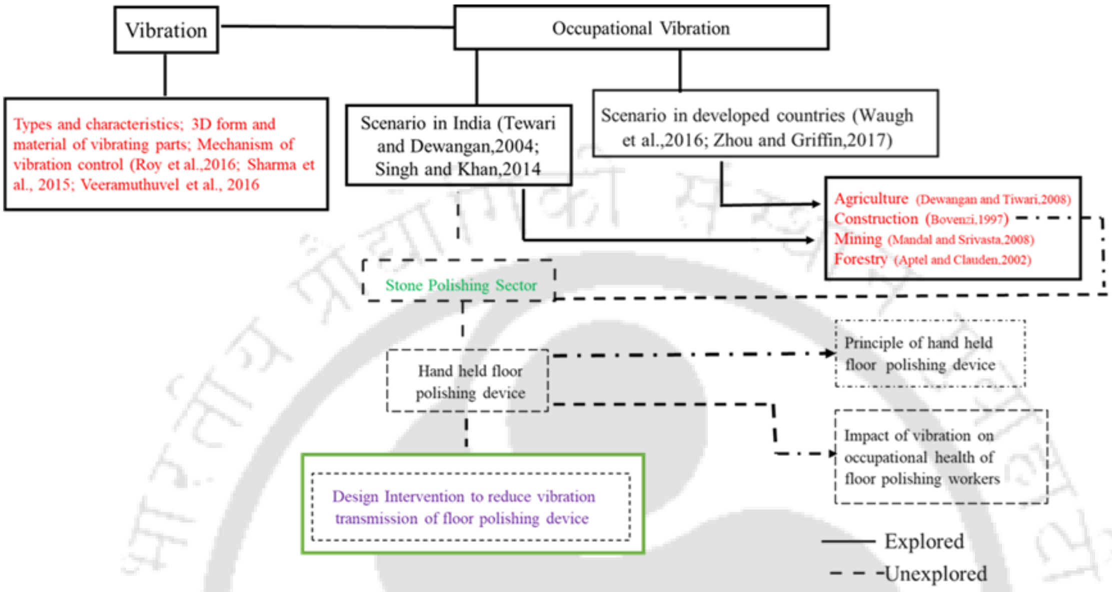


Fig.1. 1. Schematic diagram showing the research gap

1.6 Research Questions

Mainly four research questions have been raised after a literature survey and initial field visits to observe the working condition and hand-held vibrating equipment/ device used in floor polishing work.

1. What is the level of vibration to which the workers are exposed while working with a floor polishing device in the unorganized sector?
2. What are the possible ways to reduce biomechanical stress associated with the hand and arm of the operators involved with hand-held floor polishing device in the unorganized sector?
3. Can a supportive mechanism for avoiding sustained load holding during the use of hand-held floor polishing devices significantly reduce the muscular effort required to perform polishing activities?

4. Can design intervention of hand-held floor polishing device ameliorate vibration exposure of the workers in the unorganized sector working with vibrating tool/equipment/device and enhance the work performance of the workers?

1.7 Problem Statement

The purpose of this study is to reduce the impact of exposure to vibration of the hand-held the floor-polishing device during floor polishing work. For this purpose, a detailed literature survey and an initial pilot study have been carried out through field observations and market surveys. Following the pilot study, various problems have been noticed as described below.

i) High level of transmission of vibration from the polishing device to the hands and arms of the operator.
ii) Using the polishing device for a prolonged duration (8 to 10 hr) during a shift.
iii) Awkward posture and sustained load holding for around 30-45 minutes at a stretch.
iv) Repetitive and strenuous manual actions.
v) Lack of ergonomic considerations in the design of the polishing device.

1.8 Aim

The aim is to study the occupational exposure to vibration during the use of hand-held floor polishing device and come up with ergonomic design intervention for reduction of exposure to vibration and improvement of usability.

1.9 Objectives

1. To study the health hazards among the floor polishing workers.
2. To quantify vibration exposure level among the workers while using a hand-held floor polishing machine.
3. To understand the effectiveness of specific vibration reduction interventions and their practicability.
4. To introduce ergonomically designed intervention of hand-held floor polishing device to reduce vibration content.
5. Validation of redesigned floor polishing devices and evaluating their effectiveness in terms of reduction of vibration exposure and improvement of usability.

1.10 Hypotheses

Following hypothesis have been formulated for proper research guidance.

H1: Design Interventions towards the reduction of vibration generation and vibration transmission of the hand-held polishing device would significantly reduce exposure to vibration and thereby improvement of occupational health of the operator/ worker.

H2: Proper anthropometric and biomechanical compatibility of hand-held floor polishing devices can significantly improve the usability of the device.

H3: Supportive/ weight-bearing mechanism for avoiding sustained load holding during the use of handheld floor polishing device can significantly reduce muscular effort.

1.11 Expected outcome

The outcome of the present research is expected to enable an impactful reduction of occupational vibration on the stone polishing workers using hand-held floor polishing devices through easier maneuverability, avoiding sustained hand-holding of weight, use of vibration dampening material to reduce the transmission of vibration and improvement of usability.

1.12 Organization of the thesis

A short outline of the whole thesis is presented below.

1.12.1 Chapter 1-Introduction

This chapter deals with the establishment of the need for the present research work. It focuses on the physical hazards of occupational vibration on the workers engaged in floor polishing activities with hand-held floor polishing device in the unorganized construction sectors. Identification of research gap and related questions; justification of the present research; aim and the objectives for the current research have also been presented in this chapter. The hypothesis of the thesis, expected outcome and flow of the research is also summarized

1.12.2 Chapter II Review of Literature

This chapter presents an overview of the extensive literature survey carried out on the subject matter. Overview of research work on occupational exposure to the different magnitude of vibrations and their ill impacts on human health in diverse sectors have been demonstrated in both Indian and global scenarios. Literature review has been presented under different headings and sub-headings which include the impact of vibration on human health; general principles of hand-tool design; ergonomics of hand-tool design; product design methodology; material selection strategies; consideration of aesthetics in design; categorization of vibration by contact site, effect and frequency; measurements of human exposure to vibration; standard for assessment of hand-transmitted vibration, muscular fatigue due to vibration and its quantification; and System Usability Scale (SUS) for evaluation of product’s usability.

1.12.3 Chapter III- Methodology

Chapter III outlined the locations in Guwahati city where floor-polishing activities were being carried out regularly and then convincing /motivating the workers to be volunteers for the study. Further, designing the questionnaire to evaluate and study the impact of vibration on the occupational health of the workers who were involved in this sector for more than one year has been discussed in this chapter. The postural assessment through the REBA (Rapid Entire Body Assessment) method and quantification (using hand-arm vibration meter) of the exposure level to vibration during the use of hand-held vibrating tools by the workers have been documented. This chapter also includes the methodology of effective design intervention to reduce the impact of vibration during the use of the hand-held floor-polishing device. Equipment and procedure for Electromyography study to compare the required muscle force for performing a polishing activity with the existing and redesign floor-polishing device has been presented along with the technique for usability evaluation.

1.12.4 Chapter IV-Results

This chapter presents the outcomes from each step of the redesigning process of floor-polishing device and results of quantification of the level of vibration to which workers were being exposed to during the use of both existing and redesigned floor-polishing devices. This chapter also describes the findings of the evaluation of working posture, comfort/ discomfort, electromyography study, the usability of both existing and redesigned polishing machine to demonstrate the superiority of redesigned device in comparison to the existing one.

1.12.5 Chapter V- Discussion and Conclusion

Chapter V outlined the key findings of the present research and describes how the pre-set objectives were fulfilled through the reported methods and observations of the current research. This chapter also presents the testing of hypothesis, a summary of features to explain the superiority of redesigned floor polishing device in comparison to existing one, novel contributions of the thesis, limitations of current research along with future scope and conclusions are drawn from the reported research.

2 Literature Review

2.1 Introduction

The labor force belonging to the informal sector is increasing in the urban areas with an increase in infrastructural development of India. The implementation of a job in the informal sector comprises all such workers who, throughout the particular period, happened to have engaged in minimum one non-formal section, irrespective of their rank in a job and regardless if it was their main or unimportant appointment. The definition of the 'informal sector' has continued to be unconfirmed over many years. Since the 1970s, the concept of the informal sector has been extensively discussed. However, a comprehensive document termed as "Report on Definitional and Statistical Issues Relating to the Informal Economy" was proposed in 2008. The non-formal sector that is highly unorganized is not an authorized set-up unrelated from its possessors and did not enter in the Factories Act. It is also not possessed or supervised by one particular or group of members of the household. It is an enterprise that is not registered along with employees, and the numbers of persons employed were continuously below the threshold determined by a country. In the informal sector, the workers are known to work in deprived working conditions like restricted and congested workplace, poor illumination, high noise levels (80-90 dB), exposed to hazardous substances, resulting in work-related stresses consequently causing incidents of health-related problems like musculoskeletal disorder, headache, respiratory problems, hearing losses, etc.

For India, the informal sector serves as the backbone of the economy. The informal sector possesses a leading position in the Indian economy about its benefits to GDP and the implementation of jobs. In rural areas, nearly 82% of the total workforce and 72% in the civic areas were involved in the informal sector. An additional 50% of the GDP comes from this informal sector. In India, 81% of all the working people, sustain their living by carrying out their work in the informal sector, whereas only 6.5% of the employee works in the formal sector. Amid the five South Asian countries, the top position in formalization of labor is in India and Nepal (90.7%), with Bangladesh (48.9%), Pakistan (77.6%), and Sri Lanka (60.6%) performing effectively on this forefront. As stated by ILO India Market Update (2016) and NSSO data (2011-12), the agriculture sector covers more than 90% of the employment of the informal sector. Next to agriculture, the other industry groups whose shares of informal workers are more than 90 percent are Trade (98.11%), and the Construction sector (97.33%) (Tiwari and Gangopadhyay, 2001).

2.2 Occupational Exposure to vibration

Workers are subjected to occupational vibration via the use of power or pneumatic hand tools or other equipment/device, or by operating big transportation, agricultural or construction vehicles (Bovenzi 2010a; 2010b, 2015; Griffin 2004, 2015; Krajnak, 2018). Workers accomplishing jobs like crop production, logging of wood, etc. are subjected to Whole Body Vibration (WBV) by the use of vehicles like tractors, bulldozers, etc. Studies carried out in developed countries had mentioned that 74% of the workers are engaged in a profession where they might be exposed to vibration by the use of hand tools like grinders, impact wrenches, sanders, and drills (Bovenzi et al., 2005; McDowell et al., 2015). Bovenzi et al., 2015 had mentioned that 23-25% of all workers in the European Union are subjected to vibration in their workplace. Almost 20% of male workers out of 35% of the total male workforce are subjected to occupational vibration during their work shift for almost all the time. Among the female workforce, about 5% out of 10% of the female workforce are subjected to vibration during their work shift. According to the Sixth European Working Conditions Survey (6th EWCS), 20% of the workers in the European States are exposed to vibration produced by tools or machinery working in Agriculture, Construction, Transport jobs, etc. (Carra, S. et al.,2019). In countries like South Korea and Malaysia, 5- 18% of the workers working in the quarry and construction industry are subjected to hand-arm vibration (HAV) (N.A.Azmir et al., 2015). However, there is no such documentation disclosing WBV and HAV scenarios in India.

2.3 Construction Sector

One of the oldest industries in this sophisticated world is the construction industry. The importance of the construction industry to the economic and social life of the country is significant. Construction as a part of the gross domestic product differs broadly in industrialized countries. In the USA, it is about 4% of GDP, in Germany 6.5%, in Japan 17% and India 5% of GDP and 78% of capital formation in the country (Lakhani, 2004). It is an extremely capital-intensive as well as labor-intensive part of the industry. In the construction industry, the workers keep moving, and there is no perceptible and stable relationship between the manager and the workforce. In India, the appropriate figure for construction workers differs from 3 million to 25 million. However, 95% of the workers were determined to be short-term workers, and a mass is periodic.

The most significant challenges in occupational health and safety are to protect the construction workers from injury and diseases. Construction workers are exposed to a wide variety of health risks on the job. The workers are deprived of a secure and reliable system of community support as the labor force keeps changing continuously, and with it, their hours and locale of work vary, and they are always away from their home and family. The European Agency for Safety and Health at work had mentioned that when it comes to occupational safety and health, it is the most hazardous industry in terms of occupational safety and health. The construction laborers are three times at risk to die and two times to experience bruises at work at an average compared to the other activities at a global level (V.Sousa et al., 2014). As already mentioned, the construction workers are subjected to noise, vibration, temperature, hearing loss, etc. in their particular workplace (Eashw, 2008; Drever, 1995).

2.4 Vibrating hand-held tools used in unorganized sectors including construction

As mentioned, many workers were subjected to hand-transmitted vibrations daily in their enterprise by the use of hand-held powered tools varying from compact percussion drills to huge pneumatic breakers. The extensive use of hand-held vibrating tools stands to be the greatest source of vibration-related bruises among the workers in the informal sector. Among all the executive sector, the construction sector possesses the highest figure of about 23.5% in the hand-arm and about 12.9% in the whole body of workers pretentious by vibration, accompanied by the other manufacturing sector (16.6% in the hand-arm and 7.85 in the whole body) (INSHT,2007). There are again variants of construction equipment/device machinery such as wheel loaders, hydraulic excavators, bulldozers, pavers, vibratory compactors, drills, etc. (Pethaperumal and Sivakumar, 2017).

In construction work, for drilling large holes, pneumatic rock drills and electric rotary hammer drills are used into the solid surface for tectonic upgrades to highways, buildings, airport tarmacs, and bridges as because pneumatic rock drills are regarded as the most productive and robust tool for trimming huge holes by the rock miners, stone workers, and structural contractors. Nevertheless, these rock drills turned out to be the major source of severe injuries among the workers due to the extensive levels of vibration, noise and heavyweight (Rempel et al., 2019). In comparison to Pneumatic rock drills, electric rotary hammer drills are light-weighted but also regarded as less suitable and less productive for heavy use (Rempel et al., 2019; Lopez Alonso et al., 2013; Nataletti et al., 2014). However, there is very little information about the productivity, exposure to noise and vibration of these two types of drills. Earthmoving Equipment (EME) like dozers, graders, haul trucks, scrapers, pail loaders, etc. is used extensively to carry out jobs specifically excavating, earthmoving, and paving on the construction areas in the construction industry. WBV is experienced in the operation of Earthmoving Equipment at various frequencies (Akinnuli et al., 2018). Again, Jack hammering has been ranked as one of the most challenging tasks that require high force and repetitive motion and involves a segmental injury that increases the likelihood of an overexertion injury (Bureau of Labor Statics, 2013; Johnson et al., 2017). The handling of such construction equipment requires a safety procedure to protect against physical and mental distress, which is lacking in the construction industry.

According to European Union Machinery Directive (1998), it was made mandatory that the tool manufacturer gives ‘declared vibration emission values for their tools, measured as stated by proper test code. The actual value is not required to publish, but the manufacturers were required to state whether it is less than 2.5m/s^2. The measurement methodology adopted needs to be described by the manufacturer when a suitable test code is not mentioned. Some of the standard test used were described by the EN 60745 (EN 60745, 2003), and the ISO 8662 (ISO 8662-1, 1988) family of quality, which consist of various portions, each of this portion was certain to an individual tool type (Rimell et al., 2008).

2.5 Adverse impact of vibration on occupational health

Subjection to hand-arm vibration is a complex and possibly damaging state involving one or more distinct vascular, musculoskeletal, and neurological characteristics associated with exposure to the hand-held vibrating tool (Heaver et al., 2011). Hand-arm vibration syndrome is possibly damaging persistent disorder among the workers, stone drillers, shipyard workers and stonecutters (Harada and Mahbub, 2008). There is more than 70% higher risk among the workers working with grinders, pneumatic drills and impact wrenches (Harada et al., 2001). According to the ISO weighting constituent, the peak intensity of acceleration at the frequency of 50 Hz dispense a significant health risk. The chance of health risk is much excessive for frequencies in the 4–50 Hz range than in the 63–1250 Hz range based on ISO weighting. Exposure to the vibration of the fingers or the hands can increase the chance of various disorders. The magnitude and inter-relation between the various symptom and characteristics were not perceived, and only five types of disorders were identified. A person can be affected by more than one disorder at the same time, and the existence of one disorder could accelerate the advent of another disorder. The terms ‘vibration syndrome’ or ‘hand-arm vibration syndrome’ are mostly used to mention an unstated amalgamation of a single or many effects of hand-arm vibration, which are listed below (Table 2. 1). The vibrations transmitted through tools are mainly determined by tool design and procedure for use, but then it is not always easy to classify the independent tool category as ‘safe’ or ‘dangerous.’

Table 2. 1. The kind of disarray related with hand - transmitted vibration exposure (Griffin 1990)

Type	Disorders
Type A	Circulatory disarray
Type B	Bone and joint disarray
Type C	Neurological disarray
Type D	Muscle disorders
Type E	Other general disarray (e.g. central nervous system)

2.5.1 Vascular disorders

The probability of ‘neurosis due to vibration’ was examined by the Departmental Committee on Compensation for Industrial Diseases in the United Kingdom in 1907, known as ‘vibration-induced white finger’(VWF), distinguished by patchy whitening (blanching) of the fingers. Usually, the fingertips use to blanch, and then it extends all over the fingers with prolonged exposure to vibration. The attacks of blanching may increase in cold conditions and continues till the fingers rewarmed and dilatation permit the return of the blood circulation. There is also additional indication and manifestation such as insensibility and tingling, and in some cases, cyanosis and rarely gangrene has been disclosed. However, there are no understandable details to what extent these indications are caused by or can be related to the pounce of VWF. If the sign and indication of the attacks are restricted to the region in proximity with the vibration (fingers), and there was no family history of the symptoms, then it is considered vibration-induced white fingers. A diagnostic test was not the only reliable test to check the presence of VWF. Sometimes the quantification of systolic blood pressure, finger cooling and the quantification of finger rewarming times after that cooling can be effective, along with the recording of the severity of the effects of vibration through a verbal declaration made by the affected person (Neilsen and Lassen, 1977; Bovenzi, 1993).

2.5.2 Neurological Disorders

Some of the disorders like tingling, numbness, high sensory intensity for vibration, touch, vibration, pain, reduce nerve conduction velocity, and the pain was considered not just symptoms and signs of VWF but considered different effects of vibration. The procedure of examining the level of neurological consequences of vibration was proposed and it is not associated with any particular objective test. It is just an individual opinion of a medical practitioner established on the declaration of the pretentious person or any clinical observation and identified through evaluation of sensory tasks such as the intensity for the sensation of vibration, cold, warmth and heat on the fingers.

2.5.3 Muscular effects, articular disease and other effects

Workers exposed to vibration seemed to be complaining of pain and muscle weakness in the hands and arms (Bovenzi, 1989). The decrease in muscle force is an indication of regular exposure to vibration as described by subjects workwith vibrating tools. Muscle action is of significant importance for tool users as a secure grip is necessary for the execution of the job and safe control of the tool. Many times workers subjected to hand-transmitted vibration were reported to have problems with their grip, locked grip, and lower agility, reduced grip strength. The occurrence of vibration on a handle may pressurize the adjustment of a tighter grasp.

The operators of various hand tools, mainly in metalworking jobs, quarrying, and mining, were reported for bone and joint problems. It is theorized that some of the attributes like low-frequency shocks of such percussive tools might be responsible for these kinds of disorders. Some of the other disorders related to these jobs are decalcification of bone, vacuoles or other osteolysis and malformality of the metacarpal, phalangeal, and carpal bones. Users of percussive tools also reported other problems of the wrist, shoulder, osteoarthritis, and olecranon spur at the elbow (Howart and Griffin, 1990). However, then there is no general acceptance of the fact and dose-effect relation that vibration could be the cause of particular problems. In the absence of particular data, it seems that in compliance with recent guidance for the precaution of VWF might give adequate protection.

Studies had reported a high prevalence of sleeplessness and headaches amidst the vibrating tool users apart from disorders of fingers, arms, and hands. These symptoms concluded as symptoms of disorders generated by hand-transmitted vibration. Even though these are the actual sufferings faced by the workers, researchers do not yet acknowledge it. Some contemporary research is attempting on the physiological base for such an indicator.

2.6 Principles of hand tool design

A useful hand tool must satisfy some fundamental necessity. The tool must execute the purpose effectually for which it is considered. It must be outlined as stated to the body dimension of the operator, also considering the robustness and work volume of the operator. Poorly designed hand tools increase the chance of prevalence of cumulative trauma of the wrist, hand, and forearm (Armstrong 1983; Aghazadeh and Mital 1987). The four main work-related factors that develop cumulative trauma disorders (CTD) were mainly: 1) immoderate force (2) utmost or tricky joint motion (3) excessive level of recurrence of the same movement and (4) absence of adequate rest for the disturbed joint to recuperate (Putz Anderson, 1988). Temporary fatigues and discomfort were also regarded as the risk factors and connected to handle and work inclination in hammering tasks (Schoemarklin and Marras 1989a; 1989b) and to tool design and work height in work performed with screwdrivers (Ulin et al., 1990; Ulin and Armstrong 1991). The grip of the tool with poor design also causes excessive grip forces and severe wrist deviations (Stasser, 2007). A primary ergonomic concern of hand tool is the correct selection, investigation, and use of hand tools, since, 80% of all hand tool injuries were caused by hand-powered hand tools mainly by knives (44.3%), wrenches (8.9%), screwdrivers (5.7%) and hammers (10%). Drills, hammers, grinders, and powered saws were the tools that mostly cause injuries as compared to other tools (Strasser, 2007).

The evaluation of hand tools must give due consideration to the functional properties, quality, and reliability and, at the same time, deal with the user's supposition and concern (Kadefores et al., 1993). The essential criteria of hand tool design were: shape, surface texture, and motive, ease of operations, size, weight, and shock absorption (Meagher, 1987). Moreover, some of the other indicators for the faulty hand tools: (1) Steady stacking of arm and shoulder muscles (2) tricky hand posture, mainly wrist divergence, (3) extensive force on the palm and fingers (4) exposures to vibration and cold from power tools (5) pinch points with double handle tools and (6) handles requiring an extension of the hand to grip or high force to hold (Anderson, 1990). Hand tool shape must be given significant importance to refrain from wrist deviation, shoulder abduction and to assist grip (Chaffin et al., 1999). Some of the crucial criteria to be contemplated for assessment of hand tools were: (1) repetitive finger movements (2) static muscle loading (3) tissue comprehension (4) awkward wrist position (5) gender (6) handiness (7) posture.

A stable muscle pack is caused if arms were raised while using tools or tools held for longer periods. In such a situation, the arms and hands may be stacked statically, causing fatigue, minimize the work capacity, and cramp. During a tricky wrist position, the wrist is moved from its neutral position, which results in a loss of grip strength by 12%, flexion/extension by 25%, and radial/ulnar deviation by 15% (Terrell and Pursell, 1976). Tissue compression takes place when the hand applies considering force, during the operation of hand tools — significant compression force on the palm or the fingers that result from actions. While operating hand tools, Gender also plays an essential part in terms of grip hardness. Female grip strength ranges from 50 to 60% of male strength (Chaffin et al., 1999). The posture during task performance of the hand tools affects torque exertion capability (Mital, 1986). With increasing reach distance, the torque strain capability minimizes linearly. When the index finger is involved in repetitive finger action for operating triggers, symptoms of trigger finger develops (N.N. 1983).

2.6.1 Ergonomic considerations in hand tool design

A hand tool should assure practical properties, reliability, and form characteristics of a specific tool. In the design of the tool handle, due thought must be given to the following factors: length, materials, Shape-on-handles, mechanical output, the center of gravity and weight and vibration for powered hand tools.

2.6.1.1 Hand Physiology

The practical capacities of the hands were significant for work effectiveness in humans. The type of job being carried out sets the human hand requires a definite amount of hardiness and exactness. The correct form of the amalgamation of hardiness and exactness in grasping the function requires fine management of the receptive structure of the hand. When designing working hand tools, the deliberation of anatomical and physiological attributes of the hand-arm system established on the calculation “in conformity with a human in conformity with the hand” is an absolute principle (Strasser, 1991) (Fig.2.1).

Many attributes of hand physiology in designing hand tools require specific awareness that includes the connective tissues and flexor hand muscles, issuance of fat in hand, as well as position and responsiveness of different nerves and arteries implanted in the hand. The human hand is a composite formation of nerves, ligaments bones and tendons and arteries. The muscle Extensor flexor Capri controls the movement of fingers, which pass through a carpal ligament. The bone of the wrist joins the two long bones in the forearm, the ulna and the radius. The radius is attached to the thumb side of the wrist, and the ulna joining the little finger of the wrist. The inclination of the wrist joint makes a motion in only two planes, each at 90 degrees to the other. The first arise to palmar flexion and extension.

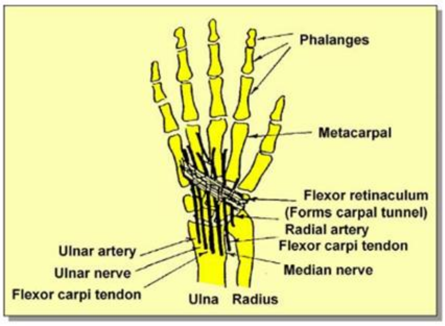


Fig.2.1. Hand Physiology (Strasser, 1991)

2.6.1.2 Anatomy of hand

There are three regions of hand, which are contemplated as coercion responsive, which are palmar arch, the ulnar nerve in the heel of the hand and the mid palmar area. The arteries, the median nerve and the sensorium of the finger flexion tendons in the center of the palm make the region highly vulnerable to repeated force exertions (Tichauer and Gage, 1977). Thus, the handle of the hand tool should be planned to be wider in the areas where it presses countering the heel of the hand to reduce strain in these areas. The tool handle should also be designed so that it extends beyond the palm to avoid stress concentration in the mid palmar region.

2.6.1.3 Hand Anthropometry

The primary assumption of ergonomics is that the design should incorporate the total male and female community so that the job could be conducted perfectly. The hand anthropometry for hand tool design must consider the different portion of the hand for both the male and female communities. The size of the hand for the 5th, 50th, and 95th percentiles male and female populations are given below.

Table 2.2. Applicable anthropometric quantification (cm) of hand for the design of hand tools handles (from Woodson et al., 1992; Konz, 1995)

	Male (adult)			Female (adult)		
	5th	50th	95th	5th	50th	95th
Width of hand at metacarpal	7.9	8.6	9.7	6.9	7.6	8.6
Thickness of at metacarpal	2.8	3.0	3.3	2.0	2.5	2.8
Width of Hand at thumb	9.4	10.4	11.2	8.1	8.1	10.2
Hand length	17.8	19.3	20.8	16.3	16.3	18.8
Grip breadth inside diameter	3.9	4.9	5.9	3.8	3.8	4.8

The hand dimension of both males and females differs not only in size but also in hardiness. Fransson and Winkel (1991) stated that 35% of the sex distinction in hand toughness was because of hand dimension differentiation. Pheasant (1983) had pointed out that there is less confirmation to recommend the requirement for a specific hand tool for female operators. The interplay of handle width and form with the kinematics and hand anthropometry has significant consequences on hand position and grasp robustness (Buchholz, 1989). Hence, different sizes of handles should be provided to satisfy individual anthropometry of the workers' hands. The larger handle fits 50th to the 95th percentile of the males, and a smaller handle fits the 5th and 95th percentile females.

The right hand for about 90% of the population is the dominant hand, and the percentage appears persistent over society and for both males and females. Non-significant hand inclined to have 94% of the grasp toughness of the favoured hand (Konz 1995). A single finger on the non-dominant hand is feeble than the parallel fingers on the superior hand, and the accuracy is worse with the non-preferred hand. Therefore, a hand tool functional with both hands has two advantages. The first is for the 10% of the population opt-out and the second one is that non-preferred hand can be used when the preferred hand is otherwise engaged or testing. Strasser and Wang, (1998) had noted that considerably more significant differences in screwdriver torque strength of the dominant hands during pronation and supination.

An ample amount of anthropometric data is accessible as a source of information and use (Gite and Yadav, 1989) – like details of Aerospace Medical Research Laboratories (Dayton, USA), ERGODATA databank of Anthropology Laboratory of Paris University (France), National Aeronautics and Space Administration (NASA, USA) etc. in developed countries. In India, only the Defence Research and Development Organization, the Government of India, had developed central anthropometric details on the Indian Army population (Zachariah et al., 2001). Chakrabarti, (1997) collected anthropometric data arranged from individual states of India for both male and female with sample size 961 in his book 'Indian anthropometric dimensions for ergonomic design practices' which is used as a source of information all over India for product and workstation design. The hand dimensions for the 5th, 50th, and 95th percentiles male and female populations are given below (Chakrabarti, 1997).

Table 2. 3. Hand dimensions for the 5th, 50th, and 95th percentiles male and female populations (Chakrabarti, 1997)

Parameters		Min	Percentiles					Max	mean	SD
			5th	25th	50th	75th	95th			
Hand grip length	Male	36	39	45	50	55	65	95	51	8
	Female	40	41	46	50	55	63	64	51	7
	Combined	36	40	45	50	55	64	95	51	8
Hand grip breadth	Male	65	82	91	99	104	109	130	98	9
	Female	51	70	82	86	91	96	104	86	9
	Combined	51	79	89	96	102	109	130	96	10
Hand breadth with thumb	Male	78	86	93	99	104	111	117	99	7
	Female	75	77	82	86	90	95	100	87	6
	Combined	75	81	89	95	102	109	117	96	9
Hand breadth without thumb at metacarpal	Male	60	72	77	81	85	90	100	82	6
	Female	60	66	69	71	75	79	92	73	5
	Combined	60	68	74	79	84	90	100	80	7
Finger-tip depth	Male	10	11	12	13	14	15	18	14	1
	Female	8	8	9	10	11	13	15	11	1
	Combined	8	10	12	13	14	15	18	14	2

2.6.1.4 Hand Grip

There are different types of grips used when holding objects. The type of grip used depends on the hand tool design and the posture reliable when using the hand tool. The conventional grip is the power grip with the finger swaddle throughout the object and the thumb placed over the first finger, as one might hold a hammer. For holding a hacksaw and a medium to large size screwdriver, the thumb is placed over the first finger. This particular type of grasp is used mainly for powered tools. The suggested weight of the tool borne by the end users is about 1.1 kg but not more than 2.3 kg (Mital and Kilbom, 1992). In the case of lateral grasp, the object is clasped between the thumb and the side of the first finger.

2.6.2 Design variables for hand-tool design

2.6.2.1 Handle Length

The length of the handle is determined by the kind of grasp used and the width of the end-user population. The minimum handle length recommended is 10cm. However, 12.5 cm would be more pleasant. The use of 10cm is contemplated to be least for outward exactness grasp. For an interior exactness grasp, the tool handle should expand far from the delicate palm but not so much away as to hit the wrist. The handle should be of 1.25 cm in case gloves so that the handle does not close in the palm (Selan, 1994). The hand/handle contact area should be maximized in hand tool design, as it minimizes shear stress on the skin and so that it reduces abrasion.

2.6.2.2 Handle size (diameter)

The size of a handle is very important in designing of handle tool. If the hand diameter is huge than the pressure put in with the fingertip than the resultant tendon pressure could be two times more than the force put in with the bottom of the fingers (Kroemer et al.,1994). As a result, more pressure has to be generated by the muscle that causes muscle fatigue very soon. Moreover, if the size of the handle is too compact than the finger flexor muscles were contracted to that particular extent that they cannot generate the required tension. Thus, much pressure cannot be applied that causes in sizeable local tissue coercion (Krommer et al., 1994). The most significant push intensity in handles of about 4.1 cm corresponding circular diameter (based on their 13.0 cm circumference) from both gender. Kodak, 1983 based on company incident had recommended 3.0-4.0cm with 4.0 cm for power grips and 0.8-1.6 cm with a best of 1.2 cm for accuracy grips.

2.6.2.3 Handle Shape

The shape of handle for a power grip should have utmost surface contact to reduce unit force of the hand. A tool with circular cross-section was found to cause higher torque. The tool handle should not rotate in the user’s hand. A counter-torque can prevent the rotation in hand. The coefficient of abrasion of the handle should also be improved. A work that require a prevalence of both orthogonal push and pull pursuit jointly, handles of rectangular shape with a thickness to height ratio of about 1 to 1.25 is suitable and the convex surface formed by the heel of the palm and the thumb were accommodated (Selan,1994). Some degree of bend is necessary for power grips when the tool extends from the top of the hand (Konz, 1995). The tool shape directly influences a person capacity to hold the tool firmly. The position of the wrist should be in a neutral position to have grip strength that could be attained by bending the tool (Konz, 1995).

2.6.2.4 Handle precision

The precise measurement of angles of handles for power tools is necessary to sustain a straight wrist. The handle should consider the centre line of the grip, which is about 78 ° from the horizontal and should be placed in the order that the final tool axis is in line with the index finger (Silverstein et al., 1987). The best tool angle is determined by the posture. The sum of torque that could be applied also determined by the working posture. Tedious screw driving should not be done on a horizontal platform above the elbow (Konz, 1995). Pistol grip tools should be avoided, if elevated work must be done on horizontal surfaces. Muscle fatigue studies of the shoulder muscles have indicated that the shoulder abduction angle directly affects the rate of fatigue onset. The higher the angle of abduction, the shorter is the time to reach significance in muscle fatigue. The fatigue rate increases when the arm is abducted more than 30°.

2.6.2.5 Handle material

The material used for the handle is essential as it determines the surface abrasion property and later the capacity to grip and influence the hand tool. The abrasion characteristics of the tool surface differ with the coercion applied by the hand, the evenness and passable of the surface and the type of contamination. Sweat gives rise to the coefficient of abrasion, while oil minimises it. Comprehensive grip materials such as compressible plastic or wood, rubber, are superior for the hand than hard plastic or metal. Konz, (1995) states that non-conductivity materials (wood, rubber) are suitable for two reasons. First, they release heat to the hand more slowly, and so they can be held for a longer time before an injury occurs. Second, they gain heat more slowly and so are unlikely to reach a high temperature.

2.7 Product form and functions

The base of elements of volume, line, space and plane in design are studied with a high degree of control and the advanced problems pose more complex exercises, which require the correlation of these elements. The theoretical experience based on manufacturing involves the design and organizing of contrasting forms, the latest experience of grouping forms to create related movements and a deeper understanding of the balance of directional forces and tensional position in space. The manufacturing process is made up of elements, which may be used as found, bent, or shaped in some way and then combined. Materials suitable include wire, metals, string, plastic, rods, glass, wood, fiberglass, stone etc. A combination of volumetric elements, planar and sheet metals should be used for manufacturing process. A variety of elements needs to be considered for manufacturing process to express the idea clearly. The construction should be abstract and emotionally expressive (Hannah, 2002).

To create ideas elements like communication, chemistry, electricity, construction equipment, music, jazz etc. should be kept in mind and see how they can express their essence in a visual form. These are ideas that can extract feelings and could be used to develop own feeling for abstraction. The emotional content and the objective could be captured through two-dimensional sketches on large sheets of paper by getting the ideas out and also some quick three- dimensional sketches in cardboard, wire and clay. A final sketch that establishes the first big tension between planes and volumes or groups of planes and volumes. The tension relationship must strongly suggest the proportions of the negative volume and establishes a balance of directional forces from every position. It establishes the major theme that will hold the piece together. Once the way of elements sit in space is organized, concentrations can be given on the form themselves.

2.7.1 Working in product concept

Organize volume, planes and lines- in that order: The elements of various materials should be put together in a pleasant relationship. There are two major objectives here: maintaining the spirit of idea and learning how to combine materials in a logical intact.

Establishment of the dominant, subdominant and subordinate elements: The dominant element should be beautiful in line and proportion, interesting in character, in the key position and should express the movement demanded by the space sketch. The subdominant element should be beautiful in line and proportion and should complement the dominant.

Creation of the first big spatial relationship between the dominant and subdominant elements: This consists of two or three exciting movements that express the whole design and suggest the negative volume. It should be noted that the placement of planes in two dimensions and not to line them up because spatial relationships consist of movements.

Refinement of volumes, planes and lines: Strengthen the spatial relationships and tensions between elements. All the lines including those created by planes should be examined and how they relate to each other in space and position should be enquired. In this problem, the relationship of surfaces to one another- the transition from one surface to another is very important. While working with surfaces, it is like learning how the eye moves across form and across space.

Establishment of unity of all design elements and forces: The joining of elements should be done very sensitively. There are two levels to this problem: the visual relationships and interconnections between elements, and how the elements flow.

2.8 Affordance in design process

Gibson (1979) stated that we view things in order to operate on the environment. Perception is designed for action. Gibson called the perceivable possibilities for an action affordance and a cornerstone of his theory is that affordances are perceived directly and immediately. They are not inferred from sensory clues. This theory is attractive from the perspective of visualization because the goal of most visualization is decision-making. Thinking about perception in terms of action is likely to be much more useful than thinking about how two adjacent spots of light influence each other's appearance. Much of Gibson's work was in direct opposition to the approach of theorists who reasoned that we must deal with perception from the bottom-up, as with geometry. The pre-Gibsonian theorists tended to have an atomistic view of the world. They thought we should first understand how single points of light were sensed, then we could work on understanding how pairs of lights were sensed, and then we could work on understanding how pairs of lights interacted. Gradually, building layers of theory from the bottom-up, we would eventually gain an understanding of how people perceive the vibrant, dynamic visual world in which we live. Gibson took a radically different, top-down approach. He claimed that we do not perceive points of light; rather, we perceive possibilities for action. We perceive surfaces for walking, handles for pulling, space for navigating, tools for manipulating and so on (Ware,2020).

In general, our whole evolution has been geared towards perceiving useful possibilities for action. In an experiment that supports this view, Warren (1984) showed that subjects were capable of accurate judgments of the "climb ability" of staircases. These judgments depended on their own leg lengths. Gibson's affordance theory is tied to a theory of direct perception. He claimed that we perceive affordances of the environment directly and immediately, not indirectly by piecing together evidence from our senses.

Translating the affordance concept into the interface domain, we might construct the following principle: A good interface has affordances that make the user's task easy; for example, if we have a task of moving an object in 3D space, it should have clear handles to use in rotating and lifting the object in 3D space, it should have clear handles to use in rotating and lifting the object. Fig. 2.2 shows a design for a 3D object manipulation interface from Houde (1992). When an object is selected, "handles" appear that allow the object to be lifted or rotated. The function of these handles is made more explicit by illustrations of gripping hands that show the affordances.

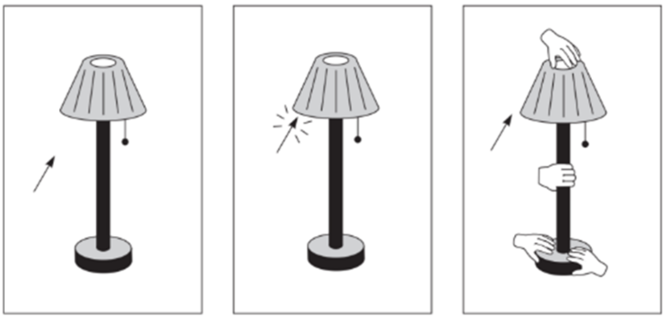
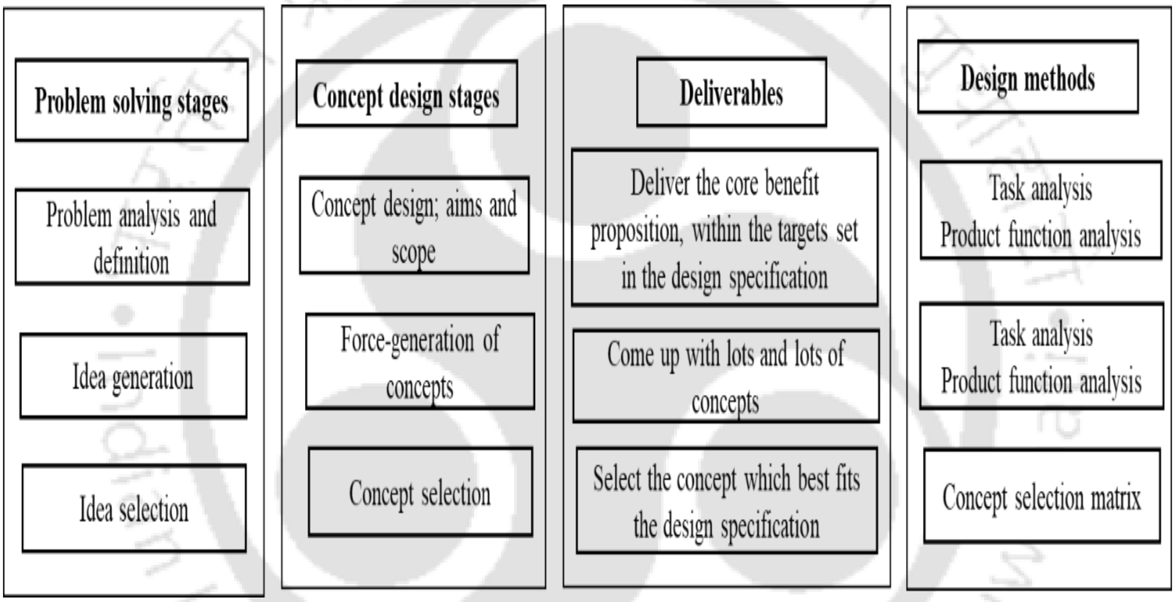


Fig.2.2. Cartoon cues used to illustrate what interactions are possible (from Houde, 1992)

2.9 The concept design process

The concept design aims to produce the design principles for the new product (fig.2.3). These should be sufficient to satisfy customer requirements and differentiate the product from others on the market. Concept design should show how the new product would deliver its core benefit proposition. Essential requisite for effective concept design are, therefore, a defined core benefit proposition and a good understanding of both customer needs and competing products. There are two simple secrets to successful concept design. First, generate lots and many concepts and secondly select the best. Concept design is the stage of product development, which usually demands the greatest creativity. It is at this stage that inventions are invented (Baxter, 2018).



Problem solving stages	Concept design stages	Deliverables	Design methods
Problem analysis and definition	Concept design; aims and scope	Deliver the core benefit proposition, within the targets set in the design specification	Task analysis Product function analysis
Idea generation	Force-generation of concepts	Come up with lots and lots of concepts	Task analysis Product function analysis
Idea selection	Concept selection	Select the concept which best fits the design specification	Concept selection matrix

Fig 2.3. the stages of problem solving and alongside, the corresponding stages of concept design, the deliverables from each stage and the design methods available.

2.9.1 Establishing the aims and scope of concept design

The aims and scope for concept design differ greatly for different products. The concept design aims to develop a set of working principles concerning the overall form and function of the product. During product planning, attention should be focused primarily on customer needs and secondarily on the feasibility of manufacturing the product. Before the process of concept design is about to begin, there is a need for re-examination of the implications of product planning for concept design, crystallize them in our minds and check that they are sensible, meaningful and useful. Therefore, problem gap and analysis acts as distilling and focusing procedure. It also acts as a check on the completeness of the product planning conclusions. The next stage of problem analysis is to explore the problem boundaries. What constraints are appropriate to be imposed on the range of potential concepts, which could be generated. These are the design constraints imposed on how the core benefit of the new product is to be delivered in a commercially realistic way. These constraints are established to try to ensure that product development is not over-ambitious in relation to the existing business position of the company (Baxter, 2018).

2.9.2 Product function analysis

Product function analysis is a method of systematically analyzing the functions performed by a product. It is also known as FAST analysis (Function Analysis Systematic Technique), the most basic and probably the most important analytical technique in new product development. The basic requirement for product function analysis is to know how the product will operate in use. The functions of the product should be predicted as perceived by the customer and how the customer rates the relative importance of these functions. It can be applied both to existing products and to those still being designed. A function tree is generated based on the need statement and its primary functions to be achieved. Once the product function analysis is complete, new concepts can be generated by exploring how each function could be achieved differently from a product. The alternate ways of achieving the higher-order functions are found, the more the basic assumption is being challenged. Therefore, product function analysis can reveal radical, blue–skies innovations by focusing on high-order functions or small incremental innovations by focusing on low order functions. Idea generation is the heart of creative thinking. The ideas produced are the lifeblood of the creative process. They are what put the creative into creative thinking. A key issue in idea generation is how to go about organizing and managing the process. For many people and most industries, idea generation means brainstorming. A classical brainstorming session involves a group of people sitting around a table and coming up with new ideas for solving a stated problem. A key aspect of brainstorming is that the ideas from each person are meant to fuel ideas from the group and tend to be channeled into a limited number of lines of thinking.

2.9.3 Concept selection

Following concept generation, the final stage of concept design is concept selection. Pugh developed the notion of controlled convergence, by which a range of generated concepts is systematically made to converge, by which a range of generated concepts are systematically made to convergence on a single selected concept. The important feature of controlled convergence is that concept selection is not simply a matter of picking the best of the generated concept. A great deal of creativity can be incorporated to combine concepts, amalgamate the best aspects of several concepts and even generate further new concepts. Much value can, thereby, be added to the 'raw' concepts generated earlier. The principles of controlled convergence are shown in fig.2.4.

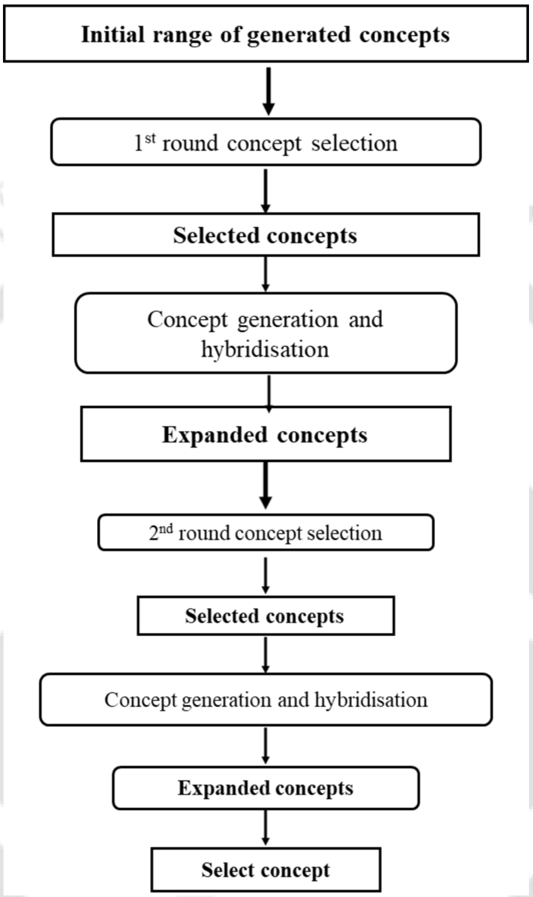


Fig.2.4.The concept selection process

The first round of concept selection ranks the concepts in relation to a series of selection criteria from the opportunity specification. This is done by means of a concept selection matrix in which the concepts are arranged along one axis of the matrix selection criteria along with the other. To make the ranking procedure simple; each concept is judged better than (scored as +1), 'worse than' (scored as -1) or 'the same as (scored as 0) a reference concept. This reference concept should be the best current competitor to the proposed new product. The outcome of the ranking process will be a single number that expresses the relative merit of each concept. Now comes the concept of hybridization and generation phase. Essentially this sets out to take all the good features from the different concepts and combine them into a single product. At the same time, weak features should be eliminated. Therefore, the concepts which were strong overall but which scored (-1) on any of the criteria were to be selected.

Provided at least one of the concepts has a better than (0) overall score, the concept selection procedure should be repeated. Only the strongest concept should be taken. The highest scoring concept from the last matrix as the reference. This will reveal slightly different strengths and weaknesses in the concepts since the characteristics of the new reference concepts are different. In the end, there will be two results; firstly, the reference concept might no longer be the best. If any concept achieved a positive overall score, then the concept selection procedure should be repeated with a new reference concept. This process should be repeated until no new ideas emerge and no concept reaches a positive score. With a creative and imaginative team involved, this may take many iterations. The benefit will, however, always outweigh the cost of time and effort. Eventually, however, the second result will emerge in which the reference concept retains its leadership, with all other concepts managing only (0) or negative scores. At this point, the best concepts out of all those under consideration were found.

2.9.4 Embodiment prototyping and testing

After reaching the point at which an embodiment solution has been found, it is now time to check that this embodiment is fit for its intended purpose. This involves prototyping and testing the new product. Prototyping is a key aspect of product development but it is an activity that can take up a misappropriate amount of time relative to the value, which it adds to the design. Prototypes fulfill several functions in product development (fig.2.5). They can help the designer to develop new product ideas, especially when the new product is complex and highly three-dimensional and, therefore, difficult to visualize on paper. In addition, they can be used to test products or components in order to verify designs. Obviously, different types of prototype are required for these different functions. Prototype is a time-consuming activity but adds more value.

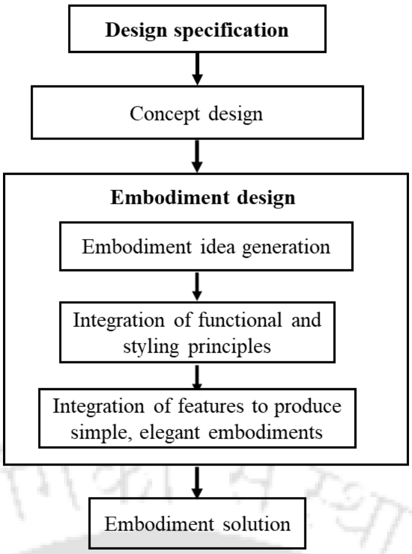


Fig.2.5 stages of embodiment design

2.10 Design Aesthetics

‘Aesthetics’ refers to sensory perception and understanding or sensuous knowledge. In the eighteenth century, the philosopher Baumagar picked up the term and changed its meaning into the gratification of the senses or sensuous delight (Goldman, 2001). Since works of art are mostly produced for this reason, i.e., to gratify our senses, the concept has since been applied to any aspect of the experience of art, such as aesthetic judgment, aesthetic emotion, and aesthetic value. These are all considered part of the aesthetic experience and although we can still experience nature or people aesthetically, the phrase is most often used in relation to the arts, especially visual art (Hekkert, 2006).

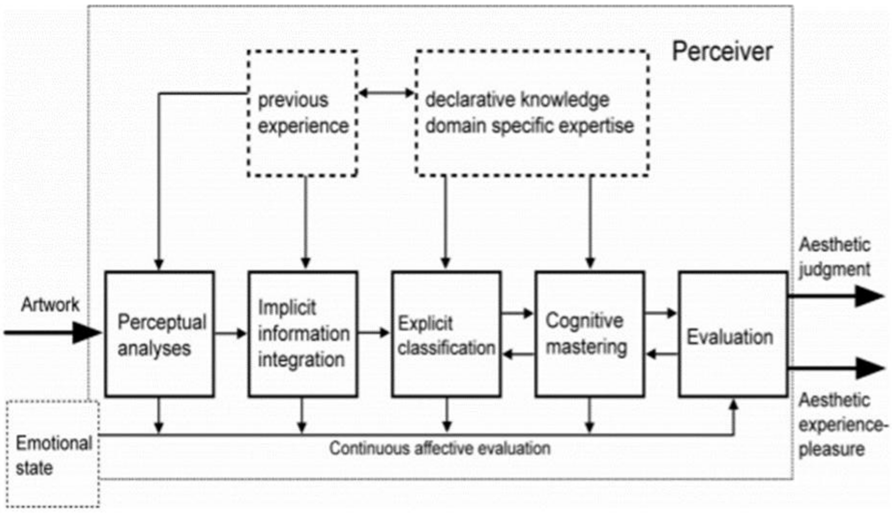


Fig.2.6. Schematic model of aesthetic experience (adapted from Leder, Belke, Oeberst and Augustin, 2004)

The observation that the aesthetic experience is held to cover all processes involved in our interaction with a work of art is perfectly illustrated in a recent model by Leder, Belke, Oeberst, and Augustin, 2004 (Fig.2.6). In this “ model of aesthetic experience,” an observer of artwork starts with a perceptual analysis of the work, compares this to previous encounters, classifies the work into a meaningful category and subsequently interprets and evaluates the work, resulting in aesthetic judgment and aesthetic emotion. Only the first two (or three) stages would be considered aesthetic judgment and aesthetic emotion. In these, mostly automatic stages perception is at work and the degree to which our perceptual system manages to detect structure and assesses the work’s novelty/familiarity determines the effect that is generated. At these stages, we talk about sensuous delight whereas at larger stages cognitive and emotional processes enter the experience.

2.11 The management of design risks

Section 6 of the Health and Safety at Work etc. Act 1947, imposes on designers to ensure, that articles and substances for use at work are safe and without risks to health when used. This Act makes it clear that, as well as fitness for purpose, aspects of quality include freedom from minor defects, appearance and finish, safety, and durability. The designer will find these definitions challenging to put into practice as they stand, for they are open to interpretation. Similarly, superlatives and comparatives by themselves provide little guidance to the designer: they have to relate to something specific to gain perspective. Expressions such as ‘best quality,’ ‘highest standard’ and ‘largest capacity’ have no real meaning unless they refer to graduated degrees of quality, standards or capacities.

2.12 Vibration, its types and its characteristics

2.12.1 Vibration

Vibration is described as a fluctuating movement, categorized by the frequency of the oscillatory cycle, its intensity, and its direction. The immensity of oscillatory motion is measured in terms of its maximum velocity or displacement and is expressed as acceleration and root-mean-square (RMS) magnitude (time-averaged). The unit of frequency of motion is Hertz. Vibration is a formation of automotive motion, which transfers energy. Vibration requires a mechanical form to move along one side and out of the other side. This form might be partly a vehicle, tool, person or a machine but if a mechanical coupling finished then the vibration will no more disseminate. Vibration can be deterministic or random. For determination, it goes within a fixed pattern so the significance of vibration is predictable at any specific future time from history. If it is random, then it is having unpredictable future value besides probability. In statistical terms, random vibration can be understood as the indication of a chance of happening of classified frequencies and magnitudes.

Vibration can be free or forced in terms of the physical structure of the vibration model consisting of a mass and a spring; vibration may be free or forced. In free vibration, it is the outcome of persistent initial disturbance and no addition of energy to the system. An ideal system can contemplate as undamped for the analytical purpose; in such a structure, the free vibration is presumed to persist for an indefinite period. In any real system, the energy displacements (dampening) generate the amplitude of free vibration to deteriorate steadily to an insignificant value. Periodically such vibration is also called transient vibration. Forced vibration that continues down the steady-state condition, since the energy is being imparted to the method consistently to recompose for that debauched by damping in the system. In common, the frequency at which energy provided seems in the vibration system. Forced vibration can be either deterministic or random; the vibration of the system determined by the correlation of the excitation properties of the system. This association is known as the essential characteristic of the mathematical feature.

2.12.2 Types of vibration

Vibration waveforms can be classified into the following categories:

- Harmonic or sinusoidal vibration
- Periodic vibration
- Random vibration
- Transient vibration

Harmonic or periodic vibration, which repeats itself in time, is made up of one or many sinusoidal components, for example, road vehicle vibration caused by out of balance tires. The vibration not repeating by itself regularly is called random vibration, like vibration felt while driving a car on an uneven road. The vibration caused by mechanical shock, for short duration is called transient vibration, for e.g. a vehicle strike a pit. In application, there will be mainly an amalgamation of random, transient and harmonic vibrations (Mandal and Srivastava, 2006).

2.12.3 Categorization of Vibration by contact site, effect and frequency

A regular movement that replicate of its own evenly in a time interval called as period. The frequency of the motion specified by reciprocal of the period and symbolize as the figures of cycles of motion per second. The S.I unit of frequency is hertz (Hz). In a sinusoidal oscillation at a single frequency, simple harmonic motion occurs, which is the easiest kind of movement as it has only single frequency. In a few cases, many frequencies are regular, i.e., integer multiples of the smallest (i.e., fundamental) frequency. In many instances human being susceptible to vibration include some movement happening through a span of frequencies. It is obligatory to designate the frequency content of vibration as a human being susceptible to vibration usually determined by frequency of vibration. There were various ways to determine frequency like electronic filters and computers. People exposed to localized vibration which affects only the hand-arm system or which affects the whole body. Hand-arm vibration syndrome happens if the vibration intensity is high and its effect is noticeable at relatively high frequencies (8 to 1000 Hz). Localized vibration can happen at the feet due to pedal vibration, which does not have any unfavourable human responses. Whole body vibration can felt within the frequency range 1 to 20 Hz. The final categorization of human vibration by communication area, frequency is vibration that causes motion sickness. It can happen, when a person subjected to actual or low frequency motion (below 1 Hz). The frequency ranges of interest and the effects of vibration that cause motion sickness are definite from those that apply to whole body vibration.

2.12.4 Classification of vibration by magnitude and axes

In different industrial sectors, vibration is treated in different ways, essentially due to associated magnitude and coupled effects. Automotive industry focuses on low magnitudes, perception, and issue of refinement for the product development like steering and seat wheel vibration is adjusted to maximize quality and condition. With a large-amplitude low-frequency movement, it is viable to perceive the displacement connecting the highest summit motion in one particular direction and the peak motion in the conflicting direction through a large-amplitude low motion and it is the peak-to-peak displacement. However, it is not possible to measure vibration with high-frequency motions while the displacement is minimal to be recognized by the eye. Alternatively, the immensity of the oscillation narrated by velocity, straight connected to the energy involved in the motion. The differentiation between the extreme velocity in one direction and the extreme velocity in the conflicting direction is called the peak-to-peak velocity. The standards had suggested that the intensity of human vibration exposure demonstrated in terms of vibration acceleration rather than velocity.

Vibration prevails in any direction. Vibration spur concurrently move laterally, vertically and in the fore art directions, rotation is feasible, causing six axes of possible movement. The fore-and-aft direction for whole body vibration described as the x-axis, y-axis for lateral and vertical for z-axis. Considering head motion, roll (rotation around the x-axis) commensurate to the level of the head to either side, pitch (rotation around the y-axis) corresponds to an inclined movement and yaw (rotation around the z-axis) commensurate to the regular shaking of the head. The thighs aligned to the x-axis for a sitting persons and z-axis for standing persons

In case of hand-transmitted vibration, the x-axis moves across the palm, the y-axis moves over the palm towards the thumb and z-axis expand in the direction of the fingers corresponding to the back of the hand.

2.12.5 Peak, Average or Dose measures

The peak-to-peak acceleration is the acceleration immensity of vibration. It is generally expressed as the severity of vibration in terms of a mean measure as complex motion might produce in the extremity of vibration resolved by one divergent peak. In engineering, the highest use of vibration measurement is the root-mean-square (RMS) value, and it is the square root of the midpoint value of the acceleration record. The suggested method for measuring the intensity of human vibration exposure is the root-mean-square acceleration (i.e., m/s^2 RMS), as it is one of the convenient methods for measurement, investigation of the human vibration exposure and balancing with some further section of engineering. However, when measuring the immensity of exclusively behaved motions same general trends having different numerical values of a peak-to-peak, RMS and peak were found.

2.13 Human Vibration and its characterization

Vibration is an occupational hazard and many studies had outlined the harmful consequences of occupational vibration exposure (Griffin, 1990; Bovenzi, 2005; Kucuk et al., 2016). There are around 3 billion workers in the world and about 25% of workers subjected to vibration in their workplace (ILO, 2013). Human reaction to vibration is a multi-disciplinary subject that includes an understanding of different areas as divergent as mathematics, engineering, medicine, statistics, psychology, physics, and physiology. Each of this domain proposes its scientific word, which sometimes may be not understood by people from different field (Griffin, 1990). The impact of vibration was taken seriously since the early 1900s. Dr. Alice Hamilton, a famous occupational medicine pioneer, in early 1918 evaluated the therapeutic consequences of power tool vibration exposure on workers (Wilder and Wasserman et al., 2002).

E.E. Dart in (1946) had reported swelling, hand pain, tenosynovitis among aircraft workers working with vibrating hand-tools. It was in the 1960s in many industrialized countries that vibration white fingers (VWF) were established (Wasserman et al., 1997). NIOSH vibration team in the early 1970s had determined near about eight million workers in the U.S. subjected to vibration and then in the late 1970's NIOSH team jointly with Dr. W. Taylor and P.L. Pelmear, supervised a series of VWF studies and evaluated among the workers using vibrating tools (Wilder and Wasserman eta al.,2002). The International Labour Office (ILO) in 1977 had categorized vibration as a job-related threat and recommended for preventive measures through proper supervision of employees in their workplace. In the Indian Scenario, the earliest information on occupational hazards was available on the miners. The extensive use of jackhammers, drillers, riveting gun, chipping machine, etc. are the source of HAV exposure in mines and source of WBV were dozer, dumper, load-haul-dump vehicles through feet, buttocks, and back (Mandal and Srivastava,2006).

Occupational Vibration considered as a significant ergonomic concern that requires continual surveillance, supervision, and constant control. The long-term consequences of whole body vibration (WBV) and hand-arm vibration (HAV) connected to health risks as musculoskeletal disorders, spinal deterioration, low back pain, carpal tunnel syndrome, vibration-induced white fingers, and muscle and tendon disorders. Evaluation of the harmful effect of vibration injuries formed on prediction models, which deal with health risk evaluation by quantifying the vibration and considering other variables like direction, duration, and frequency. Knowledge on parameters of vibration measurement like computer technology, electronics, digital signal processing, mechanical engineering, mathematics, physical principles is essential. Similarly, the fundamental principles of technology and method of instrumentation and guidance are essential to generate authentic set of data.

Hand-arm vibration explained as the quantification of 'dose,' 'effect' or 'dose-effect relationship,' where various variables considered for a proper understanding of the importance of vibration severity. The different procedure of understanding the consequences of hand-transmitted provides complementary data. However, no single method will yield all the required information. It is recommended that experimental 'convenience' as much as perception of the biodynamic, personalized, morbid, physiological and epidemiological reaction to vibration. The practical investigations determine the attributes of vibration (direction, magnitude, etc.) due to the vibration transmission to the hand-arm system. It also defines the difference in vibration transmission due to the attribute of the contact (shape, orientation, handle size) with vibration and also body postures and other individual features.

The physiological and pathological investigation contributes to the comprehension of the method of the changes originated by vibration and analyses how they determined on some of the attributes of the vibration and other variables. The standard for hand-transmitted vibration helps in evaluation of vibration magnitudes. It also does health monitoring, used to prove if a problem exists. The reduction in vibration magnitude or exposure time lessens the intensity of vibration exposure. It is hard to ascertain the accuracy of the consequences of vibration exposure based on the projection of the standard and observations. However, based on inhibitory actions, it is necessary to know whether changing the vibration immensity or vibration frequency or daily exposure, etc. will change the severity of the injury as predicted by the standard. There is very less knowledge available in the literature in the primary level to support the form of the relations between vibration frequency, exposure duration and vibration as described in the standard (Griffin, 2012). There is also very less information on an exposure-relationship for the subjection to Hand Vibration syndrome and neurosensory indication (Sauni et al., 2008). The precision of the dose-effect information could help evaluate specific tool types to define its exactness; the consequences of vibration frequency, grip force, etc. Proper regulation in hand-transmitted vibration standards could help in designing or choosing of tools. If a frequency weighting of a particular tool is high, then it could be replaced accompanied by another lower frequency-weighted acceleration.

The amalgamation of numerous sensory pathways recognizes the feeling of sensation. These sensory signals through our hands decodes as size, texture, shape, location, temperature, pain and movement. The receptor for interpretation of the sense of touch in glabrous skin embedded within the skin mentioned as the speed of action, psychophysical channels. Due to the strain of stimulating of separation of any one channel in inter-individual differences, the specific frequency range of reactivity of each passage is not effectively described. Type 1 reception can sense the location of sensation precisely as it found close to the skin surface. Type II receptors are more common in terms of receptive field size as it is found more profound in the dermis.

The vibration sensation can increase with an increase in the area contact. In a similar way threshold also affected by probe design and push force on the probe. Eventually, the results can be pretentious by the precise position on the hand (Morimoto and Morioka, 1999). Therefore, to quantify the perceived vibration exposed by a person both intensity and frequency of the vibration along with the essence of the touch and individual differences must be considered. The term *Wh*, a single-frequency weighting is used for hand-transmitted vibration. To evaluate the chance of bruises from vibration the weighting (*Wh*) is used to brace the reaction of the hand-arm system to vibration.

2.13.1 Measurements of Human Vibration

An accelerometer is used to quantify the intensity of vibration. It is conveyed in terms of acceleration in meters per second (i.e., ms-^{2} / m/s^2). The unit of frequency of vibration is Hertz (Hz). The effect of frequency of vibration depends upon to what magnitude the vibration is imparted by the body and the surface of the body and reaction to vibration inside the body. The measured magnitude of vibration may be affected by the duration of vibration exposure. The considered intensity of vibration may also be pretentious by the period of vibration exposure if the motion is not numerically static. The root-mean-square (RMS) acceleration is frequently used, but then it might not give a fair indicator of vibration extremity. The results may vary if the vibration is regular, shocks or changes in intensity from time to time. Accelerometers that transform the acceleration of the surface into electric signals are used to measure the vibration. The oscillatory movements are transuded that convert the acceleration of the surface into electric signals. The transducer does not entirely mean all feasible movements. The calculated signal is an adequate representation of the vibration accompanied by the pertinent parts of the movement. It requires presumption to which part of the motion is the source of disorders. Then the measurements could be deposited as tables of the number, waveform drawn on paper, etc.

The assessment of the quantification of human reaction is to check the severity of the vibration. Hence, all frequencies or all directions of motion cannot be assured of equivalent significance. Therefore, an assessment process can find out the comparison of the extremity of independent vibration differentiated. This process needs thorough information of the comparative significance of different qualities in the evaluation. Values could show the assessment in an interval or as a ratio scale.

The assessment of vibration includes the assessment of the consequences in a mathematical value stating the vibration extremity and the consequence of the vibration extremity. It is mainly the severity, the type, or probability of disorders. A specific type or origin of vibration could be classified as intolerable or prohibited without the information of the vibration magnitude. Hence, an evaluation does not necessarily require assessment and consideration of vibration, which can also be accessed through the utilization of somatic values to brace the end.

2.13.2 Standards for assessment of hand-transmitted vibration

There are guidelines provided by international standards and government ordinance on the measurement, evaluation, and assessment of the extremity of subjection to hand-transmitted vibration. The method of assessing hand-transmitted vibration is described in ISO 5349-1 (ISO2001b) and ISO 5349-2(ISO2002), ISO8662, and ISO 28927. The same frequency weighting (called *Wb*) is used by the national and international standards to assess hand-transmitted vibration above the estimated frequency range 8-1000 Hz. The standards recommend that all the intensity of hand-transmitted vibration should be deliberated from the root sums of the square of the frequency-weighted acceleration in three directions (*X*, *Y*, and *Z*). The quantification of tool vibration must be acquired in typical functioning situations. The standard implicit that if two tools exposed to hand-arm vibration for the same duration, then the tool with the smallest frequency-weighted acceleration would cause injury or disease. The concept 'equal energy' was used for the quantification of hand-arm vibration so that a composite subjection pattern of any period throughout the day could mean by the equal value for an exposure of 8 hours. For subjection of the period, t, to a frequency-weighted RMS acceleration, $_{\mathrm{ahw}}$, the 8-hour energy-equivalent, $_{\mathrm{ahw}}$ (eq,8h), is given by:

$$\mathbf{a_{hw(eq.8h})} = \mathbf{a_{hw}}\sqrt{}\ \mathbf{(t/T_{(8)})}$$

Where T $_{(8)}$ is 8 hours (in the same units as t) the value of $a_{hw\ (eq,\ 8h)}$ is occasionally indicated by A (8). The immensity needed to speculate the occurrence of 10% VWF after 8 years were presumed to be dependent on vibration frequency from 8 to 1000 Hz for subjection period from 1 minute to 8 hours per day.

In 2002, Directive 2002/44/EC (2) was taken on for safety of European workers. It specifies least necessity for the protection of workers from the risk rising from vibration. The directive has put down the following limit value.

Table 2. 4. The limits of HAV and WBV, according to EU directive 2002/44/EC

	Hand-Arm, RMS	Whole-Body, RMS	Whole-Body, VDV
Exposure action value	2.5 m/s^2	0.5m/s^2	9.1$m/s^{1.75}$
Exposure limit	5 m/s^2	1.15m/s^2	21$m/s^{1.75}$

The employer needs to start and execute a plan of scientific and organizational measure if the exposure value is surpassed meant to minimize the exposure to vibration, explicitly considering the following points:

- A working process that has minimum subjection to mechanical vibration.

- Ergonomically design work apparatus generating the minimal vibration.
- Uses of additional protective apparatus that decrease the chance of bruises.
- Proper maintenance programme for work apparatus.
- Plan and arrangement of workplaces.
- Sufficient knowledge and instruction to teach workers to use work apparatus accurately and securely.
- Restriction in the continuation and magnitude of the exposure.
- Sufficient rest periods in between work schedules.
- Protection from cold and damp through proper clothing to workers.

In any circumstances, the workers exceed the exposure limit value; the employee has to take quick effort to minimize the exposure limit value. The procedure might contain sampling, which must be reprehensive of the personal subjection of a worker to the mechanical vibration in question. In the Directive, the daily exposure action and exposure values are described as an 8-hour energy equivalent frequency-weighted acceleration (A (8) value) and vibration dose value (VDV) for WBV. The measurement to vibration exposure discussed in two Annex which refers to ISO 5349-1:2001 (4) for HAV and ISO 2631-1:1997) (5) WBV. Hence, the HAV exposure is obtained from the root-sum-of-square of the three single-axis values (tri-axial vibration) and three directions at the seat (sitting) or feet (standing) for WBV. For the calculation of A (8), it is not mandatory to assess over 8 hours. Construction of short-term quantification throughout the work steps. The outcome is averaged to 8 hours. The daily subjection to vibration is calculated as follows.

$$A(8)=a_{we}\sqrt{\frac{T_e}{T_0}}$$

Equation 1

where

A (8) is the everyday subjection

a_{we} is the energy equivalent mean value of the frequency weighted acceleration through subjection, for Hand-Arm Vibration the *X/Y/Z* vector sum of *Wh* frequency-weighted RMS values (Equation 2)

$$a_w=\sqrt{a_{wx}^2+a_{wy}^2+a_{wz}^2}$$

Equation 2

T_e is the entire period of subjection throughout one workday

T_0 is the reference throughout 8 hours

Everyday subjection may have composed of some limited subjection with dissimilar vibration intensity, in case of prolonged interference in the work process or the work equipment/device is different. A limited subjection segment should have an approximately continuous intensity or not much than 10% interference. The daily subjection is deliberated as follows.

$$A(8)=\sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{wi}^{2} T_{ei}} \qquad \text{Equation 3}$$

Where

A (8)	is the daily exposure
a_{wi}	is the energy equal to the mean value of the Wh frequency weighted acceleration of limited exposure segment i
n	is the amount of uniform exposure segment
T_{ei}	is the period of exposure i
T_0	is the mentioned period of 8 hours

2.13.3 Human Vibration Meter

Since 1990, human vibration meters have been in use to measure vibration, mostly in reaction to the formation and execution of the European Union Physical Agents (Vibration) Directive. It is a basic device used to assess the vibration intensity with no analysis required in the laboratory. However, then it is not able to stock the acceleration wave shape, used to explore the character of the signal and constancy of its quantification. It usually is essential to find a solution by recognizing the problem and understanding the reason for the problem. The device needs to be configured all the parameters axis multipliers, calibration analysis methods; frequency axis must all be programmed accurately for an adequate evaluation. For fundamental measurement, meters might be comfortable than adjustable systems, but there is still a chance of scientific fallacy. It is not possible to compare some measures since the waveform is not stored on the meter.

The VM31 specifically developed for the measurements and evaluation of human vibration, machine condition monitoring, quality control, and building vibration measurement. The device in amalgamation with a tri-axle accelerometer, it can assess hand-arm vibration and whole-body vibrations complying with ISO 5349, ISO 2631, EU Directive

2002/44/EC, and ISO 8041. The VM31 can calculate vibration acceleration from 0.2 to 1500HZ and 1 to 1000 Hz, vibration velocity from 1 to 100 Hz, 2 to 1000 Hz (an evaluation of machine vibration to ISO 10816) and vibration displacement from 5 to 200 Hz. The VM31is powered from three fixed alkaline batteries size AAA (LR03) or rechargeable NiMH batteries of type HRO3. It starts with TEDS1 (fig.2.7) identification when it is switched on, or a sensor is connected. IEEE 1451.4 TEDS template no.25 (presence or absence of transfer function) is supported, and the assessment of X/Y/Z and channel A exhibit for some seconds. The user text of TEDS (ID) also exhibits for each channel. The VM31 is capable of fastening any less power IEPE accelerometers that can run with a 1mA supply current. The inner complying potential of the current source is 18VDC.

TEDS

Sens. X: 10.200 $\mathrm{mV/ms^{-2}}$
ID X: www.mmf.de

Sens. Y: 10.157 $\mathrm{mV/ms^{-2}}$
ID Y: www.mmf.de

Sens. Z: 10.249 $\mathrm{mV/ms^{-2}}$
ID Z: www.mmf.de

Sens. A: 01.115 $\mathrm{mV/ms^{-2}}$
ID A: www.mmf.de

OK: Continue

Fig.2.7.TEDS detection display on the screen of VM31

For measuring hand-arm vibration, the sensors have to be attached near to the grip ends of the hand, without hindering the work process (Fig 2.8, 2.9 and 2.10). A similar hand pressure force needs to be used under usual working conditions for assessment. There is also provision for some mounting accessories to attach sensors for the irregular surface. The measurement begins when the sensor and the workers' hands were set on the handle of the object performing the activity.

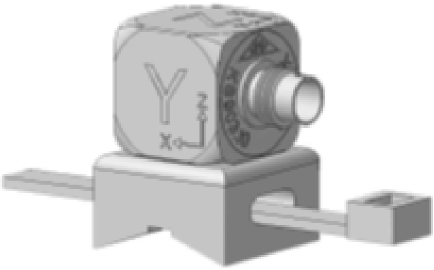


Fig.2. 8. Handle adapter 141 for attaching on the surface handle

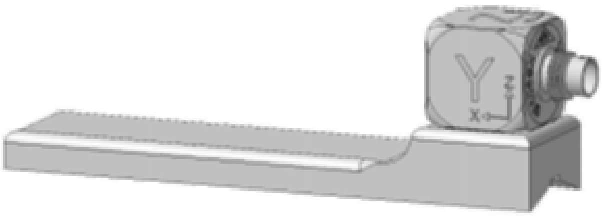


Fig.2. 9. Hand-held adapter 143 for attaching the sensor on the hand

It is important to have immediate connection linking of the sensor and the machine because any the movement of the sensor would falsify the assessment.

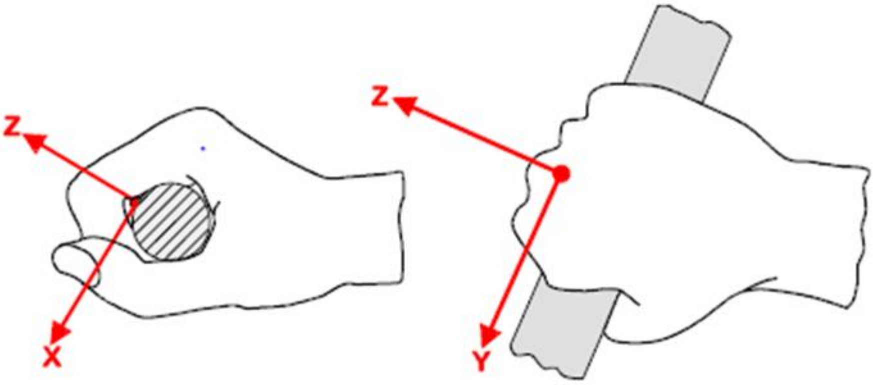
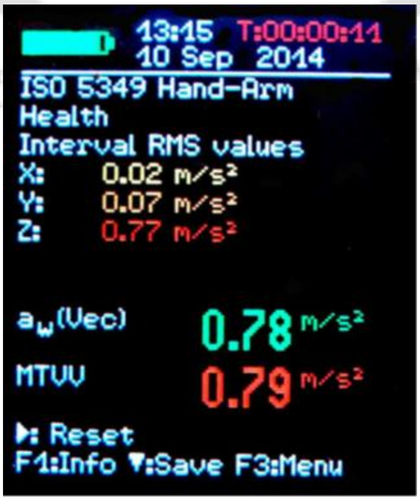


Fig.2.10. Harmonizing system of the hand (from ISO 5349-1)

To assess the hand-arm vibration both interim RMS values of *X/Y/Z* and their vector sum *aw* should be considered. The four values were measured concurrently. It also gives the Maximum transient Vibration Value, MTVV known as the maximum running RMS, to designate the shock vibration. The weighting frequency for hand-arm vibration is *Wh*. Fig.2. 11. shows the sieve of the VM31 and the forbearance bands to ISO 5349.



13:15 T:00:00:11
10 Sep 2014
ISO 5349 Hand-Arm
Health
Interval RMS values
X: 0.02 m/s²
Y: 0.07 m/s²
Z: 0.77 m/s²

a_w(Vec) 0.78 m/s²
MTVV 0.79 m/s²

▶: Reset
F1:Info ▼:Save F3:Menu

Fig. 2.11. Display of Hand-arm measurement on the screen of VM31

Over the complete measuring time, the RMS values of X/Y/Z and the vector sum are averaged to reduce the fluctuation that takes place for longer measurement, and slowly, the small shock pulses have no impact on the displayed outcome. The suggested calculating time for hand-arm vibration is minimum of 30 seconds.

It also gives a simple FFT function to perceive the central frequencies, and it shows a 125-line peak spectrum of acceleration. Four ranges of frequencies: 3 to 244 Hz, 7 to 488 Hz, 15 to 977 Hz, and 30 to 1954 Hz can be selected. It can store 10,000 data records and contain comment, date and time, filter and measuring mode, and the saved data could be viewed on the display screen. The VM31 has a USB attachment with a VM2x-USB cable (fig. 2.12) that could be connected to the VM31 through its eight-pin connector. The other end of the cable could have connected to a USB port on the computer. The stored measurement data could be transferred to a PC using the Excel macro file vm31.xlsm. The stored data from the connected VM31 memory into Excel tables, vibration exposure A (8) and FFT data could be calculated and displayed graphically from the human vibration meter.

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Fig.2. 12.USB cable VM2x-USB

2.13.4 Muscular fatigue due to vibration and its quantification

Powered tools induce vibration largely, and the operators of powered tools were exposed to a high level of vibration. During the use of vibrating tool high level of coupling, forces are required which results in an increase of transmissibility of vibration to the hand. The increase in vibration exposure causes the muscle too voluntarily, involuntarily and reflexively contract (known as the Tonic Vibration Reflex); which promotes muscles fatigue, stress (Park and Martin, 1993), and are known to decrease productivity through compromising hand dexterity, making manual handling tasks harder to perform (Bovenzi, 1990; Brameer et al., 1987; Deshmukh and Patil, 2012). Muscular fatigue occurs when the motor units are not in a condition to continue the existing force level. Muscle fatigue is a complicated situation surrounding the diverse sources, procedures, and forms of explanation. It evolves due to a chain of metabolic, constructional and dynamic changes in muscles due to lack of oxygen and nutritive material furnish through blood circulation, which causes the effectiveness of the nervous system. According to Merletti et al., 2004 the possible areas of neuromuscular fatigue can be categorized into three headings: (1) primary fatigue (2) enervation of the neuromuscular joint and (3) muscle enervation. The muscles fail to cause the essential force in the neuromuscular situation.

2.14 Evaluation of muscular effort during operation of hand-held devices

2.14.1 Surface electromyography

The uninterrupted observation of local muscle fatigue through the execution of particular work is feasible by assessing the myoelectric activity of the specific muscles by the procedure of surface electromyography (EMG) (fig.2.13) (Cifrek et al., 2009). The determination of localized muscle fatigue is one of the critical parameters in the industrial application of ergonomics. Surface electromyography (EMG) records bioelectric signals caused by neuromuscular activity with the help of surface electrodes (also known as topical or cutaneous electrodes). It has broad areas of application like posture analysis, gait, product certification, motion analysis, ergonomic design etc. Electromyography is an extension of the clinical examination. It can differentiate myopathic disease from neurogenic muscle wasting and weakness. It can detect abnormalities such as chronic denervation in normal muscle by determining the neurogenic distribution abnormalities, different focal nerve, plexus or radicular pathology.

Many studies had used EMG to investigate handgrip intensity, the task of fingers by observing EMG signals acquired from thick locale hand muscles on a dynameter, evaluation for wrist position, activation of one muscle with another and supremacy of hand muscles in finger flexion, assessing exhaustion of the erectors spine etc. (Dolon et al., 1995; Duque et al., 1995; Johnston et al., 2010; Sukaini et al., 2016; Yokoyama and Yanagisawa, 2019). Electromyography signals were also used in assessing exhaustion of the erectors spine in the frequency range from 5 to 300 Hz and the activation of one muscle co-ordinately with another through two-digit avaricious movement utilizing the thumb and the index finger with multiple wrist angles (Dolon et al., 1995; Johnson et al., 2010; Sukiani et al., 2016). Some studies also had considered Flexor Carpi Radialis (FCR), Extensor Carpi Radialis (ECR) and FDS for recording EMG screw driving tasks and other gripping activities (Mogk and Keir, 2003 and Bano et al.,2012). Similarly, Bicep muscles and Deltoid muscles were considered to examine the effect of overhead drilling on the muscular activity of the (Garapati, 2007). EMG data recorded using wireless 4-slot face electrodes with skin interfaces (fig.2.14) is drawing increasing importance in the ergonomic evaluation of various physical tasks. The ergonomic analysis using EMG provides the experimenter with valuable and quantitative measures of the load on a pertinent muscle at a given work posture.

Fig.2. 13. EMG set up

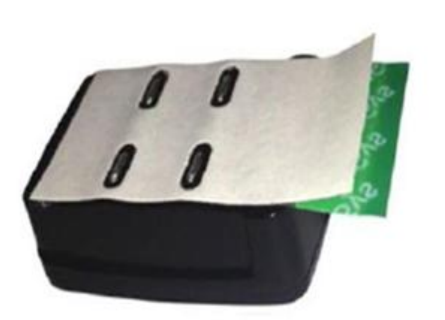


Fig.2. 14. Trigno Sensors 4-slot with skin interfaces

In electromyography, the power spectrum analyses were achieved through the Fast Fourier transform (FFT) technique that changes raw EMG signals from the time realm to the frequency realm. After these various frequency components, the median frequency and the power contained (area under the curve) can be calculated and studied. This electrophysiological data of the muscle allows discerning physiological changes and progression towards eventual fatigue even though no external or mechanical indicators can be apprehended.

2.15 System Usability Scale (SUS)

The System Usability Scale (SUS) was developed by Brooke (1996), known as a speedy and filthy “survey scale and cost-effective tool that would permit the usability practitioners to easily evaluate the usability of a product. SUS is open-minded enough with a broad scope of interface technologies. In SUS, the survey is a single score on a scale, which can be easily perceived by a project manager to a computer programmer. It is also easily understood for people having less or no practice in human factors and usability. The original SUS is of 10 statements that are scored on a 5-point scale of the strength of agreement. The final scores specify better usability. Later, a seven-point, adjective- anchored Likert Scale was accepted to decide if a word or phrase could be correlated with a small range of SUS scores. It was found that the adjective rating is highly correlated with the SUS score. The adjective rating was found helpful in interpreting the individual scores and explaining the consequences to non-human factors. Based on sufficient history of test scores for a basis of differentiation, these data give the usability exponent with adequate confirmation that a given interface is unable or not. The SUS allows administering difficult tasks and a low-frequency task and allows the investigator to investigate two different aspects appropriately (Bangor et al., 2009).

Usability is not a standard that lives in actual or outright perception. Maybe it can be estimated as being a universal standard of the applicability to the motivation of any specific trace. The usability of any tool or system has to consider with regard to the context in which it is used and its application to that context. Usability is a flexible feast, it follows that measures of usability must themselves be supported on the way in which usability is defined. In spite of usability is getting extensive acceptance, considerable confusion exists over the actual of the term. Sometimes usability explained in very narrow and distinguished from. ISO’s broad definition of usability consists of three distinct aspects: Effectiveness, which is precision and fullness that helps users to achieve certain goals. Measure of effectiveness includes the standard of solution and error rates. Efficiency the relation between the accuracy precision and fullness with which users attain certain goals. Signs of efficiency includes task completion time and learning time. Last is the satisfaction that is the users’ comfort with and positive attitudes towards the use of the system. It is enticing to presume simple general relation between effectiveness, efficiency and satisfaction, any relation between them seem to depend on a range of matter such as application domain, use of context, user experience and task complexity (Frokjaer et al.,2000). For the routine tasks, good performance depends on the efficient, well-trained implementation of a succession of actions, which is known to yield stable, high-quality results (Card et al., 1980). Literature also says that while administering SUS, a significant proportion of non-native English speakers failed to understand the word “cumbersome’ in Item 8 of the SUS (Kraig Finstad, 2006).

3 Methodology

In today’s world, power or pneumatic hand tools and other machinery are extensively used in various workstations of construction, transportation, forestry etc. In 1911, the health consequence of hand-transmitted vibration was reported in the literature by Loriga and eventually in 1918 by Hamilton. The incidence of Reynaud’s episode has been described for more than 100 years (Hamilton, 1943; Loriga, 1911; Nilsson et al., 2017). Earlier the neurological indication of subjection to hand arm vibration was generally specified by insensibility and tingling sensation in the hands or fingers (Gemne and Lundstrom, 2000; Aroori and Spence, 2008; Van Rijj et al., 2009; Vihlborg et al., 2017). These neurological indications influence dissimilar thresholds in the hands (touch, vibration and temperature) (Nilsson, 2017). There was no understandable connection connecting the frequencies, vibration subjection magnitude or period and which senses are pretentious. Hand arm vibration syndrome is related to the application of hand-held vibrating tools but then studies related to design intervention of vibrating tool to ameliorate the exposure to vibration are rarely reported except agriculture, mining, forestry, automobile etc. The Stone polishing activities, an important part of the construction sector where hand-held floor polishing device is extensively used is not reported. Hence, in this present research, it is emphasized to formulate ergonomic design intervention of the existing floor-polishing device to reduce the vibration transmission and improvement of the device in terms of usability.

3.1 Location of the study

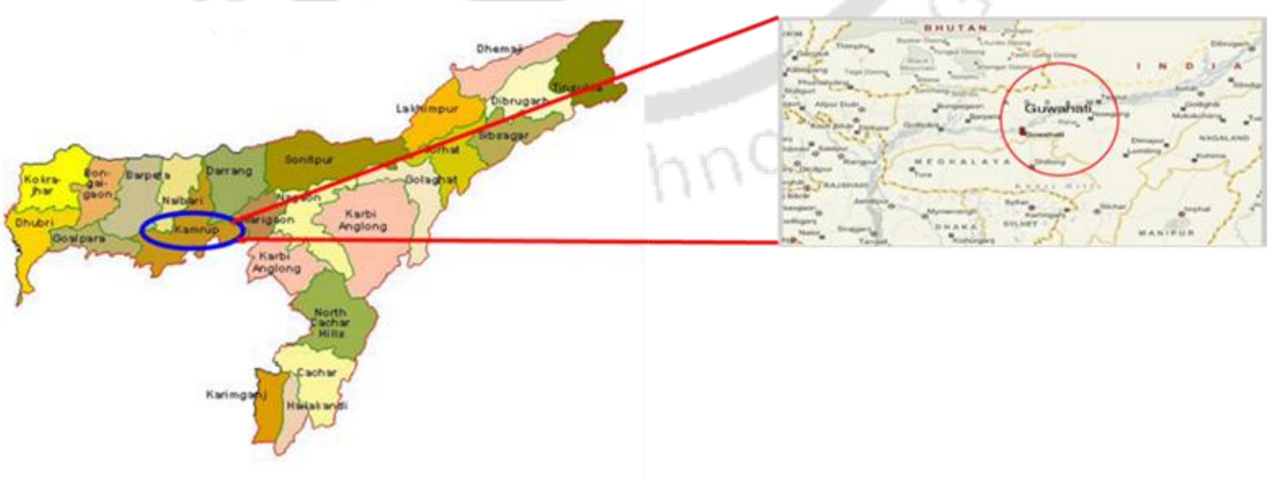


Fig. 3.1 Map showing of Northeast Region of India

Guwahati city was selected as the site of the study (Fig. 3.1). Guwahati, the largest city of Assam (also the Northeast of India) as well as the gateway to the North East, has been witnessing a lot of infrastructures and economic development, which has been the prime reason for these, has been an increase in the number of upcoming constructions, the cardinal site of floor polishing work. Apart from this, the connectivity to Guwahati is also much better than other major cities in northeast India, as far as carriage of sophisticated instruments is concerned. Above all, it was envisaged as the most prominent location to carry out an experiment on floor polishing workers (greater sample size obtainable) due to availability of a large number of construction works, thereby having a greater number of floor polishing workers.

3.2 Sampling

Using purposive sampling techniques, various places of Guwahati city like Lokhra, Ambari Fatashil, Ganeshguri, Jalukbari and Amingaon were selected for the study, where various construction activities were taking place. A total of 45 adult floor-polishing workers were purposively selected with age ranging between (18-46 years) from the above-mentioned construction sites. The inclusion criteria for the selection of floor polishing workers was minimum work experience of one year and being in sound health and having no medical evidence of any long-term illness. The male workers mainly performed polishing works. So, only male polishing workers were selected as participants for the experimental study. These workers were involved in the floor polishing activities and were not involved in any other construction activities.

3.3 Data collection

The subjects were briefed about the experimental strategy and their part in the research in detail. The complete data collection was executed per with Helsinki guidelines (World Medical Association, Helsinki, 2001) and an agreement was taken in written form for all the participants. The personal and demographic information (birthplace, age, gender, height, weight, education, income, etc.), job experience (years), daily working hours, working condition, job satisfaction, perceived vibration discomfort, etc. was collected through questionnaire-based interview and direct observation of the polishing process at the construction sites. A detailed study on body parts discomfort was also carried out using a modified Nordic questionnaire (Kuorinka et al., 1987), which had considered the information about body parts discomfort, job stress and work nature. The questions were described in their local language and duly filled by the examiner, as the participants were not well versed in English language.

3.4 Research Framework

The research attempted to apply various ergonomic theories and evaluation theories for design intervention of vibrating equipment/devices used in floor polishing activities. The research design chosen to achieve the research goal for the research is shown in Fig.3.2. The research aimed to reduce the vibration transmission to the hand –arm system during polishing activities. Therefore, various risk factors related to the floor polishing activity were evaluated in detail and problems were recognized. Exposure to excessive vibration while handling the floor-polishing device was the main drawback of the polishing device. Therefore, the existing vibrating device used in floor polishing work was redesigned at the Department of Design, Indian Institute of Technology (IIT) Guwahati. The existing floor-polishing device was redesigned to ameliorate the impact of vibration in terms of proper anthropometric compatibility, use of vibration dampening material and providing a supportive mechanisms to avoid holding the weight of the device. A pilot study was carried out to identify the problems related with the existing polishing machine.

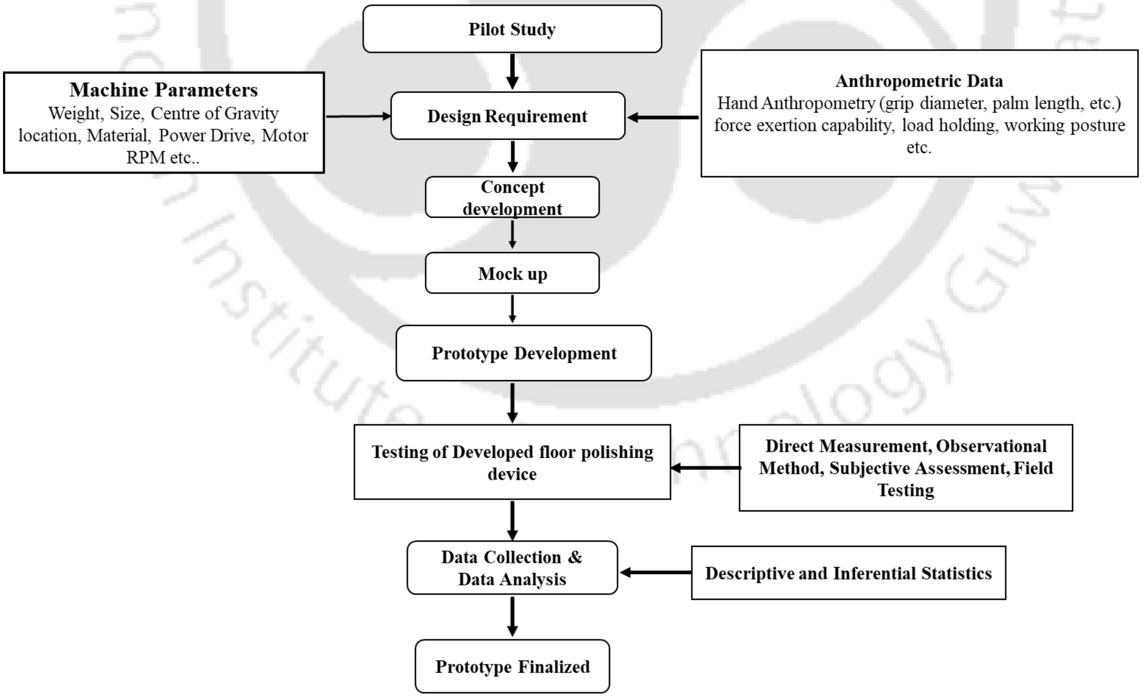


Fig. 3.2 Schematic diagram of the research design followed for present work

A systematic evaluation of the outcome was carried out for design intervention of floor polishing device. Trial and testing of the existing and redesigned floor-polishing devices were carried out in laboratory and field conditions to assess the efficiency/efficacy/productivity of the device. The various tools and instruments used for evaluation were Human Vibration Meter, Electromyography, REBA, Nordic Questionnaire etc. Thus the research design was broadly divided into three phases i.e. Quantification of exposure level of vibration of the existing floor polishing device and questionnaire study, design intervention of the existing floor polishing device and evaluation of the redesigned machine.

3.5 The product development process

The redesign of the existing hand-held floor-polishing device, an appropriate development process was adopted. The various stages of the product development process have been discussed below.

3.5.1 Pre-conceptual phase

In designing any product, there may exist an abundance of ideas for redesigning product, but once the best was selected among the available ideas, the next process is to find the similar kinds of products available in the market. A user survey was conducted among the stone polishing workers to gain information regarding the type of device being used in stone polishing activities and the specific features needed for development to meet the needs of the users. A market survey was also carried out in the local market of Guwahati city to find out what kind of similar products were available in the market.

3.5.2 Concept generation

The stages of conceptual design are shown below in Fig. 3.3. The basic goal of concept generation is to develop as many ideas as possible. This process began with the investigation of the customer needs and the initial focus was emphasizing the basic needs of the users. In fact, all the needs must be satisfied through concept generation. The design task was fragmented based on customer-need focus into subproblems that could be easily understood and solved. Brainstorming was done to generate ideas focusing on the functional need of the floor-polishing device. A morphological chart was used to combine all the important functions of the floor-polishing device along with the possible solutions. Pugh chart was used for screening the concept generated based on the functions of the floor-polishing device.

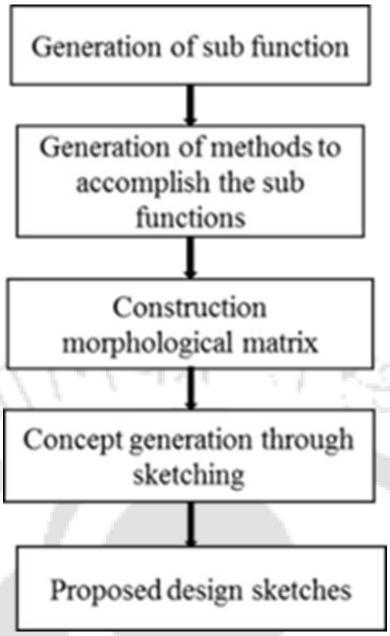


Fig. 3.3 Conceptual design stage

3.5.3 Pre design and detailed phase

The CAD model was created to figure out all the finer details of the device by looking at the 3D model. It helped to have a magnified look of the full three - dimensional concept of the different parts of the redesigned floor-polishing device. The prototype of the final selected concept was fabricated testing and evaluation.

3.5.3.1 Quantification of exposure level to vibration during the use of the floor polishing device of both the existing and redesigned floor-polishing device.

During the polishing activity, the intensity of transmitted vibration (from the handle of the polishing machine) at the wrist of the right hand of the operator was evaluated using hand-arm vibration meter (Make: Manfred Weber, Model: VM31-HA) following the assessment method as reported in European Occupational Health Directive 2002/ 44/EC and ISO 5349-1. The intensity (acceleration) of the hand-transmitted vibration for all three axes (X, Y and Z) and their vector sum (as mentioned in EN ISO 5349: 2001) were recorded for 30 sec. (after 1 min. of polishing activity) while executing the polishing activities at floor, wall-base and staircase. The accelerometer was attached to the wrist and handle by a plastic tape as shown in Fig.3.4 to measure the vibration transmitted to the hand and handle during the use of existing, and redesign polishing device.

Fig. 3.4 Tri-axial accelerometer attached on the wrist of the operator during use of polishing machine (right-image)

3.5.3.2 Evaluation of difference in muscular effort required to perform floor-polishing activities both with existing and redesigned floor polishing device.

Electromyography was used to study the muscular effort required for doing floor-polishing activity. Electromyography of selected muscles was recorded with Trigno ™ Wireless EMG System (DAC Filter bandwidth DC- 500 Hz, 160 dB/Dec, baseline noise <0.5 mV RMS; specification is given in Appendix) as shown in Fig.3.5.

1 - Wireless Sensor; 2 – Base Station; 3 – USB port; 4 – Power Jack/ Power Supply; 5 – Analog Ouptut Connectors; 6 – Trigger Port; 7- Antenna

Fig. 3.5 Delsys Trigno ™ Wireless EMG system

The system has 16 wireless EMG sensors and a base receiving unit. EMG data were digitized using a 16 analog to digital (AD) Converter, using a ± 5V range and recorded by using EMG Works- Acquisition ™ software (Delsys™ , Boston, MA), using a sampling rate of 2000 Hz with an overall gain of 300 for each EMG channel.

3.5.3.2.1 Muscle Selection

In the present study, EMG activities of Deltoid, Biceps, Extensor Carpi Radialis (ECR) and Flexor Digitorium Superficialis (FDS) muscles were considered to investigate the requirement of muscular effort for polishing activity. The Deltoid is a rounded triangular muscle located on the uppermost part of the arm and top of the shoulder, which is responsible for the abduction of the arm (Kindell, 1993; Konrad, 2006). Bicep muscle is a two- headed muscle located in the front side of the upper arm whose function is mainly flexion and supination of the forearm (Kindell, 1993; Konrad, 2006). ECR muscle originates from the humerus attaching to the base of the hand starting that controls the movement of wrist muscles (Kindell, 1993; Konrad, 2006).

3.5.3.2.2 Placement of electrode on the skin

One of the most important factors for best signal acquisition is the placement of electrodes at the proper location, which is parallel to the muscle fibers. The arrow of the electrode placed in the center of the muscle belly should be parallel to the muscle fibers underneath the sensor. The location of electrodes placement such as the top electrode, the bottom electrode and the middle right electrode and their respective EMG signal strengths is shown in Fig. 3.6.

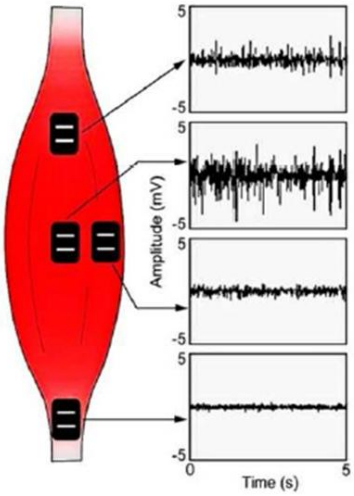


Fig. 3.6 Electrodes location in amplitude spectrum of the EMG signal

Fig. 3.3 Placement of electrodes on muscles

The electrodes were placed on the anatomical landmark done based on dominant bone areas when the participant was sitting and standing with arms resting and extended along sides and palm facing upward as shown in fig. 3.7 (Mogk and Keir, 2003;Konrad,2006, Garapati, 2007). The identification of muscles for the location of the electrodes was made with the help of physiologists and previous studies (Bano et al., 2012; Kindell, 1993; Konrad, 2006). The electrodes on deltoid muscle were located at the point midway connecting the sideways aspect of the acromion procedure and insertion of the deltoid on the deltoid tubercle. The location of surface electrodes on Bicep muscles was positioned on the lateral epicondyle of the humerus. The electrode for ECR was located within 10-20 mm after a lateral epicondyle, which was close to the origin of the muscle and far from the tendon zone at a distance of 20mm. The electrode for FDS muscles was put over the belly of the muscle, parallel to the presumed longitudinal central line of the muscles (J. R. Blackwell et al., 1999).

3.5.3.2.3 Experimental protocol

The EMG signals during maximum voluntary isometric contractions (MVC) tests and floor polishing activity were collected. The examiner's succession of each participant was randomized and they were introduced to the procedures used during the experiment. They were asked to stand still with relaxed arms along sides and palm facing upward. The skin preparation was done before attaching surface electrodes. The skin (at muscle location) was cleaned with alcohol and electrolyte gel to improve the electrical conductivity and mechanical contact of electrodes. Afterward, the surface electrodes were attached to the belly of DT, BB, FDS and ECR muscles (Toussaint et al., 1992; Tang et al., 2014) (Delsys Inc., Natick, Massachusetts, USA) as shown in Fig.3.5. This phase of the experiment was carried out in two parts. The first part of the experiment included the recording of MVC data and EMG normalization, while the second part examined the comparative data of normalized EMG (NEMG) of existing and redesign polishing device.

3.5.3.2.4 MVC recording

Following the placement of the electrodes on the skin and signal quality verified, a small warm-up session (2 min) for the preparation of the next step of MVC (maximum voluntary contraction) data collection. MVC was carried out to standardize the muscle actuation level to the percent of maximum voluntary contraction (%MVC). As the EMG signal determined by a different components like muscle contraction, muscle crosstalk, sensor characteristics, electrode placement, etc., the best way to reduce the consequences of these components is to normalize the muscle activities using the MVC test. The participants were asked to perform posture specific MVC for each muscle group to collect the individual muscle MVC value. The participants were asked to apply their extreme strength (isometric contraction) and hold their extreme attempt for 5 seconds. They were provided with a recovery break of 60, and the experiment was repeated thrice to collect the best MVC data. The same procedure was adopted to collect the MVC data for each muscle. The participant was given a rest break of 15 minutes' rest between each exercise to remove any muscle fatigue. To record the MVC, the exercise carried out for deltoid muscle was shoulder abduction pressing against the forearm with the elbow extended. For bicep muscle MVC was recorded with elbow flexion slightly less than or at a right angle with the forearm in supination and pressure was put against the lower forearm. Flexion of the proximal interphalangeal joint extended for FDS muscles and extension of the wrist towards the radial side pressing against the dorsum of the hand as shown in Fig.3.8.

(a)MVC experiment for deltoid muscle (b) MVC experiment for bicep muscle

(c)MVC experiment for ECR muscle (c) MVC experiment for FDS muscle

(d) Experiment with existing device (e) Experiment with redesign device

Fig. 3.8 EMG recording and Normalization

After completion of MVC tests, the second part of the EMG study was acquiring data during the polishing task. The participants were instructed to perform polishing activities for 15 minutes with the existing and redesign floor-polishing device on the floor (mosaic) of area 0.557 m^2. The raw EMG signal was collected during the last 3 minutes of the polishing work. The participants were asked to take rest for 15 minutes in between while performing polishing activity with the existing and redesign floor-polishing device. After the collection of raw EMG signals for 3 minutes, middle 30 seconds data were trimmed for analysis. Each trimmed signal was band-pass filtered (20-500 Hz) and was full-wave fixed (Li, K.W 2002).

3.5.3.3 Modification/ Analysis

Positive feedback was received thorough testing of the product, as it solved the mentioned problem sated above. Genuine feedback received from real users about the product can help in making some strategic decisions that will be beneficial for product success.

3.5.3.4 Statistical Analysis

The data collected was compiled and put through to statistical analysis using Statistical Package for the Social Sciences (SPSS v.22.0.0, IBM Corporation, USA). The data collected were subjected to suitable statistical analysis and a significance level of $p \leq 0.05$ was regarded as remarkable for all statistical tests (Dianat et al., 2016). A descriptive statistical analysis was used to establish the personal data, distribution of reported pain, perceived vibration discomfort, measured vibration value and REBA scores of separate body parts as well as overall REBA score. Spearman’s correlation was performed to examine the strength and direction of the association between different adopted posture and perceived discomfort. Spearman’s correlation was used to found monotonic relationships between perceived discomfort and magnitude of hand-transmitted vibration, adopted posture and vibration discomfort and perceived discomfort, to find out the value of one variable increases so does the value of the other variable. For small sample sizes, the collected datasets did not follow the normal distribution. Hence, non-parametric statistics techniques were used for nominal, ordinal and small samples (Das and Das, 2004; Kothari, 2011). Wilcoxon signed ranks test was performed to compare the muscular effort and transmission of vibration between the existing and redesign floor-polishing device.

3.5.3.5 Usability testing

The Usability of the redesign floor-polishing device was evaluated using the System Usability scale (SUS) (Brooke J. and Brooke, 1996). This scale is a low-cost, reliable and effective usability scale. SUS can provide an overall view of subjective evaluation of usability, making it widely used too for assessment of websites, interactive systems and hardware (Bangor et al., 2008). This scale consists of ten items, and each of the ten items is rated on a 5-point Likert scale (Joshi et al., 2015; Likert, 1932) starting from strongly disagree (1) to strongly agree (5).

Table 3.1 SUS scores with corresponding adjective and acceptability rating

SUS Score	Adjective rating	Acceptability
89-100	Best Imaginable	Acceptable
84-88	Excellent	
71-83	Good	
50-70	OK	Marginal
32-49	Poor	Unacceptable
20-31	Awful	
0-19	Worst Imaginable	

The overall score of the SUS scale, ranges between ‘0 to 100’, these scores were interpreted in terms of adjective rating and acceptability, shown in Table 3.1. The average score higher than 68 is taken as a good usability score for product evaluation. In this study, the SUS questionnaire was administered to 15 floor-polishing workers after using the redesign floor-polishing device in real working conditions. Each of the items was explained to the workers and asked to mark the Likert scale accordingly.

4. Result

4.1 Demographic exploration

The average age, height, and weight of the participants were 25.64±5.4 years, 156.16±6.6 cm, and 49.87±4.7 kg, respectively. The workers had experience for 3.42±1.6 years. These workers mainly involved in construction activities, where they did only floor polishing work. On average, the workers had 4.64±0.9 working hour per day contemplated to 4.96±0.2 working days per week. The average duration of a break in a day was ½ to 1 hour, and the average daily working hours without a break was about 5 hours (SD = 2 hours). The workers worked at a stretch for 2 + 1 hour. The workers were mostly married (80%), and their educational level varied as illiterate (33.3%), primary school (53.3%), and secondary school (3.33%). The majority of the workers found their work to be stressful to the extent of high (26.7%) to extremely high (56.7%). A large section of the workers reported a high extent of job responsibility (53.3%) with comparatively low job satisfaction. The demographic characteristics and job profile of the workers are given in Table.4.1.

Table 4.1 Demographic characteristics and job profile of the participants (n=45)

Characteristics	Mean (±SD)
Age (years)	25.64(5.4)
Height (cm)	156.16 (6.6)
Weight (Kg)	49.87(4.7)
Work experience (years)	3.42 (1.6)
Working hours per day	4.64 (0.9)
Working days per week	4.96 (0.2)
Number of breaks in a day	3.16 (1.1)
Duration of total breaks in a day	2.20 (1.2)

4.2 Discomforts in various parts of the body of the polishing workers

The performance and efficiency of the floor polishing workers could be affected by various factors like experience, age, vibration discomfort, etc. Table.4.2. displayed the observations of the subjective responses to quantify the discomfort in different body parts using the Nordic Questionnaire. The data demonstrated that the prevalence of pain in various body parts of the workers was high in general. The percentages of the participants with body parts discomfort at the neck, shoulder, wrist, elbow, ankle/feet, and knee during the last 12 months were 51%, 52 %, 70%, 60%, 57.7%, and 46.6%, respectively. The pain affected their normal activities both at work and outside their work. During the last 12 months, the numbers of participants whose normal activities were disrupted due to discomfort at the neck, shoulder, wrist, elbow, ankle/feet, and knee were 75.6%, 63.8%, 67%, 51%, 64%, and 43.5% respectively. The occurrence of discomforts/ pain in various body parts of the participants and thereby, disruption of their regular activities at the workplace or outside the workplace are shown in Fig.4.1.

Table 4. 2 Discomfort in different parts of the body of floor polishing workers

Body part	*Duration*	*Frequency (%)*	*Pain score (scale 1-5) Mean (SD)*
Neck	Every day	15(33.3%)	4.02 (0.89)
	more than 30 days, but not every day	19(42.2%)	
	8-30 days	8(17.7%)	
	1-7 days	3(6.6%)	
	0 days	0	
Shoulder	Every day	17(37.7%)	4.11(0.88)
	more than 30 days, but not every day	19(42.2%)	
	8-30 days	5(11.1%)	
	1-7 days	3(6.6%)	
	0 days	0	
Wrists/Hand	Every day	30 (66.6%)	4.60(0.61)
	more than 30 days, but not every day	12(26.6%)	
	8-30 days	2(4.4%)	
	1-7 days	1(2.2%)	
	0 days	0	
(Elbow	Every day	26 (57.7%)	4.29(0.61)
	more than 30 days, but not every day	10 (22.2%)	
	8-30 days	5 (11.1%)	
	1-7 days	4 (8.8%)	
	0 days	0	
Ankles/Feet	Every day	21(46.6%)	4.11(1.04)
	more than 30 days, but not every day	16(35.5%)	
	8-30 days	4(8.8%)	
	1-7 days	4 (8.8%)	
	0 days	0	
Knee	Every day	23(51.1%)	4.11(0.88)
	more than 30 days, but not every day	16(35.5%)	
	8-30 days	3(6.6%)	
	1-7 days	2(4.4%)	
	0 days	0	

Table 4.3 Musculoskeletal symptoms reported by the floor polishing (n=45)

Symptoms/variable	*Body parts*	*Pain score (Mean ± SD)*
Trouble (ache, pain, discomfort) during the last 12 months	Neck	3.13 (± 1.455)
	Shoulder	3.91 (± 0.848)
	Elbow	4.78 (± 0.560)
	Wrists/hand	2.93 (±1.074)
	Ankles/Feet	3.09 (± 1.019)
	Knee	2.73 (± 1.074)
Visit to a physician for any pain or trauma	Yes	1.56 (± 0.503)
	No	-
Pain which disturbed your normal work at home or made you away from home	Neck	3.76 (± 1.433)
	Shoulder	3.89 (± 1.301)
	Elbow	4.67 (±0.680)
	Wrists/hand	3.22 (± 1.126)
	Ankles/Feet	2.80 (± 1.217)
	Knee	3.18 (±1.173)

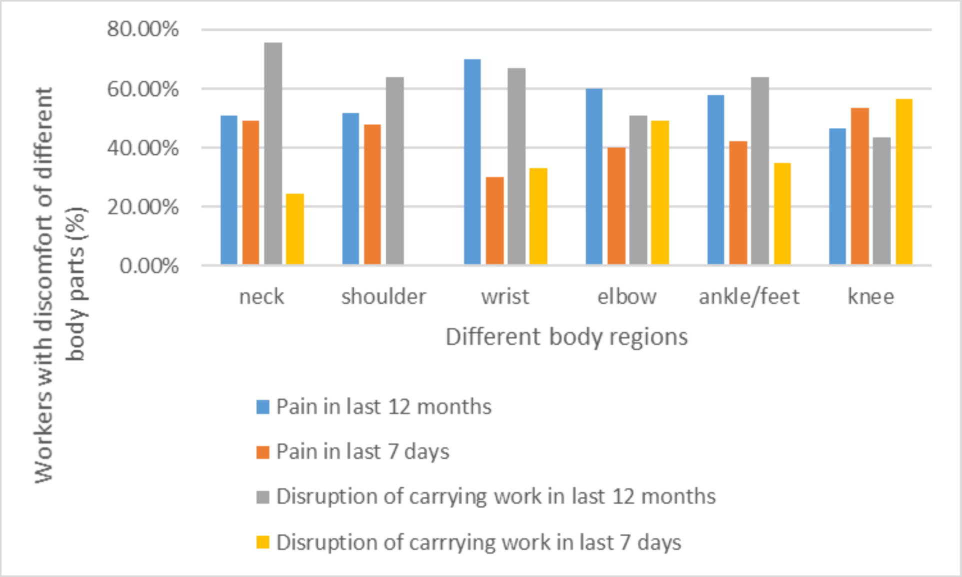


Fig. 4.1 Body parts discomfort and disruption of work as reported by the participants

4.3 Posture Analysis

The REBA score (score A, score B, and final score) of floor polishing worker during carrying out polishing work at different locations (floor, wall-base, and staircase) with the existing stone polishing machine are shown in Table 4.4. During polishing work, both the upper arm(s) of the operators re-main abducted and flexed between 20°-45°. In the present study, the score of the upper arm was found between 2 and 3. The lower arms score was found to be 3 as the participants were working across the midline of the body with elbow flexion less than 60° or more than 100°. The wrists of participants were in extension (sagittal plane) of up to 15°, and thus, the REBA score was 3. The neck score and trunk score were 2 and 3 as the participants' necks and trunks were in more than 20° flexion to the front while performing the polishing. The leg score was generally found to be 2. The REBA grand scores were 9 (floor), 7 (wall-base), and 10 (staircase) for different locations of polishing. Overall, the postural load was of very high risk. Therefore, immediate intervention strategies had to be implemented to rectify the awkward postures of the workers. Percentages of workers with the final REBA grand score of 9 and 10 were 66.7% in floor polishing, 86.7% in wall polishing, and 73.3% in staircase polishing. It was observed that the mean value of final/ grand scores for the floor, wall, and staircase polishing was 9.6, 7.2, and 10.7, respectively. It showed that the overall postural load was of higher risk, and investigation and implementation of needful changes were required soon.

Table 4.4 REBA scoring for floor polishing worker during polishing activities at different locations (n=45)

REBA Score	*Floor polishing*			*Wall-base polishing*			*Staircase polishing*		
	Score	Score	Final Score n(%)	Score	Score B	Final Score n(%)	Score A	Score B	Final Score n (%)
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	5(3.92)	-	-	-	3(6.7)	7(15.6)	1(2.3)	-	-
6	7(15.6)	2(4.5)	-	9(20)	8(17.8)	13(28.9)	1(2.3)	-	-
7	8(17.8)	2(4.5)	-	2(4.5)	20(44.5)	5(11.2)	-	3(6.7)	-
8	23(51.2)	15(33.4)	-	31(68.9)	6(13.4)	10(22.3)	3(6.7)	5(11.2)	-
9	2(4.5)	14(31.2)	25(55.6)	-	8(17.8)	5(11.2)	3(6.7)	2(4.5)	2(4.5)
10	-	12(26.7)	13(28.9)	3(6.7)	-	3(6.7)	19(42.3)	8(17.8)	8(17.8)
11	-	-	7(15.6)	-	-	2(4.5)	18(40)	27(60)	35(77.8)
Mean (SD)	7.2 (5.2)	8.7 (4.4)	9.6 (6.0)	7.7 (7.3)	7.2 (4.5)	7.2 (3.5)	10.0 (5.5)	10.2 (6.1)	10.7 (8.4)

There was no change in REBA score (score A, score B, and final score) of floor polishing workers during carrying out polishing work at different locations (floor, wall-base, and staircase) with the redesign stone polishing device. However, there was a significant change in wrist score with correction of wrist posture through modification of handle design. The result of REBA for an individual worker working with the redesign floor-polishing device at different locations (floor, wall-base, and staircase) is presented in Table.4.5. In the earlier case, the wrist score was 3, which means that the wrists of floor polishing workers were in extension position whereas the wrist score was +1 for the floor polishing workers working with the redesign floor polishing device which means the wrist of the floor polishing workers were not in the extension position.

Table 4.5 Distribution for REBA scoring for participants in floor polishing for the redesign floor polishing device (n=45)

REBA score	Neck n (%)	Trunk n (%)	Leg n (%)	Score A	Upper arms n (%)	Lower arms n (%)	Wrist n (%)	Score B	Final Score n (%)
1	9 (20)		1 (2.2)			42(93.3)	45(100)		
2	36 (80.0)	5(11.2)	44(97.8)	2 (4.4)	44(97.8)	3 (10.0)			
3		40(88.0)		6 (13.3)	1 (2.2)				
4				2 (4.4)				39(86.7)	5(11.2)
5				35(77.8)				4 (8.9)	5 (11.2)
6									30 (66.7)
7								2 (4.4)	4 (97.8)
8									
9									1 (2.2)
10									
Mean (SD)	1.80 (0.40)	2.88 (0.31)	1.97 (0.14)	4.55 (0.88)	2.02 (0.14)	1.06 (0.35)	1.0 (0.00)	4.22 (0.66)	5.82 (0.83)

4.4 Perceived discomfort and magnitude of hand-transmitted vibration

A large part of the participants of the present investigation reported extreme vibration discomfort irrespective of their working location (floor, wall and staircase). The arm/ elbow of the operators was generally supported on their knees to bear the load/ weight (2.8- 4.0 kg) of the polishing machine. The responses collected from the participants regarding their perception related to overall vibrational discomfort (on a 5-point visual analogue scale starting from ‘very less discomfort’ and ending at ‘extreme discomfort’) during polishing activities were analyzed. As high as 71.2% of the participants reported the level of perceived vibrational discomfort as extreme or very high; 20% reported as high; 4.4% of the participants felt it moderate; 4.4% of the workers felt the vibrational discomfort as low while operating the floor-polishing machine. It was also noticed that 95.6% of the participants had numbness and tingling sensation on their palms and fingers. About 46.7% of the workers had high muscle and joint pain in their hands and arms, and 55.6% of the participants had visited a physician for pain in the hands and arms during the last 12 months.

4.5 Association between different adopted posture and vibration discomfort

The correlation between the REBA score of individual body parts with the level of perceived discomfort at individual body segments (from the Nordic questionnaire) was evaluated (Table-4.6). There was no significant correlation between the previously mentioned two data sets.

Table 4.6 Correlation of individual REBA score and perceived discomfort of individual body parts.

Perceived discomfort of body parts	REBA Individual score (Floor)	REBA Individual score (Wall)	REBA Individual (Floor)
Neck	0.027	0.012	0.027
Trunk	0.061	0.076	0.043
Upper arm	0.018	0.053	0.047
Lower arm	0.033	0.074	0.092
Wrist	0.072	0.086	0.076
Feet	0.086	0.052	0.058

The participants in the questionnaire rated perceived overall discomforts (irrespective of individual body segments). Both the REBA grand score and perceived discomfort were high for the participants due to their adopted awkward posture but, there was no significant correlation between the REBA grand score and the perceived overall discomfort (irrespective of individual body segments) (Table 4.7).

There was an insignificant correlation between the REBA score of individual body parts with the level of perceived discomfort at individual body segments (from the Nordic questionnaire). Likewise, the correlation between REBA grand score with overall perceived discomfort was also found to be insignificant. The root causes of discomforts at individual body segments or overall body discomforts were not the awkward postures adopted during polishing activities. The original source of discomfort might be connected with vibration produced and transmitted to the human body from the polishing device.

Table 4.7 Correlation between REBA grand score and overall perceived discomfort

		Perceived overall discomfort
Spearman's rho	REBA Grand score (Staircase)	0.073
	REBA Grand score (Wall-base)	0.167
	REBA Grand score (Floor)	0.044

*Correlation is significant at the 0.05 level (2-tailed).

Table 4.8 Correlation between perceived discomfort of individual body segments and measured vibration intensity at wrist during polishing activities at different locations

Different location – Vector sum of vibration at wrist	Neck	Shoulder	Wrist	Elbow	Feet	Knee
Wall-base	0.748**	0.748**	0.748**	0.748**	0.748**	0.748**
Floor	0.758*	0.758*	0.758*	0.758*	0.758*	0.758*
Staircase	0.852**	0.852**	0.852**	0.852**	0.852**	0.852**

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Similarly, there was a significant correlation found between perceived overall discomfort of the participants and measured magnitude of vibration (vector sum) at the right wrist during carrying out polishing at different locations like floor, staircase and wall-base (Table- 4.8).

Table 4.9 Correlation between perceived overall body discomfort and measured vibration intensity at right wrist

	Measured intensity of vibration (Staircase)	Measured intensity of vibration (Floor)	Measured intensity of vibration (wall)
Perceived discomfort of overall body parts	0.703*	0.705*	0.810**

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

There was a significant correlation between measured vibrational intensity (vector sum) and perceived discomfort at individual body segments or overall body parts (Table-4.9). This signified that the subjection to a mostly high level of vibration intensity during polishing activities might be accountable for the perceived discomforts by the participants. There is a need for design interventions of the floor-polishing device to ameliorate the exposure to vibration to enhance safety for the well-being of the polishing workers.

4.6 Existing Design and its Evaluation

A product development process is a full set of a task required to bring a new concept to a state of market readiness (Otto and Wood, 2012). The design processes are technical activities within a product development process that work to meet the marketing and business case vision (Otto and Wood, 2012). In the product development process, there is a job of understanding, communication, the task of testing, and tasks of persuasion. Generally, a product development process is characterized by three phases. The first phase encompasses all the required decision to launch a new product development attempt. The second phase encompasses all activities to make the decision on what the product work will be. The final phase encompasses all the required activities to make every product work well all the time.

In this study, the existing floor-polishing device was evaluated to understand the limitation in it. In a typical product development process, the product is evaluated based on certain set of design criteria. The design criteria mainly formulated considering safety, cost, durability, functionality, etc. determined based on criteria set upon the product being examined. For the floor-polishing device, a particular set of criteria were formulated, and the existing device was evaluated to have a clear knowledge about the product constraints. Based on the drawback of the existing product, a new design was proposed to overcome the limitation. The criteria articulated for the floor-polishing device for evaluation of the existing device were based on: the easy holding of the device, load holding of the device, stability of the movement of the grinding stone fixed to the coupling of the device, reduction of shock and reduction of vibration transmission, etc. The constraint of the existing floor-polishing device in fulfilling the formulated set criteria had strengthened the need for a redesign of the floor-polishing device.

The existing floor-polishing device is shown in Figure 4.2. The constraints in the existing floor-polishing device for the particular set of formulated design criteria are presented in this study. A user survey was carried out in the real working conditions of polishing activities. The machine had an improper handle for holding and no dampening material on the handle of the machine to absorb the vibration from transmitting to the hand-arm system. To study the existing polishing machines, some of the shops (Kamakhya machine and tools, Ravinder Engineering House, Shakti tools and machinery, Tirupati tools and machinery and Kulkarni power tools) in A.T. Road of Guwahati city were visited. They were using the polishing device of Indian manufacturer, namely, Kobalt professional tools (1800 rpm, 2.8 kg without sanding stone), Electrolux and Kulkarni power tools. The proposed design in this study tried to abolish all the constraints in the existing one by improving the design feature along with some additional features.

Fig. 4.1 .Image of the existing hand-held floor-polishing device

4.7 Functional Modeling

Functional modeling is the establishment of the functional composition of the product of interest (Kevin and Wood, 2012). It is effective at revealing the sub-functions of a product. Fig. 4.3 & 4.4 show a simple black box diagram and the functional tree of the handheld polishing device. A black box model helps to maintain the focus on the driving product function. The generated functional tree has been evolved based on requirement obtained by field survey and literature survey.

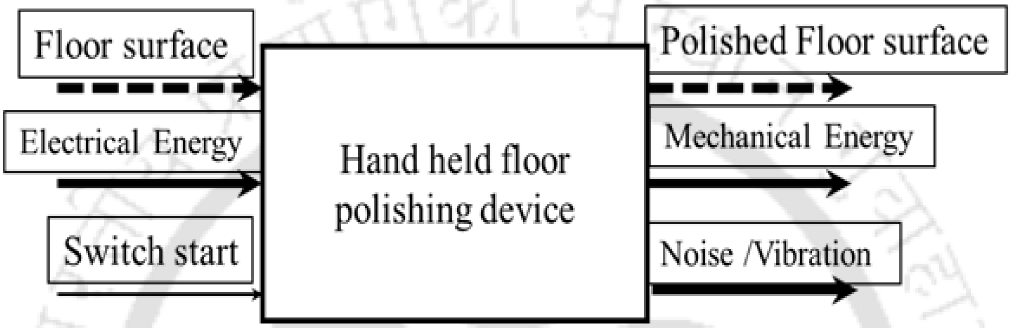


Fig. 4.2 The black box diagram for a Handy Polishing machine

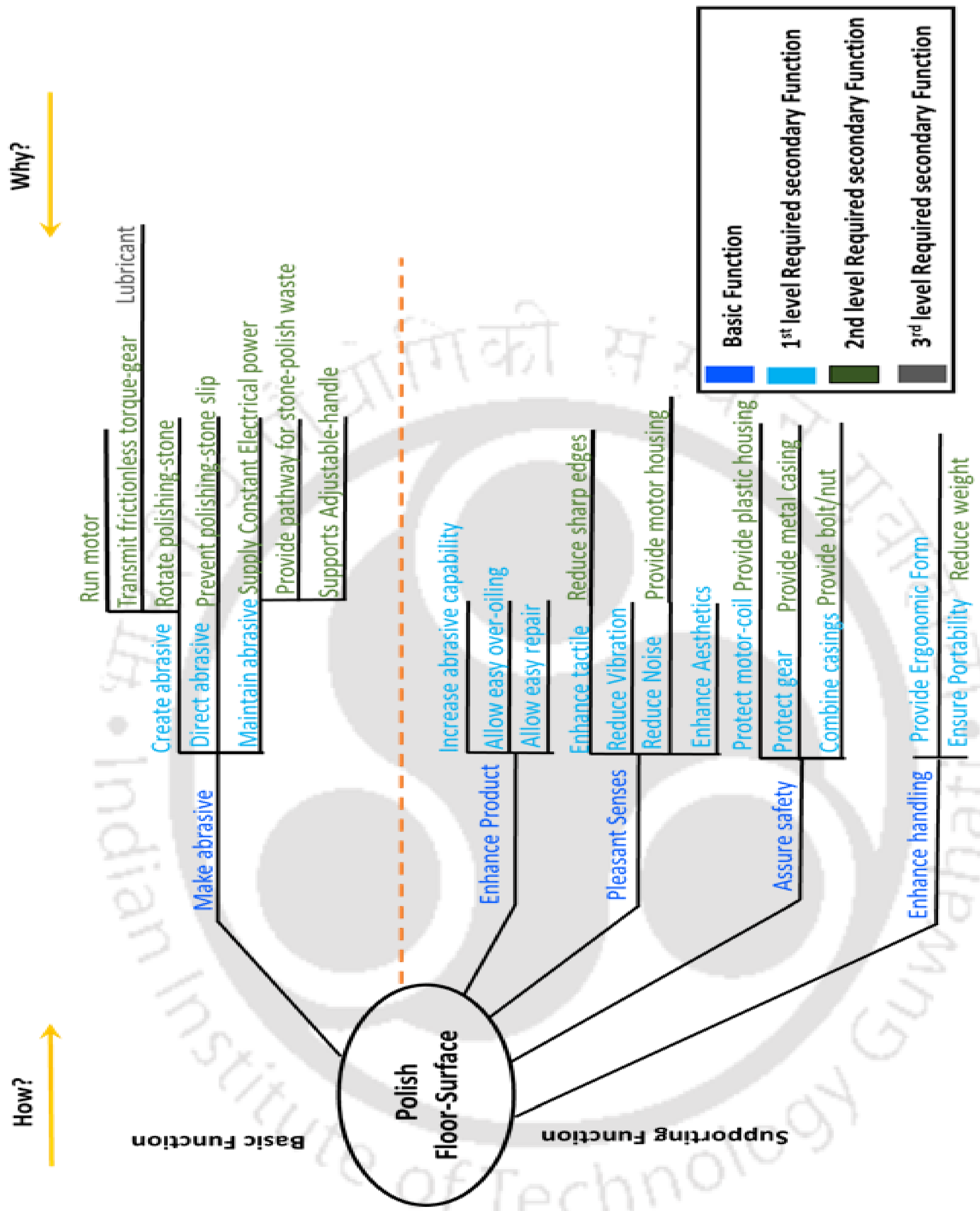


Fig. 4.3 Functional diagram of the hand-held floor-polishing device

4.8 Generation of sub-functions

At this stage, various sub-functions of the floor-polishing device required to fulfill the overall functions of the floor-polishing device were identified through a functional structure diagram. Each of the sub-functions was accomplished through different concepts.

The following sub-functions were recognized based on the functional diagram. They were 1. Easy holding, 2. Load holding, 3. Side handle, 4. Fixing of the stone, 5. Rotation of the motor, 6. Power transmission, 7. Dampening material, 8. Smooth movement of the machine. The identified sub-functions contributed to the fulfillment of the altogether function of the product.

For each sub-functions, concepts were developed as many as possible. To fulfill the entire sub-functions, different options had to be accessible. The options available for each of the sub- functions were then recognized as sub-components. These sub-components that constituted the sub-functions were set in a rational way to fulfill the main overall function of the machine. Then, the sub-components required for the developed sub-functions were decided for easy holding, load holding, etc.

4.9 Construction of morphological matrix

The depiction of a variety of sub-components to accomplish each of the sub-functions is shown in a chart called morphological chart. It has rows and columns that look like a matrix. Each row has a specific sub-functions and distinct procedure in which it can be achieved. The morphological chart once completed gives variants of feasible sub-functions that could be merged with other sub-components in the other rows by different amalgamation to come up with a broad scope of product arrangement to achieve the overall function of the product.

The individual sub-components that can possibly come up with the sub-functions mentioned above is shown in Fig.4.5. For example, to achieve the sub-function 'easy holding', the various sizes and shapes of handles like pistol grip handle, tubular handle, bridge handle, etc. were used. Each sub-component could be merged with other sub-components under individual sub-functions like easy holding, load holding, dampening material, etc. to come up with the overall function of the floor-polishing device. Thus, various designs of floor polishing devices were ideated using the morphological chart.

The amalgamation of different sub-components under different sub-functions to come up with the new floor-polishing device is shown in Table 4.10. The morphological chart and the amalgamation of sub-components (Fig. 4.6 and Table 4.10) proposed thirteen new concepts of redesign floor polishing device. For example, concept sketch 1 was developed by the following amalgamation:

(1,3) + (2,2) + (3,3) +(4,4) + (5,4) + (6,5) + (7,1) + (8,1) + (9,2)

The initial number in the parenthesis constituted the sub-function number and the second number represented the solution number in the morphological chart. For example, (1,

3) represents sub-function 1 and solution 3 in the chart. In Table 4.10, the sub-function 1 represents the easy holding section and the solution 3 represents the tubular type of handle section. Hence, it is deduced from notation (1, 3) that the tubular handle section is used for the easy holding of the floor-polishing device. Similarly (7, 1) represents sub-function 7 and solution 1. Thus, a specific type of amalgamation set out in this procedure has eight sub-components, as there were eight sub-components to be achieved. These eight sub-components arranged in the logical order were developed into the overall product under study. The amalgamation (Table 4.10) generated thirteen different floor polishing device concepts. The number of overall concepts can be explored further to evolve more concept designs.

4.10 Concept generation through sketching

During the conceptual design stage, product concepts were drawn in a paper using pencil as free hand sketches. The initial free hand sketches represented the feasible countless solution concepts for the pinpointed problem. Many possible solutions as much as possible were generated to the given problem through sketching. It has to be noted that the amalgamation matrix means only the sub-components selected under a sub-function and is not required to be in logical order in which each sub-component is associated with the other (Fig. 4.6).

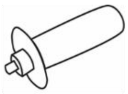
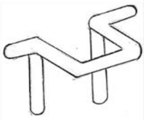
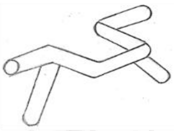
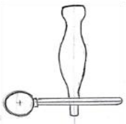
Solution / Sub functions		Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Easy Holding	1	 Straight Handle	 Pistol Grip 2 Handle	 Tubular Handle	 Accelerator Handle	 Bridge Handle	 Pistol Grip 3 Handle
Load Holding	2						
Side Handle	3	 Rubber Coated Side Handle	 Side Grip Handle	 Side Handle	 Side Handle	 Auxiliary Side Handle	
Fixing of the stone	4	 Bolt Assembly	 Flange Nut	 Anti vibration flexible			
Rotation of the motor	5	AC Motor	Dc Motor	Special Motor			
Power Transmission	6	 Helical	 Spur	 Double	 Compound	 Planetary	 Internal
Coating Material	7	Rubber	Cotton	Silk	Wool		
Ball Caster	8	 Stainless Ball Caster	 Resin Ball Caster	 Metal Ball Caster	 Plastic Ball Caster		
Material of the protection cover	9	Aluminium	Plastic	Stainless steel	Wood		

Fig. 4.5 Morphological chart of floor polishing device

Table 4.10 Amalgamation of matrix for conceptual sketches

Concept	**Amalgamation of matrix for conceptual sketch**
Concept sketch 1	(1,3) +(3,4) +(4,1) + (5,1) + (6,5) +(8,1) + (9,2)
Concept sketch 2	(1,3) + (4,1) + (5,1) + (6,5) + (8,1) +(9,2)
Concept sketch 3	(1,2) + (2,3) + (4,1) + (5,1) + (6,5) + (7,1) + (8+1) + (9,2)
Concept sketch 4	(1,4) + (2,2) + (3,3) + (4,1) + (5,1) + (6,5) + (7,1) + (8,1) + (9,2)
Concept sketch 5	(1,4) + (2,2) + (3,3) + (4,1) + (5,1) + (6,5) + (7,1) + (8,1) + (9,2)
Concept sketch 6	(1,3) + (2,2) +(3,1) + (4,1) + (5,1) + (6,5) + (7,1) + (8,1) + (9,2)
Concept sketch 7	(1,1) + (3,1) + (4,1) + (5,1) + (6,5) + (9,2)
Concept sketch 8	(1,1)+ (3,4) + (4,1)+ (5,1) + (6,5) + (7,1) + (9,2)
Concept sketch 9	(1,1) + (3,6) + (4,1) + (5,1) + (6,5) + (9,2)
Concept sketch 10	(1,5) + (4,1) + (5,1) + (6,5) + (6,5) + (9,2)
Concept sketch 11	(1,6) + (4,1) + (5,1) + (6,5) + (9,2)
Concept sketch 12	(1,1) + (4,1) + (5,1) + (6,5) + (9,2)
Concept sketch 13	(1,3) + (3,4) + (4,1) + (5,1)+ (6,5)

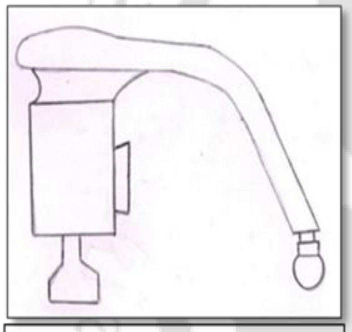


Figure 1
Concept 1-(1,3) +(3,4) +(4,1) + (5,1) + (6,5) + (8,1) + (9,2)

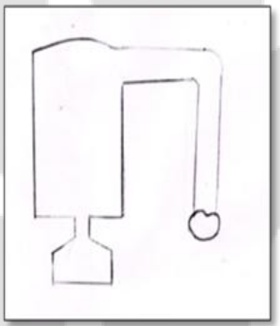


Figure 2
Concept2-(1,3)+(4,1)+(5,1)+(6,5)+(8,1)+(9,2)

Figure 3
Concept 3- (1,2)+(2,3)+(4,1)+(5,1)+(6,5)+(7,1)+(8,1)+(9,2)

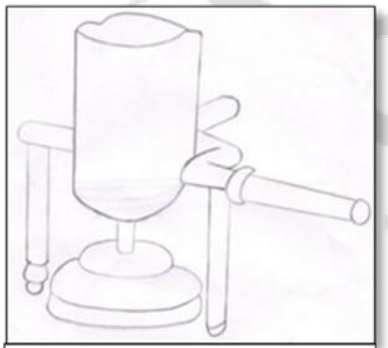


Figure 4
Concept 4- (1,4)+(2,2)+(3,3)+(4,4)+(5,5)+(6,5)+(7,1)+(8,1)+ (9,2)

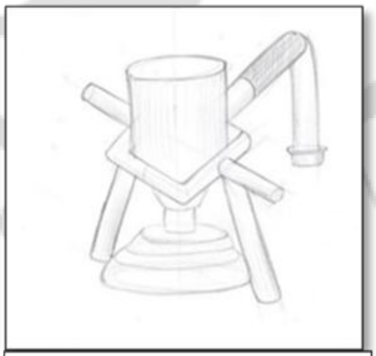


Figure 5
Concept 5- (1,3)+(2,2)+(3,1)+(4,1)+(5,1)+(6,5)+(7,1)+(8,1)+(9,2)

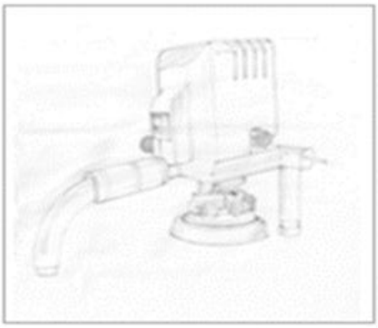


Figure 6
Concept 6- (1,3)+(2,2)+(3,3)+(4,1)+(5,1)+(6,5)+(7,1)+(8,1)+(9,2)

Figure 7
Concept 7-(1,1)+(3,1)+(4,1)+(5,1)+(6,5)+(9,2)

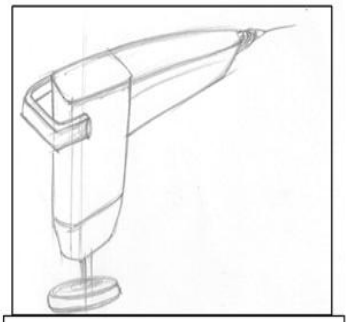


Figure 8
Concept 8- (1,1)+(3,4)+(4,1)+(5,1)+(6,5)+(7,1)+(9,2)

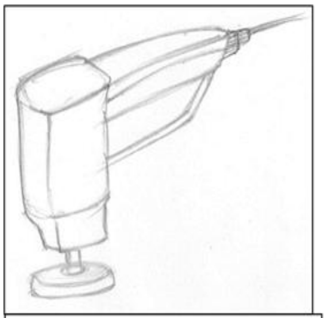


Figure 9
Concept 9- (1,1)+(3,6)+(4,1)+(5,1)+(6,5)+(9,2)

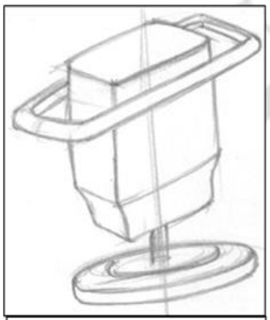


Figure 10
Concept 10-(1,5)+(4,1)+(5,1)+(6,5)+(9,2)

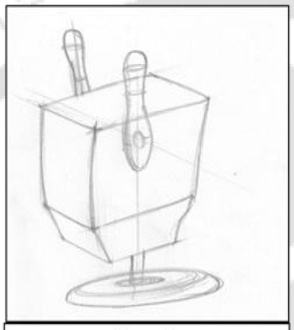


Figure 11
Concept 11-(1,6)+(4,1)+(5,1)+(9,2)

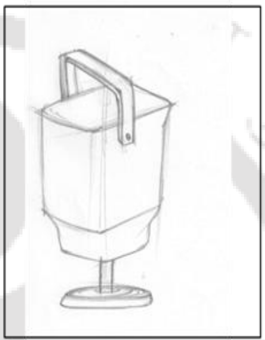


Figure 12
Concept 12-(1,1)+(4,1)+(5,1)+(6,5)+(9,2)

Figure 13
Concept 13-(1,3)+(3,4)+(4,1)+(5,1)+(6,5)

Fig. 4.6 Sketches of 13 new concepts resulted from amalgamation

Concept 1 (fig.1)**: (1,3) +(3,4) +(4,1) + (5,1) + (6,5) + (8,1) + (9,2)**

Conceptual sketch 1 proposed a polishing device with a tubular handle with a side handle attached on the body of the device and a ball caster attached on the main handle for smooth movement.

Concept 2 (fig.2) **: (1,3) + (4,1) + (5,1) + (6,5) + (8,1) + (9,2)**

Conceptual sketch 2 showed a polishing device with simple features. It had only one single handle with a ball caster attached to it for smooth movement.

Concept 3 (fig.3): **(1, 2) + (2, 3) + (4, 1) + (5, 1) + (6, 5) + (7, 1) + (8, 1) + (9, 2)**

The proposed device shown in conceptual sketch 3 had a pistol grip and a side handle similar to the drilling machine. On the side handle, a ball caster was attached for smooth movement.

Concept 4 (fig.4)**: (1,4) + (2,2) + (3,3) + (4,4) + (5,5) + (6,5) + (7,1) + (8,1) + (9,2)**

Conceptual sketch 4 proposed a design, which was having a fixed supporting frame with two stands with ball caster attached to it. It had one straight main handle and one side handle.

Concept 5 (fig.5): **(1,3) + (2,2) +(3,1) + (4,1) + (5,1) + (6,5) + (7,1) + (8,1) + (9,2)**
Conceptual sketch 5 suggested a design with a fixed supporting frame with two stands. It had two side handle and one main tubular handles along with a ball caster attached to it for smooth movement of the machine.

Concept 6 (fig.6): **(1,3) + (2,2) + (3,3) +(4,1) + (5,1) + (6,5) + (7,1) +(8,1) + (9,2)**
The conceptual sketch 6 proposed a design with one adjustable supporting frame with two stands. It had one main tubular handle with ball caster and side handle provided which could be adjusted in both left and right side.

Concept 7 (fig.7): **(1,1) + (3,1) + (4,1) + (5,1) + (6,5) + (9,2)**
The conceptual sketch 7 proposed a design with a handle along with a side handle with bolt assembly with an AC motor.

Concept 8 (fig.8)**: (1, 1)+ (3,4) + (4,1)+ (5,1) + (6,5) + (7,1) + (9,2)**
Conceptual sketch 8 had a straight handle with side handle and bolt assembly and AC motor.

Concept 9 (fig.9): **(1,1) + (3,6) + (4,1) + (5,1) + (6,5) + (9,2)**
Conceptual sketch 9 has a straight handle with side handle having bolt assembly with side handle having bolt assembly, AC motor.

Concept 10 (fig.10): **(1,5) + (4,1) + (5,1) + (6,5) + (9,2)**
The proposed design of sketch 10 had a straight handle with side handle, having bolt assembly, AC motor.

Concept 11 (fig.11): **(1,6) + (4,1) + (5,1) + (6,5) + (9,2)**
Conceptual sketch 11 had a straight handle along with bolt assembly, AC motor, planetary gear.

Concept 12 (fig.12): **(1,1) + (4,1) + (5,1) + (6,5) + (9,2)**
Conceptual 12 also has straight handle along bolt assembly and AC motor.

Concept 13: (1,3) + (3,4) + (4,1) + (5,1)+ (6,5)

Conceptual 13 had a tubular handle with side handle, bolt assembly, AC motor and planetary gear.

4.11 Concept evaluation and selection

After the different product concepts were created, the concepts had to be analyzed to choose the finest concept among the various available concepts. The first step in the concept analysis procedure was to set up the evaluation norm on which the concepts had to be chosen. These criteria were mainly dependent on the type of product to be designed and it varied from product to product.

4.11.1 Pugh chart

The Pugh chart created for the floor-polishing device is shown below in Table 4.11. The different concepts solutions were analysed by taking existing product accessible in the marker as the datum concept. For each of the criteria, the concept solutions were analysed. The ranking of the different solution was based on the scale such as '-', '0', and '+' where a negative sign (-) represented a sub-standard concept than a positive sign (+). If a design concept contributed a better performance than the datum concept for a particular criterion, then that specific concept was assigned a positive (+) rank. If it was a sub-standard, then the concept was assigned a negative (-) rank. If the execution of the datum and a design concept was matching for a particular criterion, a zero (0) rank was assigned.

The net score was estimated for each design concept (Table 4.11). The concept having the highest score was selected as the best concept over the other concepts on the Pugh chart. From the Pugh chart, concept 6 had scored the maximum score. Hence, the concept 6 was selected for further design and development.

Table 4. 11 Pugh concept selection chart of the floor-polishing device

PUGH CONCEPT SELECTION CHART	WEIGHT	CONCEPT													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
CRITERIA 1- Smooth functioning of the machine	3	-1	-1	-1	+1	+1	+2	+1	-1	+1	-1	-1	-1	-1	D
CRITERIA 2- Balance of Load Holding	3	-1	-1	-1	-1	-1	+2	-1	-1	-1	-1	-1	-1	-1	A
CRITERIA 3-Stability of the Stone	2	+1	+1	+1	+1	+1	+2	+1	+1	+1	+1	+1	+1	+1	T
CRITERIA 4- Reduction of shock	2	+1	+1	+1	+1	+1	+3	+1	+1	+1	+1	+1	+1	+1	U
CRITERIA 5- Reduction of Vibration transmission	5	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	M
∑ Weight × Concept		3	3	3	9	9	18	9	3	9	3	3	3	3	0

4.12 Existing machine with compound gear trains

The existing floor-polishing device transfers power through a planetary gear arrangement via an output shaft and hence higher torque is achieved. The compound gear train with gears arranged is shown in Fig.4.7, Fig.4.8, Fig.4.9.The calculation of the gear speed of the existing is explained below.

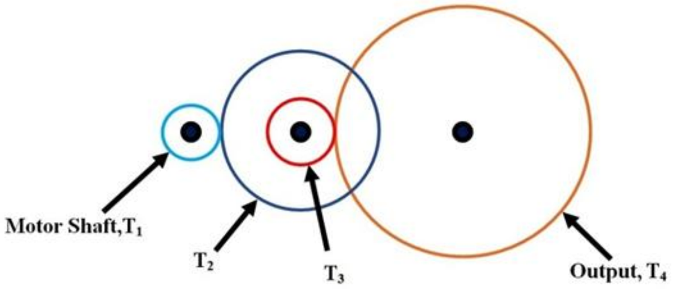


Fig. 4.7 Compound gear trains of a standard floor-polishing device

Fig. 4.8 The Motor shaft pinion of existing machine

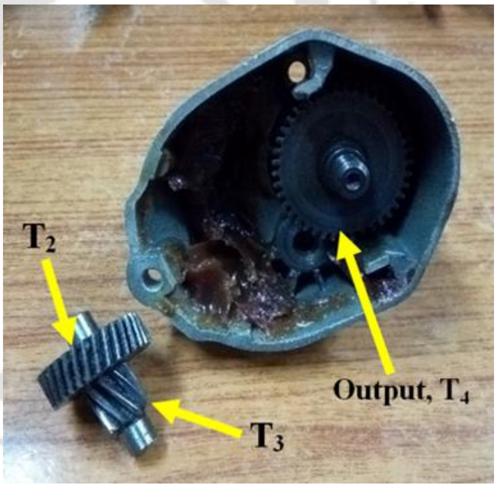


Fig. 4.9 The compound and output gear

Let T_1, T_2 T_3, T_4 be the number of teeth of the gears shown in Fig.4.7 and N_1, $N2$, N_3, N_4 are the angular velocities of the respective gears.
Hence, for the existing machine used we have;

T_1= 7, T_2= 33, T_3=9, T_4=38.
Outer Shaft RPM, N_4=1250 rpm

Now,

$$\text{Velocity Ratio, } \frac{N_2}{N_1}\times\frac{N_4}{N_3}=\frac{T_1}{T_2}\times\frac{T_3}{T_4}$$

$$=\frac{7}{33}\times\frac{9}{38}$$

$$As \quad N_2=N_3$$

$$We\ get,\ Velocity\ ratio,\ \frac{N_4}{N_1}=\frac{63}{1254}$$

$$\Rightarrow \frac{1250}{N_1}=\frac{63}{1254}$$

$$\Rightarrow N_1=\frac{1250\times1254}{63}=24{,}880\ rpm$$

Hence, the maximum speed of the base motor was found to be 24,880 rpm.

4.13 Calculation for planetary gear train

To minimize the vibration in the existing device, a planetary-geared DC motor of 250 Watt was used in the redesign floor-polishing device. The gearbox had a 2-stage reduction with an output of 750 rpm at 18V. The calculation for the velocity ratio to find the base motor speed is as shown below. The schematic arrangement of planetary gear trains is shown in Fig.4.10. The planetary arrangement of the gear box is shown in Fig.11.

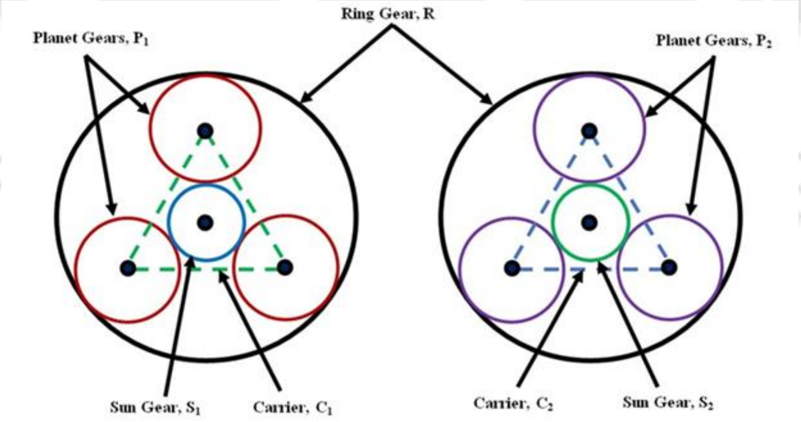
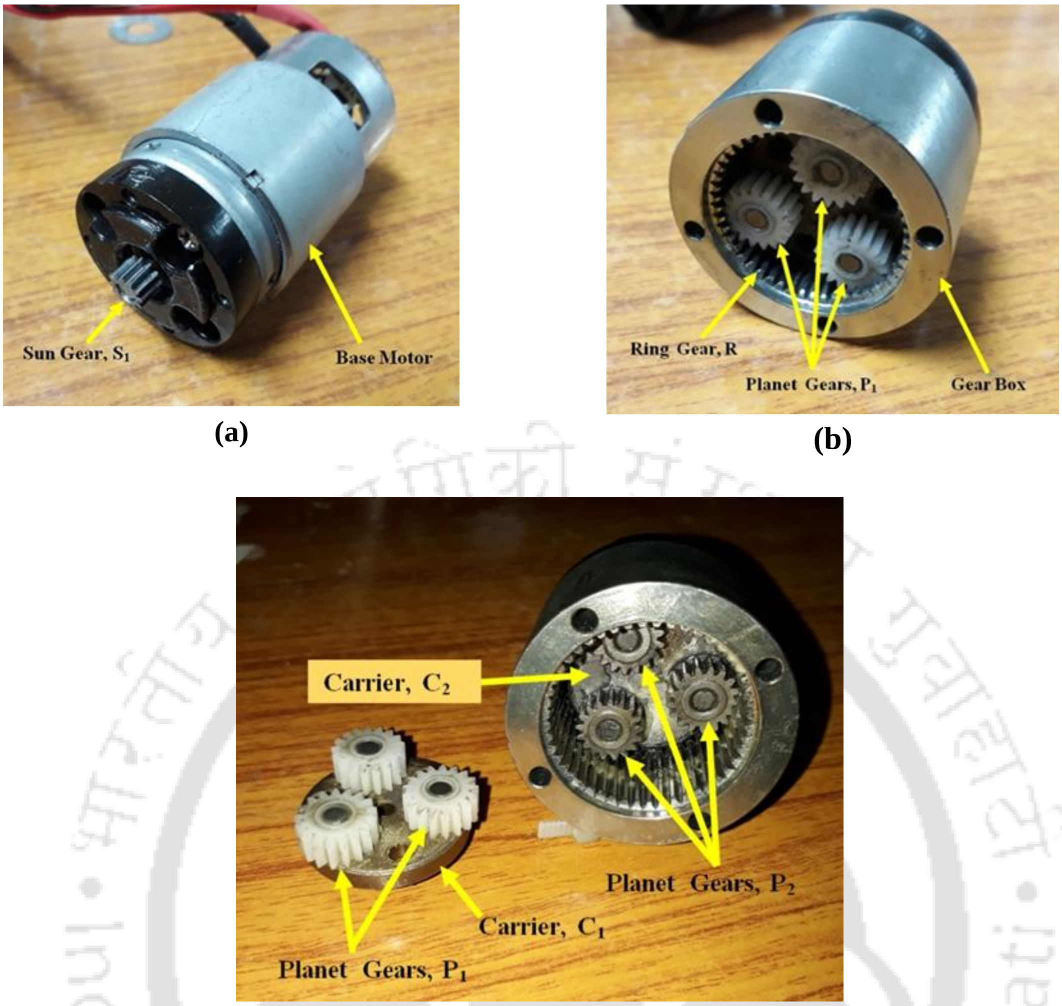


Fig. 4.10 Schematic arrangement of planetary gear trains

The following figure shows the gear arrangement of planetary gearbox.



(a) (b)

(c)

Fig. 4.11 (a, b, c) Detail gear arrangement of the planetary gearbox

In the above shown gearbox, the Carrier, C_2 acted as an output shaft of the gearbox. By counting the teeth of each gear and taking, speed of Carrier, C_2 as 750 rpm, and the speed of the base motor i.e. the RPM of Sun gear, S_1 were calculated as follows.

Let, N_S= Speed of the Sun Gear, S_1
N_R=Speed of the Ring Gear, R
N_{C1}=Speed of the Carrier, C_1
N_{C2}=Speed of the Carrier, C_2

Number of teeth in Sun Gears, S_1, S_2 = 12 (T_{S1},T_{S2})
Number of teeth in ring gear, R = 48 (T_R)
Number of teeth in plant gears, P_1, P_2 = 17 (T_P)

And the speed of the output shaft, i.e. N_{C2}=750 rpm.

The turn ratio of a planetary gear is given by

$$(T_R + T_s) = \frac{(T_R \times N_R) + (T_S \times N_S)}{Speed\ of\ the\ Carrier}$$

As the ring gear was fixed, N_R=0, and the speed of the carrier, C_2 was 750 rpm.

Hence, the equation can be rewritten as

$$(T_R + T_s) = \frac{(T_S \times N_S)}{Speed\ of\ the\ Carrier} \qquad (1)$$

For the second stage of reduction, Eq. 1 can be written as

$$Speed\ of\ the\ Carrier, N_{C2} = \frac{T_{S2} \times N_{S2}}{T_R + T_S}$$

$$750 = \frac{12 \times N_{S2}}{48 + 12}$$

$$N_{S2} = \frac{750 \times 60}{12} = 3750\ rpm$$

Now in the above shown arrangement, N_{S2}=N_{C1}
Hence,

$$Speed\ of\ the\ Carrier, N_{C1} = \frac{T_{S1} \times N_{S1}}{T_R + T_S}$$

$$3750 = \frac{12 \times N_{S1}}{48 + 12}$$

$$N_{S1} = \frac{3750 \times 60}{12} = 18{,}750\ rpm$$

As the sun gear, S_1 was directly coupled with the motor shaft, base motor rpm was 18,750 rpm. Thus by a planetary gearbox with 2 stage reduction, the speed of the motor was reduced to 750 rpm while rated torque of 3.9 Nm.

4.14 Manufacturing of the components

4.14.1 Support frame

The main frame was made with 1-inch hollow round steel extrusion as shown in Fig.4.12. It was developed for giving support, withstand the load of the whole device and minimize the vibration occurs due to the friction between the stone and the floor.

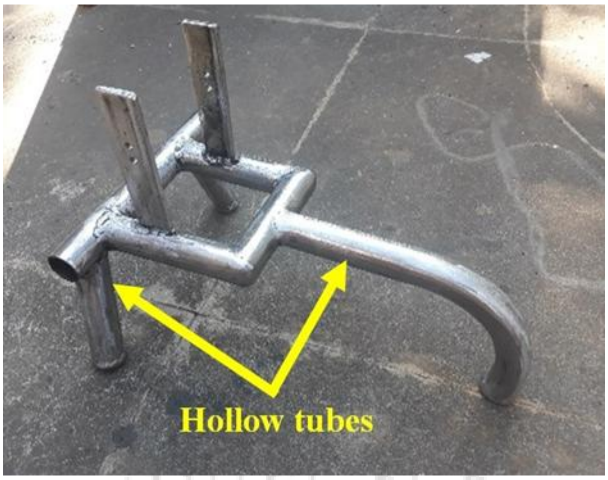


Fig. 4.12 Support frame of steel tube

4.14.2 Polishing stone coupling

The coupling of existing device as shown in Fig.4.13. had provided greater flexibility with fixing the stone assembling. No tool was required to attach the stone to the coupling. The coupling was provided with a flange of rubber as shown in Fig.4.14. The rubber flange provided stability to the stone and device at the time of polishing an uneven surface. It also increased the shock absorbing capacity of the device body.

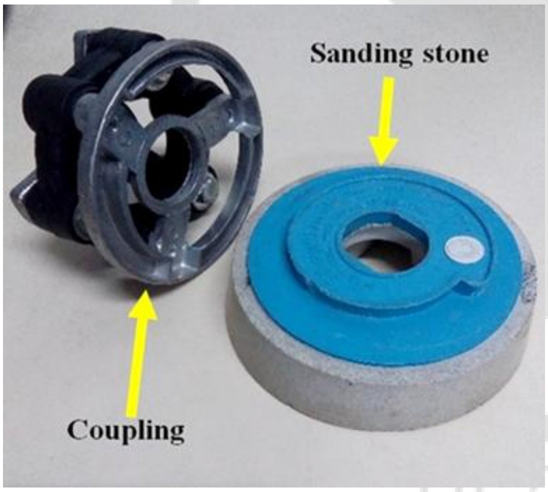


Fig. 4.4 Standard stone and its coupling

Fig. 4.14 Rubber flange inside the coupling

4.14.3 Motor mounting block

To assemble the planetary-geared motor to the existing stone coupling section, a block was designed and a pattern of wood was made. The pattern is shown in Fig.4.15. The pattern was tested for its assembly with the stone coupling and the motor, which is shown in Fig.4.16.

The pattern was used to cast out the pattern of steel as shown in Fig.4.17. Machining was done to bring the part into its desired size.

(a) **(b)**

Fig. 4.5 The pattern of wood made for casting the block

Fig. 4.6 Assembled pattern with motor

Fig. 4.7 The iron block after casting coupling

4.14.4 Sliding Blocks

Two sliding blocks were fabricated by machining iron blocks as shown in Fig.4.18. Then these pieces were welded to the motor mounting block as shown in Fig.4.19. Then, the stone coupling could slide over the guide bar provided with the frame with the help of these two sliding blocks.

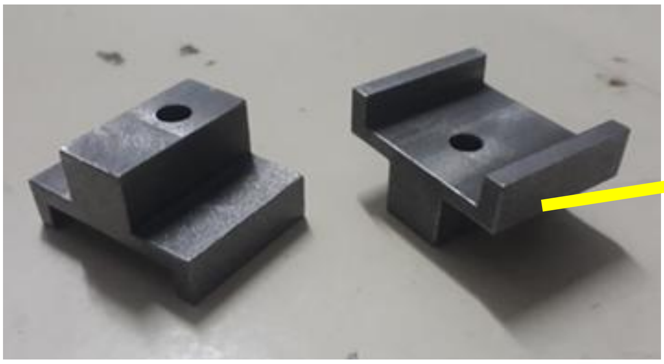


Fig. 4.18 Slider block and the guide bar

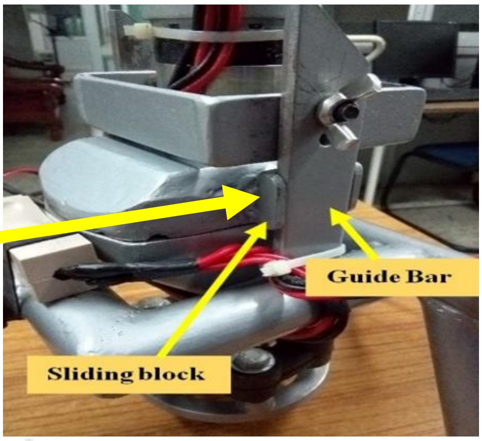
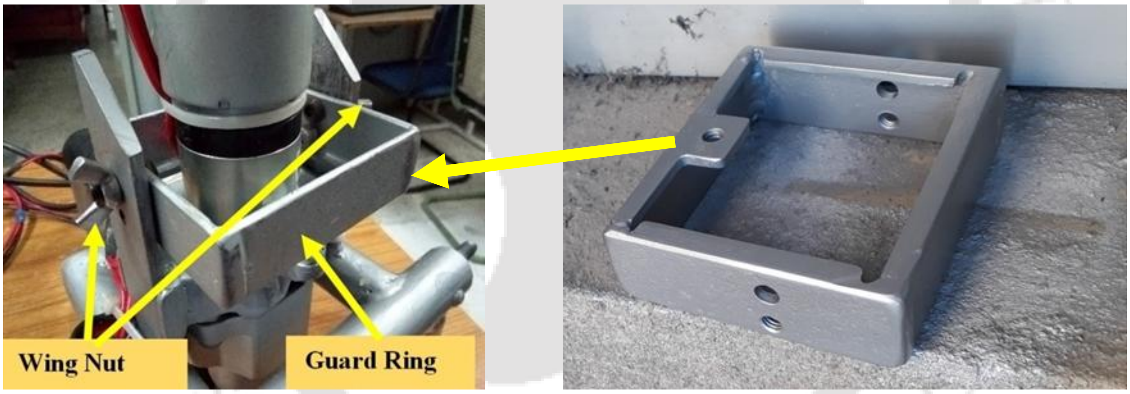


Fig. 4.19 The pair of sliding blocks

4.14.5 Guard ring

The guard ring (Fig.4.20) was provided to protect the motor from external shock. It also provided support to the guide rails. The ring acted as a clamp with which the user could adjust the height of the stone with respect to the ground surface. The adjustment could be done by releasing the wing nuts provided on both sides.



(a) **(b)**

Fig. 4.8 The guard ring of mild steel

4.14.6 Side and back handle

Holding the weight of the device was avoided by providing side and back handles. Thus, the user got proper control over the machine to polish a particular area.

4.14.7 Coating material

Rubber coating was used for handles to minimize the vibration transmission to the hands of the operators and to provide proper grip to the floor-polishing device.

4.14.8 Spherical Balls (Ball caster)

Three spherical wheels/ball caster units were fixed with screws on the side and back handle of the polishing device to provide smooth movement on the surface.

4.14.9 Power Supply

Power required for the motor of DC 18V, 22A, 400W was supplied through a 24V, 30A DC power supply.

4.15 Assembly of different components of the floor-polishing device

After the fabrication of the different components, the parts were assembled to build the prototype (Fig.4.21 & 4.22). The various parts of the machine were assembled to the main frame with the help of nuts and bolts. The sub-assemblies are as follows:

1. Ball caster assembly.
2. Handle and grip assembly.
3. Motor and coupling assembly.
4. Plastic protection cover with switch and power socket.
5. Power supply unit.

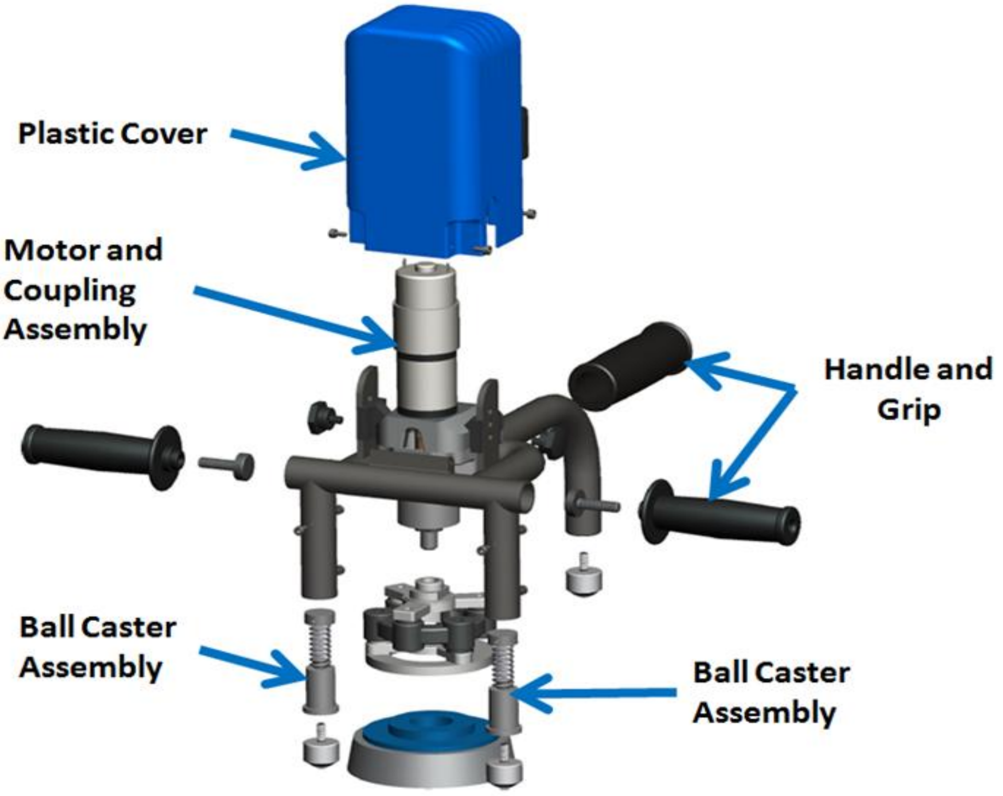


Fig. 4.9 The exploded view of parts assembled to mainframe

Fig. 4.10 Power supply unit

4.15.1 Ball caster assembly

Two front legs of the main frame were provided with spring loaded ball casters as shown in Fig. 4.23. Stoppers were fixed with the help of a pair of M4 Allen bolts. Then helical springs were inserted followed by the wheel attachment units, which were then set in place with an M4 Allen bolt. The slot in the main frame allowed the vertical motion of the main frame concerning the ground. The ball casters were fixed to M6 threaded holes in the wheel attachment unit. The rear ball caster was fixed to the M6 threaded hole in the rear leg of the main frame. The detailed drawing is given in Appendix A/Figure C.

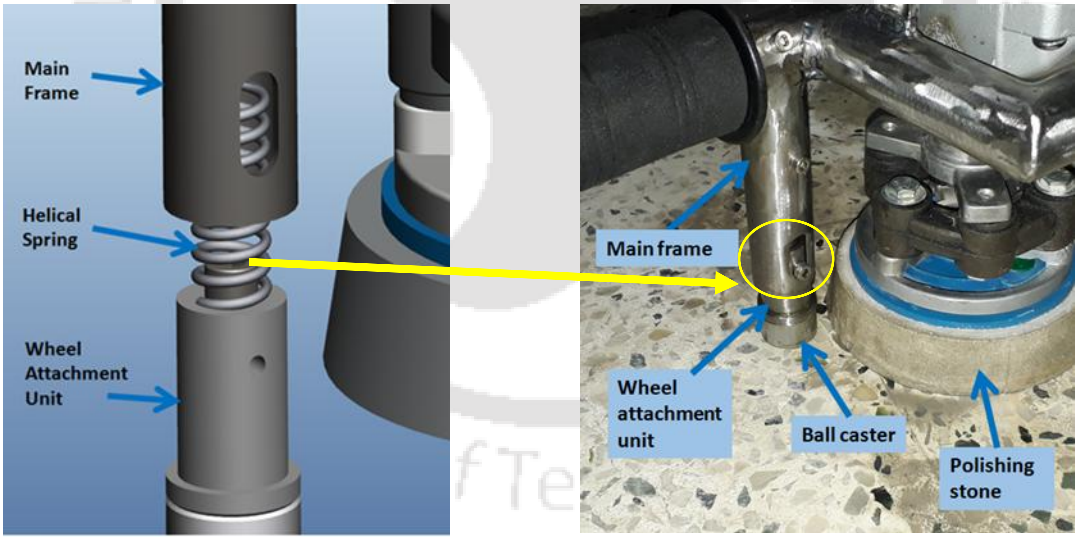


Fig. 4.11 Assembly of ball casters and spring system

4.15.2 Handle and grip assembly

The handle assembly screws were inserted through the openings on both sides of the main frame. They were set in place with M4 Allen bolts as shown in Fig.4.24 & 4.25. The handles were then screwed firmly. The rubber grip was inserted through the rear leg. The detailed drawing is given in Appendix A/ Figure E-1.

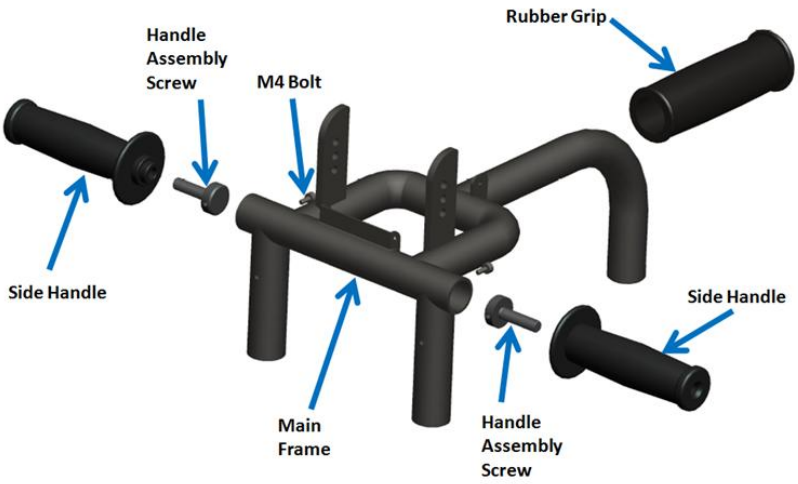


Fig. 4.12 Exploded view of handle assembly parts

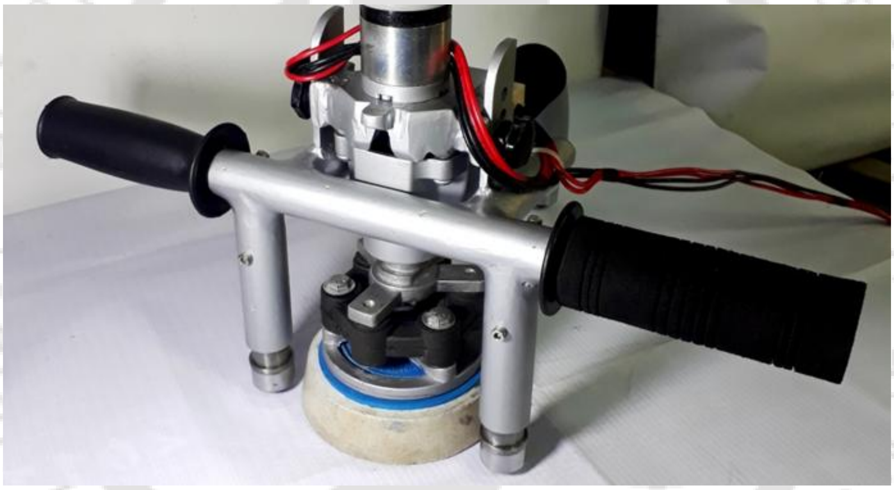


Fig. 4.13 Handles assembled to the main frame

4.15.3 Motor and coupling assembly

The planetary gear DC motor was assembled to the motor assembly hub with 4 nos. of M4×8mm Allen bolts as shown in Fig.4.26. The bearing hub had a rigid flanged coupling, which was coupled and aligned with a threaded shaft to which stone assembly coupling had to be fixed. The bearing hub was assembled to a motor assembly hub with 4 nos. of M6×20mm Allen bolts. Thereafter, the motor shaft was fixed to the rigid flanged coupling with an M6 set screw. Then the stone assembly coupling was screwed to the threaded shaft and tightened it firmly with an appropriate wrench. An exploded view of all components in order is shown in Fig.4.27. The detailed drawing is provided in Appendix A/ Fig B-3, B-4, D-1 and D-2.

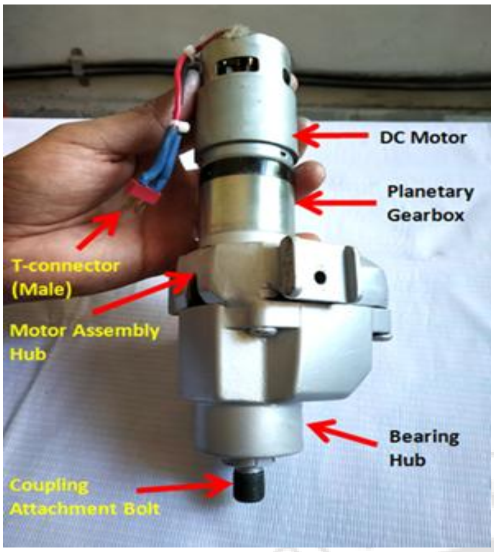


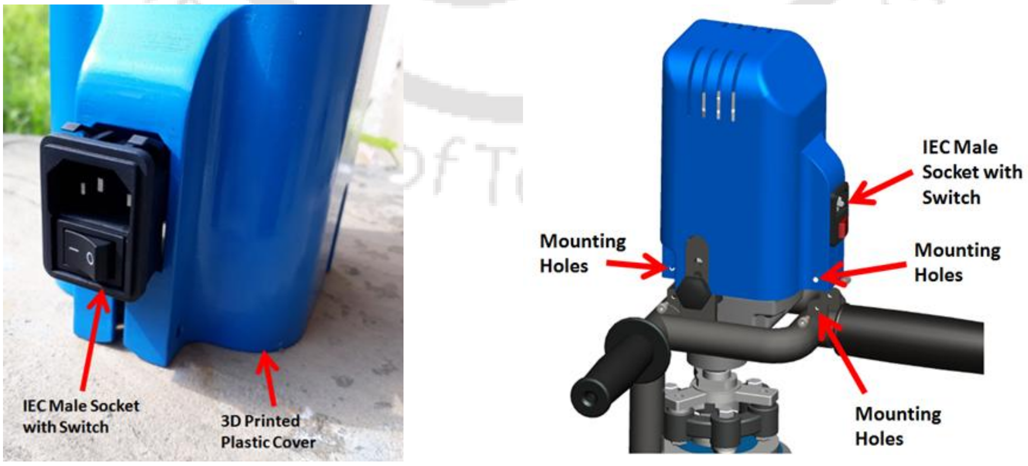
Fig. 4.14 Motor fixed to the hub

Fig. 4.15 Exploded view motor and coupling assembly

The full assembly of motor and coupling with stone (as shown in Appendix A/ Fig B-3) was fixed through the height adjustment holes on both sides of the mainframe with the help of M6 bolt knobs.

4.15.4 Plastic protection cover with switch and power socket

The protection cover made from PLA plastic was provided with 4 holes which enable it to fix to the mainframe with M4×8mm Allen bolts. The cover also had cut out portion in which an IEC male power socket with rocker switch could be snap-fit with its inbuilt clamps. The assembly is given in Appendix A/ Fig F. Fixing of the power socket is shown in Fig.4.28.



(a) (b)

Fig. 4.16 The plastic cover and its assembly to mainframe

4.15.5 Power supply unit

The power supply unit had 2 sections. The lower section was provided with a cutout portion to which an IEC male socket with fuse could be assembled with snap-fit. The upper and lower sections were fixed with 4self tapping screws as shown in Fig.4.29. Details of the parts and assembly are given in Appendix A/ Fig B-2, G-1 and G-2.

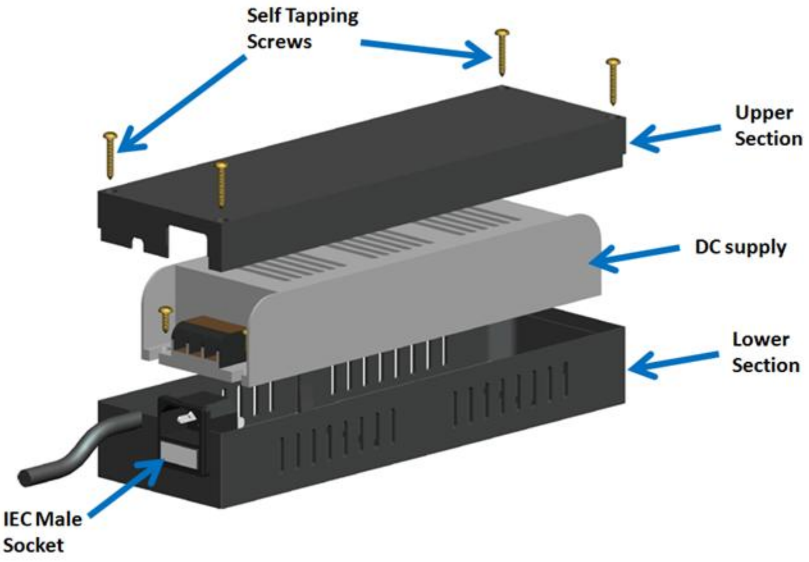


Fig. 4.17 Exploded view of the power supply unit

4.16 Raw material cost for a stone polish machine with cover and power supply

Details of the materials procured to develop the prototype is provided below table 4.12.

Table 4. 12 Standard items procured from various sources (Price as on 22-11-2018 in Guwahati)

Sl. No.	Particulars	Quantity	Cost (Rupees)	Market/Website
Raw Materials:				
1.	Steel pipe- OD-25mm, ID-21mm	4 ft	200.00	Local market
2.	MS flat bar-25mm x 3mm	200mm	100.00	Local market
3.	Ball transfer unit	3	1800.00	Online
4.	Planetary geared DC motor- 750 rpm, 250W.	1	6372.00	Online
5.	DC power supply-24V/15A	1	1,700.00	Online
6.	Grip knobs	2	30.00	Online
7.	IEC C14 male inlet socket with fuse	1	1,100.00	Online

8.	IEC C14 male inlet power socket with SPST switch	1	1,400.00	Online
9.	Power cord with IEC female-250V/10A	1	200.00	Online
10.	Right angle IEC C13 female plug point	1	500.00	Online
11.	T connector male female pair	1	50.00	Online
12.	1.5 mm double core insulated wire	5 mtr	300.00	Local market
13.	Heat shrink tubes	1	100.00	Local market
14.	Compression spring	2	100.00	Local market
15.	SS Allen bolts and nuts-M4, M6, M8	25	250.00	Local market
16.	Screws	8	40.00	Local market
17.	Rubber soft grip	2	50.00	Local market
18.	Plastic Handle	1	150.00	Local market
19.	Flexible stone coupling	1	200.00	Local market
20.	Polishing stone	1	500.00	Local market
21.	Paints	2	300.00	Local market
	Total		**15,442.00**	

4.17. Measured magnitude of vibration

Vibration magnitude was assessed at the wrist and handle of the polishing workers in terms of frequency weighted RMS acceleration (*aw* in m/s^2) which was the main feature to determine the health risk for any equipment device along with the duration of the exposure. The data collected using hand-arm vibration meter at the handle of the existing floor polishing device revealed that the eight-hour energy equivalent frequency-weighted acceleration magnitude [A (8)] for each of the participant was more than the recommended action value (= 2.5 m/s^2) for the existing device as shown in Table 4.13. The recorded values of frequency - weighted acceleration [(A) 8] ranged from 2.25 m/s^2 to 3.87 m/s^2 .The vibration magnitudes recorded on the handle of the existing floor polishing device was dominant in *z*- axis (ranged from 1.63 m/s^2 to 11.22 m/s^2) followed by *y*- axis (ranged from 1.52 m/s^2 to 10.34 m/s^2) and *x*- axis (ranged from 1.4 m/s^2 to 8.61m/s^2).

Table 4.13 Descriptive statistics for vibration transmission at the handle of the existing floor-polishing device

Handle	***awx***	***awy***	***awz***	***aw (vec)***	***MTVV***	***A(8)***
Mean	4.98	5.43	6.69	10.04	9.85	3.11
Median	4.31	3.52	6.09	8.8	10.28	2.92
Std. Deviation	3.74	6.55	6.66	9.90	8.03	0.43
Minimum	1.4	1.52	1.63	1.15	1.86	2.25
Maximum	8.61	10.34	11.22	12.64	15.47	3.87
Percentile(5)	1.4	1.63	1.52	1.15	1.86	2.25
25	1.72	1.67	2.48	3.45	3.05	2.84
50	4.31	3.52	6.09	8.8	10.28	2.92
75	6.85	7.47	6.9	12.26	11.16	3.52

For the redesign floor polishing device the eight-hour energy equivalent frequency-weighted acceleration magnitude [A (8)] at the handle for each of the participant was below than the recommended daily average vibrational exposure action value (= 2.5 m/s^2) as shown in Table. 4.14. The new recorded values of frequency - weighted acceleration [(A) 8] are ranged from 0.36 m/s^2 to 1.47 m/s^2 . There was significant reduction in vibration magnitudes recorded on the handle of the redesign floor polishing device in z- axis (ranged from 1.41m/s2 to 3.53m/s2) followed by y- axis (ranged from 1.5 m/s2 to 3.73 m/s2) and x- axis (0.79m/s2 to 3.72 m/s2).

Table 4.14 Descriptive statistics for vibration transmission at the handle of the redesign floor-polishing device

Handle	***awx***	***awy***	***awz***	***aw (vec)***	***MTVV***	***A(8)***
Mean	2.33	2.48	2.57	4.31	3.30	1.06
Median	2.29	2.31	2.75	3.98	3.22	1.00
Std. Deviation	0.80	1.06	0.74	1.42	0.622	0.36
Minimum	0.79	1.5	1.41	2.51	2.37	0.63
Maximum	3.72	3.73	3.53	6.31	4.11	1.58
Percentile(5)	1.60	0.79	1.41	2.51	2.37	0.63
25	1.70	0.93	1.83	2.56	2.71	0.64
50	2.29	2.31	2.75	3.98	3.22	1.00
75	3.41	3.40	3.33	5.86	3.91	1.47

The eight-hour energy equivalent frequency-weighted acceleration magnitude [A (8)] at the wrist using the existing floor polishing device for each of the participants was more than the recommended daily average action value (= 2.5 m/s^2) as shown in Table 4.15. The recorded values of frequency - weighted acceleration [(A) 8] ranged from 2.02 m/s^2 to 3.52 m/s^2 .The vibration magnitudes recorded in the right hand using the existing floor polishing device was dominant in *z* - axis (ranged from 1.52 m/s^2 to 10.69 m/s^2) followed by *y*- axis (ranged from 1.4 m/s^2 to 9.22 m/s^2) and *x*- axis (ranged from 1.63m/s^2 to 7.47 m/s^2).

Table 4.15 Descriptive statistics for vibration transmission at the wrist of the existing floor-polishing device

Wrist	***awx***	***awy***	***awz***	***aw (vec)***	***MTVV***	***A(8)***
Mean	3.5	4.59	5.65	8.11	8.73	2.79
Median	4.31	2.93	6.09	8.8	10.28	2.84
Std. Deviation	2.06	2.08	3.23	4.23	4.78	0.41
Minimum	1.4	1.63	1.52	1.15	1.86	2.02
Maximum	7.47	9.22	10.69	13.64	16.04	3.52
Percentile(5)	1.63	1.52	1.15	1.86	2.02	0.69
25	1.67	2.48	4.07	4.58	2.50	0.72
50	3.52	6.09	8.80	10.28	2.84	0.97
75	6.63	9.47	12.26	11.16	3.12	1.09

Whereas the eight-hour energy equivalent frequency-weighted acceleration magnitude [A (8)] at the wrist using the redesign floor polishing device for each of the participant was lower than the recommended daily average action value = 2.5 m/s^2 as shown in Table 4.16. The recorded values of frequency - weighted acceleration [(A) 8] ranged from 0.69 m/s^2 to 1.47 m/s^2 . Significant reduction in vibration magnitudes recorded in the right hand in *z*- axis (ranged from 1.65m/s^2 to 3.41m/s^2) followed by *y* - axis (ranged from 1.22 m/s^2 to 3.40m/s^2) and *x*- axis (ranged from 1.12m/s^2 to 3.33 m/s^2).

Table 4.16 Descriptive statistics for vibration transmission at the wrist of the redesign floor-polishing device

Wrist	***awx***	***awy***	***awz***	***aw (vec)***	***MTVV***	***A(8)***
Mean	2.17	2.06	2.34	3.77	3.10	0.95
Median	2.24	2.18	2.24	3.89	2.63	0.97
Std. Deviation	0.60	0.67	0.40	0.923	0.90	0.21
Minimum	1.12	1.22	1.65	2.75	2.31	0.69
Maximum	3.33	3.40	3.41	5.86	4.81	1.47
Percentile(5)	1.22	1.12	1.65	2.75	2.31	0.69
25	1.49	1.25	2.07	2.83	2.37	0.72
50	2.24	2.18	2.24	3.89	2.63	0.97
75	2.53	2.51	2.57	4.35	3.72	1.09

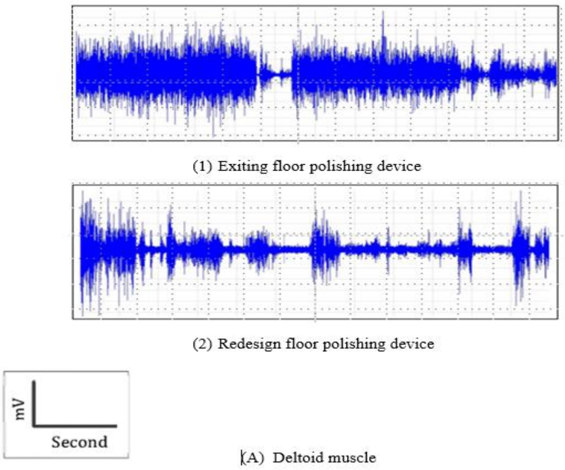
A Wilcoxon signed- rank test showed that there was a significant change in vibration transmission at the handle (Z= -3.408, $p < 0.001$) and the wrist (Z= -3.111, $p < 0.01$) while using the redesigned floor polishing device.

Regarding the permissibility of working hours with the device, the existing device could be used only for 6.82 hours daily whereas the redesigned device could be used for more than 12 hours for the same time framework. It meant the redesigned device had more than two times less hand-arm vibration exposure than the existing one.

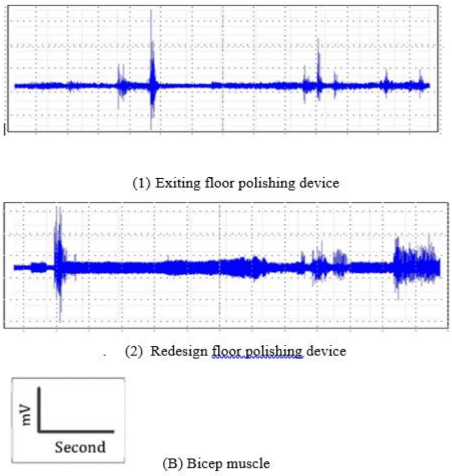
4.18 Comparative analysis between the existing floor polishing device and the redesigned floor-polishing device.

4.18.1 Electromyography

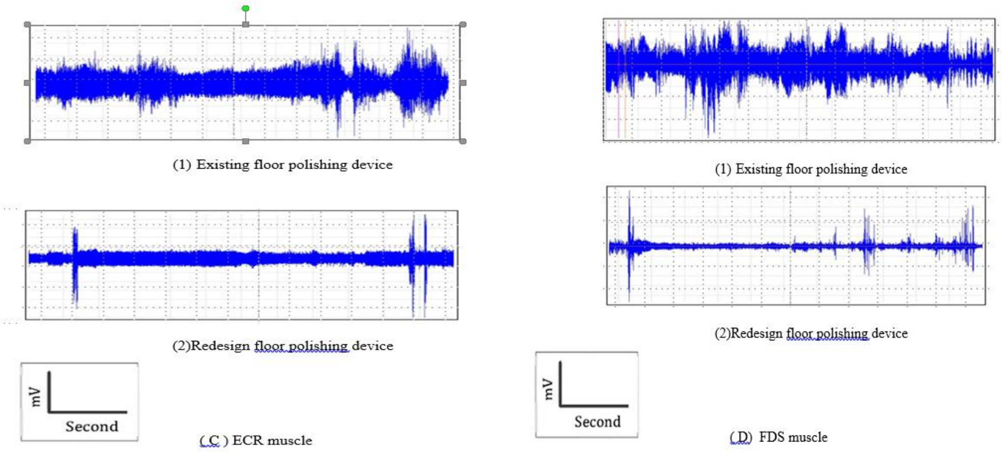
The raw EMG of selected muscles namely Deltoid, Bicep, FDS and ECR muscles were shown in Fig.4.30. The muscles had a different extent of activity, which was observed, based on the change in EMG signals. Out of the four selected muscles, maximum involvement was found for FDS muscle followed by a slow reduction of Deltoid, ECR and lastly Bicep. In the present research, field survey data (related to body parts discomfort while operating existing floor polishing device) also showed the similar mode of observations like the workers reported for wrist and finger pain, which could be due to the proactive involvement of FDS muscles in floor polishing activity.



(A) Deltoid muscle



(B) Bicep muscle



(C) ECR muscle

(D) FDS muscle

Fig. 4.18 Representative raw electromyography (EMG) data from (A) Deltoid (B) Bicep (3) ECR (4) FDS during floor polishing activity.

4.18.2 EMG (% MVC) selected for selected muscles

This experiment aimed to compare the muscular effort for operating existing and redesigned floor polishing device (Fig. 4.31). For the redesign floor polishing device, mean EMG (mV, expressed as % equivalent of mean MVC) of hand muscles viz., Deltoid, Bicep, ECR and FDS was 2.72%, 0.72%, 5.83%, and 2.65%, whereas for the existing device, it recorded 7.3%, 3.55%, 5.17% and 14.93%. The muscular effort required for the redesigned device was lower than the existing floor-polishing device by 62.73%, 79.72%, 12.77%, and 82.25% for Deltoid, Bicep, ECR and FDS muscles respectively (Fig.4.31). Further, Wilcoxon signed-ranked test showed that all four muscles extract a significant change Deltoid muscle (Z = - 3.180, p<0.001), Bicep muscle (Z= - 3.180, p< 0.001), ECR (Z= -3.180, p<0.001) in muscular effort requirement while operating redesign and existing floor polishing device. Therefore, it is visible from the results (Table 4.17) that there was a decrease in %MVC while the EMG data with the redesigned device compared to the existing device.

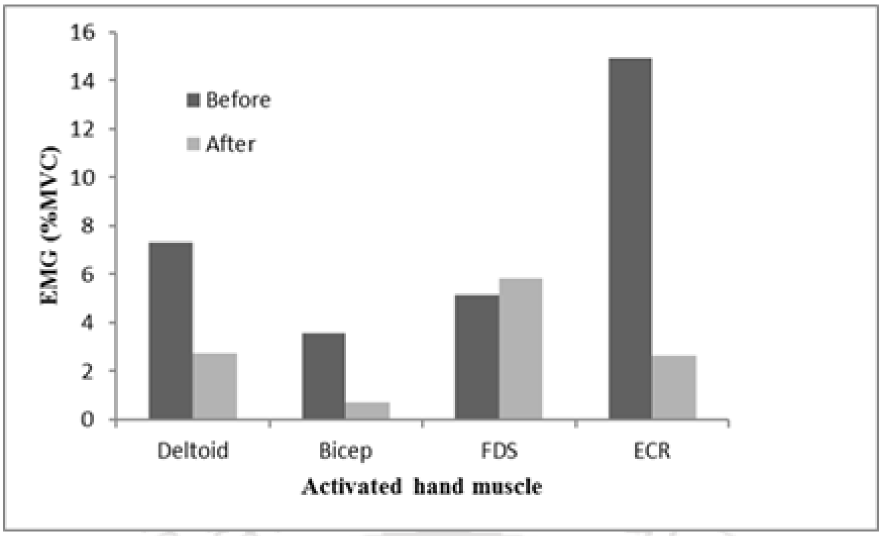


Fig. 4.19 The RMS% MVC graph plot for Deltoid muscles, Bicep muscles, Flexor Digitorium Superficialis muscles (FDS) and Extensor Carpi Radialis muscles (ECR) for existing and redesign floor polishing device

Table 4.17 The % MVC values of the muscle for the existing and redesign polishing device

	Mean		Std. Deviation		Range		Minimum		Maximum	
	Before	After	Before	After	Before	After	Before	After	Before	After
Deltoid	7.30	2.72	6.08	3.21	18.30	11.68	1.11	0.49	7.34	2.72
Bicep	3.54	0.72	3.48	0.45	12.10	1.39	0.47	0.27	3.54	0.72
FDS	5.11	5.82	6.29	4.64	23.08	16.59	0.86	0.72	5.11	5.82
ECR	14.92	2.65	13.83	1.69	53.0	4.97	3.35	0.11	14.92	2.65

Wilcoxon signed ranks test was performed to compare the muscle strength between the existing and redesign floor-polishing device. Wilcoxon signed-test showed that all four muscle elicits a statistically significant change for Deltoid muscle ($Z = - 3.180$, $p<0.001$), Bicep muscle ($Z= - 3.180$, $p< 0.001$), ECR ($Z= -3.180$, $p<0.001$) in muscular effort required while operating existing and redesign floor polishing device. For the FDS muscle, the %MVC was higher in the redesign polishing device compared to the existing polishing device.

4.19. Usability testing

System Usability Scale (SUS) was administered to 15 polishing workers for evaluating the usability of both the existing and redesign floor-polishing devices. The polishing workers rated an average score of all the respondents was calculated after each question of the SUS questionnaire for both existing and redesign floor-polishing devices. For calculating SUS score, first, the score from each item was summed up and each item's score contribution ranged from 0 to 4. For items, 1, 3, 5, 7 and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. The sum of the scores is multiplied by 2.5 to obtain the overall value of SUS. SUS scores had a range of 0 to 100.

Table 4.18 System Usability Scale items and their ratings of the existing floor-polishing device

Sr.No.	System Usability Scale questions	Ratings, % (n), total n =15				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1.	I think that I would like to use this product frequently.	87 (13)	15 (2)	0 (0)	0 (0)	0 (0)
2.	I found the product unnecessarily complex.	0 (0)	0 (0)	0 (0)	27 (4)	74 (11)
3.	I thought the product was easy to use.	80 (12)	20 (3)	0 (0)	0(0)	0 (0)
4.	I think that I would need the support of a technical person to be able to use this product.	0 (0)	0 (0)	0 (0)	20 (3)	80 (12)
5.	I found the various functions in the Product very well integrated.	34 (5)	54 (8)	14 (2)	0 (0)	0 (0)
6.	I thought there was too much inconsistency in the Product.	0 (0)	0 (0)	0 (0)	40 (6)	60 (9)
7.	I would imagine that most people would learn to use the Product very quickly.	80 (12)	14 (2)	7 (1)	0 (0)	0 (0)
8.	I found the Product very cumbersome to use.	0 (0)	0 (0)	20 (3)	27 (4)	54 (8)
9.	I felt very confident using the Product.	74 (11)	20 (3)	7 (1)	0 (0)	0 (0)
10.	I need to learn a lot of things before I could get going with this Product.	0 (0)	0 (0)	0 (0)	40 (6)	60 (9)

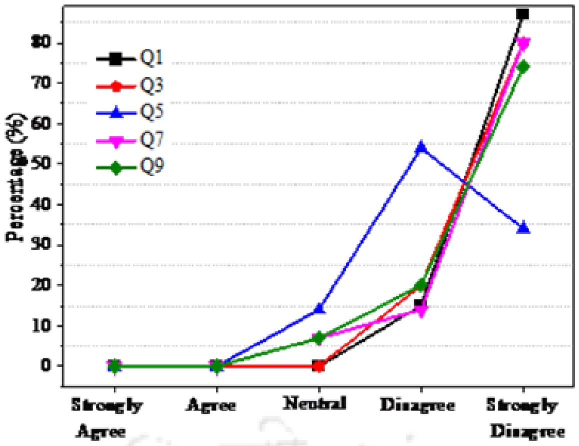


Fig. 4.20 Percentage ratings for questions 1, 3, 5, 7, 9 for redesign device

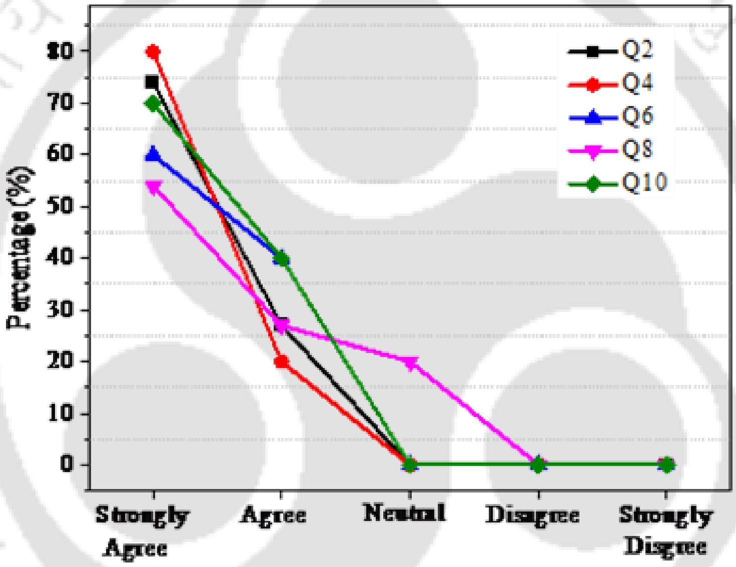
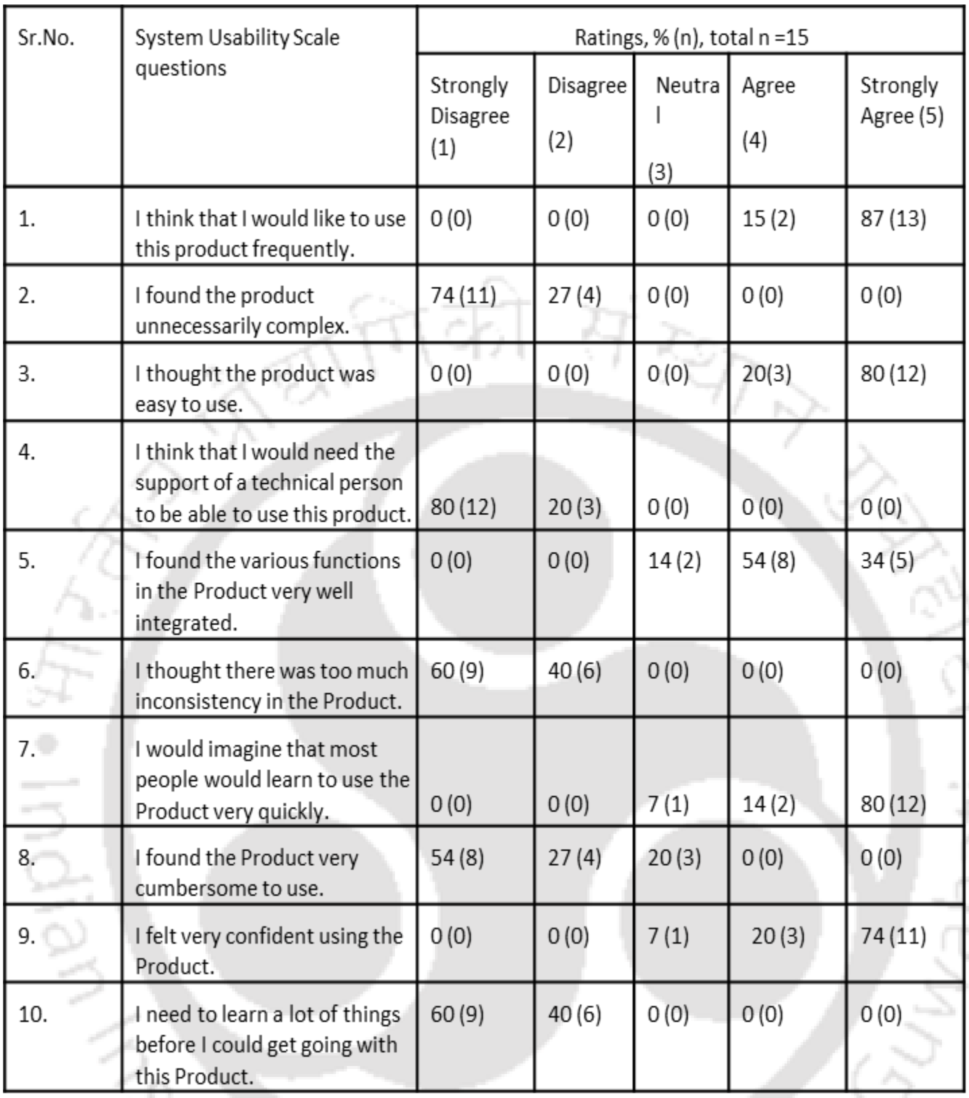


Fig. 4.33 Percentage ratings for questions 2, 4, 6, 8, 10 for redesign device

The average SUS score of all the participants for the existing floor polishing device was calculated and a score value of 13.45 was obtained which means "awful" and "unacceptable" usability rating, according to the attributes shown in Table 4.18. The ratings for the odd and even-numbered questions were shown in Fig. 4.32 and Fig. 4.33. The result showed that the responses were mostly 'agree' and 'strongly agree' for the even-numbered questions i.e. negatively phrased and mostly 'disagree' and 'strongly disagree' for odd-numbered questions (positively phrased).

Table 4.19 System Usability Scale items and their ratings of the redesigned floor-polishing device



Sr.No.	System Usability Scale questions	Ratings, % (n), total n =15				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1.	I think that I would like to use this product frequently.	0 (0)	0 (0)	0 (0)	15 (2)	87 (13)
2.	I found the product unnecessarily complex.	74 (11)	27 (4)	0 (0)	0 (0)	0 (0)
3.	I thought the product was easy to use.	0 (0)	0 (0)	0 (0)	20(3)	80 (12)
4.	I think that I would need the support of a technical person to be able to use this product.	80 (12)	20 (3)	0 (0)	0 (0)	0 (0)
5.	I found the various functions in the Product very well integrated.	0 (0)	0 (0)	14 (2)	54 (8)	34 (5)
6.	I thought there was too much inconsistency in the Product.	60 (9)	40 (6)	0 (0)	0 (0)	0 (0)
7.	I would imagine that most people would learn to use the Product very quickly.	0 (0)	0 (0)	7 (1)	14 (2)	80 (12)
8.	I found the Product very cumbersome to use.	54 (8)	27 (4)	20 (3)	0 (0)	0 (0)
9.	I felt very confident using the Product.	0 (0)	0 (0)	7 (1)	20 (3)	74 (11)
10.	I need to learn a lot of things before I could get going with this Product.	60 (9)	40 (6)	0 (0)	0 (0)	0 (0)

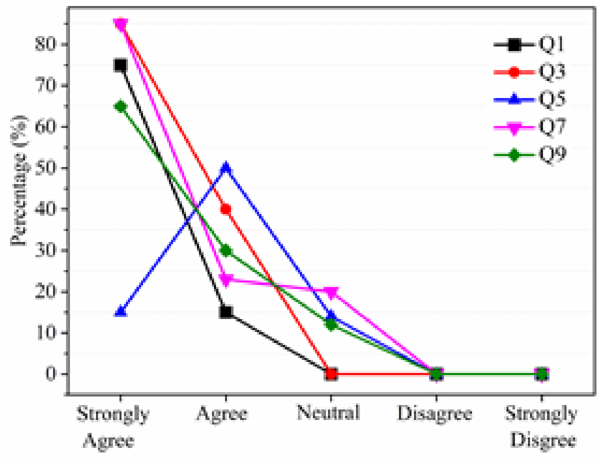


Fig. 4.21 Percentage ratings for questions 1, 3, 5, 7, 9 for redesign device

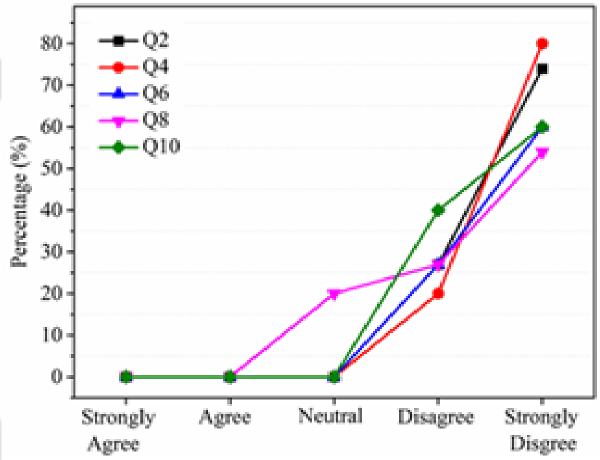


Fig. 4.35 Percentage ratings for questions 2, 4, 6, 8, 10 for redesign device

Similarly, the average SUS score for the redesign floor-polishing device was calculated and a score value of 86.8, which meant ‘excellent’, and ‘acceptable’ level of usability (Table.4.19). The ratings for the odd and even-numbered questions were shown in Fig. 4.34 and Fig. 4.35. The result showed that the responses were mostly ‘agree’ and ‘strongly agree’ for the odd-numbered questions i.e. positively phrased and mostly ‘disagree’ and ‘strongly disagree’ for even-numbered questions (negatively phrased).

5. Discussion & Conclusion

This chapter outlines the key findings of the present research and describes how the pre-set objectives were fulfilled through the methodology followed and results/ observations obtained. This chapter also presents the testing of hypothesis, a summary of features to explain the superiority of redesigned floor polishing device in comparison to the existing one, novel contributions of the thesis, limitations of current research along with future scope and conclusions are drawn from the reported research.

Erstwhile studies by the researchers across different geographical realms showed that most of the equipment/device used in construction, agriculture, forestry, mining sector, etc. exceed the upper limit of exposure as per ISO stipulations (Dewangan and Tewari, 2009; Singh and Khan, 2013; Mandal and Srivastava, 2006). There is also no quantifiable data from which one can estimate the extent of harmful vibration levels that are generated from various devices used in the construction sectors. There is also the lack of awareness among workers about ill-effects of vibration contributing to the increase in health risks. Most of the workers are unaware of the proper implementation of engineering control of equipment/ devices as well as changes in work practices. The main reason for the discomfort of the polishing workers during their working hours is the extensive vibration transmitted to the hand-arm system.

As mentioned above, among the various hazardous activities in the construction sector, floor polishing is one, where the use of hand-held floor polishing devices is a regular part of their deeds. As reported by the workers, there was a tingling sensation felt by them while performing floor-polishing activities. The suffering of the workers is many a time attributed to the improper design of the working device (Buttle, 1994). Therefore, the current research focused on ergonomic design modification of the existing polishing device to ameliorate the transmission of vibration to the hand-arm system to increase the productivity and efficiency of the polishing workers.

Following a questionnaire study, it was found that the occurrence of pain/ discomfort in different body parts among the polishing workers was prevalent. The highly tedious nature of work for a longer time span might results in pain and discomfort of the operators. This is also relevant in case of floor polishing activities where a strong association was seen between longer polishing hours and occurrence of pain in the upper arm, lower arm and lower back of the workers (Kumar et al., 2016). Prolongation of work for long duration and monotonous work without proper break likely to overstress the musculoskeletal symptoms whereas with proper break in between every working hour can significantly minimize the pain risk (Faucett et al., 2007). Another factor that has significantly affected the prevalence of body parts discomforts mainly in the wrist, elbow and shoulder of the workers is the transmission of vibrational energy from the polishing device. Buttle (1994) mentioned that more working experience could be an important factor in diminishing the risk of work-related pain in case of wrist. In case of the floor-polishing, the workers reported that during the initial days of their floor polishing work, pain was more but greater practice and experience with time lead to the reduction of pain in wrist, elbow, neck and shoulder. A greater practice can be effective in fine movements without hurting their wrist inducing in wrist pain and an increase in output (Kumar et al., 2016). A high proportion of the polishing workers reported discomforts at their neck (48.9%), shoulder (51.1%), wrist (84.4%), elbow (83%), feet (53.3%) and knee (31.1%). The incidence of musculoskeletal symptoms of different body regions of the floor polishing workers caused disruption in carrying out regular work due to pain. Out of the all participants (floor-polishing workers), the pain was reported by 93.3% workers in their neck region, 90% workers in the wrists, 80% workers in the shoulder, 90% workers in the elbow, 83.3% workers in the ankle and 66.7% workers in the knee during the last 12 months. Disturbances in carrying out regular activities because of musculoskeletal pain were reported by all the floor-polishing workers, and this resulted in pain in the neck, shoulders, wrist/hand, elbow, ankles and knee.

During the polishing work, various awkward postures like forward bending of the trunk, forward and side bending of the neck; chin kept on the knee, forward side bending, hands supported on the knee along with frequent forceful arm movements were noticed irrespective of working location (floor, wall, staircase). To estimate the postural risks related to the adopted postures of the polishing workers, working posture was analyzed using the REBA method. The analysis showed that the REBA grand score was high (floor=9, wall base 7, staircase=10) in all cases of polishing activities. These observations indicated the high postural risk and requirements of further investigations and changes of the working tool/ equipment/ device, introduction of proper work-rest cycle etc. at the earliest.

The existing device has an improper handle design. Earlier reported studies mentioned that the perceived discomfort and fatigue are associated with involvement of localized forces at the handle interface (Gurram et al., 1995; Singh and Khan, 2012). There is no dampening material on the handle of existing floor-polishing device. There is sustained load holding during the use of the existing device as the workers need to hold the weight of the device by both hands. In the redesign polishing device, a supportive frame has been provided to withstand the load of the whole device and to minimize the vibration generation due to the use of planetary gear trains in place of compound gear trains to reduce the external shock. Due to this modification in the gear system, less force is required in case of redesigned device for smooth movement on the surface. The redesigned device was given to the workers to practice for seven days for habituation with redesigned device and there after its effectiveness and efficiency were tested in real working conditions.

To check the effectiveness of the new design in comparison to the existing one, the magnitude of vibration was measured at the handled of the device and right wrist of the polishing workers. The vibration intensity was found beyond the exposure action value ($2.5 m/s^2$). Average daily vibration exposure A(8) value of 3.11 m/s^2 at the handle and 2.79 m/s^2 at the operator’s wrist were found in case of the existing floor-polishing device whereas 1.06 m/s^2 at the handle and 0.95 m/s^2 at the operator’s wrist were noticed in case of redesigned polishing device. The Wilcoxon signed-rank test exhibited a significant difference in the scores of daily exposure value A (8) (in m/s^2) at the handles between the existing and redesigned polishing devices ($Z = -3.408$, $p =<0.00$). This result indicated that there was a reduction in vibration transmission from the handle to the operator’s hand while operating redesigned polishing device. With the average daily vibration exposure A (8) value of 2.79 m/s^2, the existing floor-polishing device can be used for 6.82 hours/day whereas the redesign floor-polishing device with A(8) value of 0.95 m/s^2, can be used for more than12 hours/day.

There was also a significant difference in requirement muscular effort during the operation of the existing and redesigned polishing device. The muscular effort were recorded using EMG system mainly for four muscles which include Deltoid, Bicep, Flexor Digitorum Superficialis (FDS) and Extensor Carpi Radialis (ECR) showed that there were decrease in the requirement of muscular strength/effort (%MVC) for the redesign polishing device. The strength required for the redesigned device was lower than the existing device by 62.73% for Deltoid, 79.72% for Bicep, 12.77% for FDS, and 82.25 % for ECR. The Wilcoxon signed-test showed a significant difference in muscular strength requirements for Deltoid muscle ($Z = - 3.180$, $p<0.001$), Bicep muscle ($Z= - 3.180$, $p< 0.001$), ECR ($Z= -3.180$, $p<0.001$) while operating existing and redesigned polishing device.

The redesigned device was tested in real working conditions as stated earlier. It was given to the workers to work for seven days for habituation. During this period, they also learned and became acquainted with the assembling and dissembling of the handle, adjusting the height of the device, attaching/ detaching of the sanding stone, switch on/off the device, etc. of the redesigned device. Initially, there was a problem with the operating and handling of the redesigned device. The workers initially found it to be difficult to adjust the handle and apply pressure while performing the polishing activity. The former device did not have any spring mechanism where the variation of applied pressure was controlled by muscles of the hand and arm. However, in the redesigned device, there was a provision to adjust the pressure with the help of spring mechanisms at the legs of the polishing device as per the requirement of the floor surface. The polishing workers participated in testing and providing feedback regarding both the existing and redesigned device. According to their feedback, they were satisfied in terms of the quality of polishing on the floor surface. System Usability Scale (SUS) was administered for evaluating the usability of both the existing and redesign floor-polishing device involving 15 polishing workers. An average score of all the respondents was calculated after each item of the SUS questionnaire was rated by each polishing worker for both existing and redesign floor polishing device. The average SUS score for the existing floor polishing device was 13.45 that meant ‘awful’ and ‘unacceptable’ usability ratings. In contrary, the average SUS score for the redesigned floor-polishing device was 86.8 which meant ‘excellent’ and ‘acceptable’ level of usability (Bangor et al., 2008, 2009). According to the feedback of the redesigned device, the polishing workers were satisfied in terms of the quality of polishing on the floor surface.

5.1 Key Findings

The salient findings of the present study are listed below.

1. Symptoms of occupational health hazards were observed among the workers working with the existing floor-polishing device. Data collected from subjective responses using the Nordic Questionnaire demonstrated the prevalence of pain in various body parts of the workers was high which hindered their daily activities at work and outside work.
2. The exposure level to vibration during the use of the existing hand-held floor polishing device was high. Hand-arm vibration meter data revealed that the eight-hour energy equivalent frequency-weighted acceleration magnitude [A (8)] was more than the

recommended daily average vibration exposure (action value = 2.5 m/s^2) for the existing polishing device.

3. Awkward working posture [REBA grand scores 9 (floor), 7 (wall-base) and 10 (staircase)], repetitive and strenuous manual actions, prolonged duration of work (8 - 12 hours) were observed among the workers during the use of existing polishing device.
4. Anthropometric mismatch in terms of improper handle grip diameter, lack of use of vibration dampening material, non-alignment of the motor shaft and polishing stone axis leading to jerk and vibration, indicated the urgent need for ergonomic design intervention of the existing floor-polishing device to overcome all these constraints.
5. The weight of the redesigned floor polishing is more than the existing floor-polishing device (existing device: 2.8 kg and redesign device: 3.9 kg) due to the addition of the supporting frame and handles. However, the weight of the redesigned device is borne by the supportive structure on the ground whereas the weight of the existing device is borne by the hands of the operator (sustained load holding).
6. There was a significant reduction in vibration generation and transmission after the redesigning of the floor-polishing device due to changes made in gear mechanism by replacing the compound gear to a planetary gear. The data collected using hand-arm vibration meter at the handle of the redesigned floor polishing device and the wrist of the operator while using the device, depicted that the eight-hour energy equivalent frequency-weighted acceleration magnitude [A (8)] for each of the participant was less than the recommended action value (2.5 m/s2). The mean value of A (8) was 1.06 m/s^2 at the handle of the device whereas 0.95 m/s^2 was recorded at the right wrist of the operator.
7. The planetary gear with output rpm of 750 rpm and base motor 18,750 rpm used in the redesigned device was able to reduce vibration generation more than the existing device having compound gear with output rpm 1250 rpm and base motor rpm 25000 rpm. The vibration transmission was very less during the use of redesign floor polishing device compared to the existing floor polishing device.
8. A significant reduction was noticed in required muscular efforts for performing floor-polishing activity with redesigned floor polishing device in comparison to the existing one. The percentage reductions of required muscular effort for the redesigned device compared to the existing device were 62.73% for Deltoid, 79.72% for Bicep, 12.77% for Flexor Digitorum Superficialis, and 82.25% for Extensor Carpi Radialis muscles.

9. The polishing workers participated in testing and feedback of the redesigned device, were satisfied in terms of the quality of polishing on the floor surface. Following usability evaluation using the System Usability Scale (SUS), it was observed that the average SUS score for the redesign floor polishing device was 86.8 which meant ‘excellent’ and ‘acceptable’ level of usability.

5.2 Key features of the redesigned floor polishing device

1. The existing device has compound gear causing external jerk along with vibration generation. To resolve this issue, planetary gear has been used in redesigned polishing device to bring the motor axle and output shaft (attached with polishing stone) on the same vertical axis.
2. The extensive vibration occurred due to the friction between the polishing stone and the floor is directly transmitted from the body and handle of the polishing device to the hand-arm system of the operator. Direct transmission of vibration is reduced by the developed supportive frame with three legs around the redesigned device. The frame also withstands the device weight (3.9 kg) as well as provides stability to the machine during the operation.
3. The side and back/ rear handles with rubber coatings not only reduce the vibration transmission but also helps to get proper control of the grip over the polishing device.
4. The redesigned polishing device has the provision of attaching the handle on both the right and left side of the frame as per the requirement of the hand-dominance of the workers. The redesigned handle of the device improved the wrist posture during the polishing activities as was evident from the postural score of the wrist from the REBA score (table 4.5).
5. The addition of three spring loaded roller-ball caster units at the bottom of the supportive legs along with the provision of two-hand manoeuvrability helps in smooth movement of the redesigned device on the floor-surface. The spring allows the user to apply required force on the floor as per hardness of floor stains.
6. Provision for the vertical adjustment of the device to accommodate polishing stone of different thicknesses has been made in the redesigned device.
7. The planetary gearbox along with the DC motor is protected with 3D printed plastic cover. The proper casing of the device has been made to ensure electrical safety. The

cover has provisions to assemble the plug and switch. Slots/ cuts have been provided on the top portion of the cover for proper air circulation required for motor cooling during operation.

5.3 Testing of Hypotheses

The hypotheses formulated at the commencement of the research work have been tested by fulfilling various objectives.

H1: Design Interventions of the polishing device by modifying the gear train mechanism and using vibration dampening material would significantly reduce vibration generation and transmission and thereby exposure to vibration.

The gear mechanism of the fabricated polishing device was changed from compound to planetary gear to bring the motor axle and output shaft (attached with polishing stone) on the same vertical axis to avoid jerk and reduction of vibration. Direct transmission of vibration energy to operator's hand-arm was reduced due to the developed supportive frame around the polishing device to withstand the load of the whole device and stabilizing the load on three legs connected with the frame by minimizing the vibration occurs due to the friction between the stone and the floor. Moreover, vibration dampening coating material provided on the handle of the redesigned device reduces the vibration transmission to the hand-arm system during polishing work and provides proper grip on the handle of the floor-polishing device.

The data collected using hand-arm vibration meter revealed that the eight-hour energy equivalent frequency-weighted acceleration magnitude [A (8)] for each of the participant was more than the recommended daily average vibrational exposure (action value = 2.5 m/s^2 and exposure limit = 5 m/s^2) for the existing device. Average daily vibration exposure A(8) value of 2.84 m/s^2 at the handle and 2.79 m/s^2 at the operator's wrist were found in case of the existing floor-polishing device whereas 1.06 m/s^2 at the handle and 0.95 m/s^2 at the operator's wrist were noticed in case of the redesigned polishing device. There was a significant difference ($p< 0.001$) in vibration generation and transmission between the existing and redesigned polishing device as evident Wilcoxon paired test. Thus, it can be stated that hypothesis H1 is accepted.

H2: Supportive/ weight-bearing mechanism for avoiding sustained load holding during use of hand-held floor polishing device can significantly reduce muscular effort.

Workers used to undergo sustained load holding (2.8 kg without sanding stone) of the existing polishing device for a prolonged duration (8 to 10 hr) during a shift. In the case of a redesigned polishing device, the weight (3.9 kg without sanding stone) of the device is borne by the supportive structure on the ground. Thus, there is no requirement of sustained load holding during manoeuvrability of the device. It has a distinct provision for easy assembling and dissembling of the polishing device with the support frame. The former device did not have any spring mechanism where the variation of applied pressure was controlled by muscles of the hand and arm. However, in the redesigned device, there is a provision to adjust the pressure with the help of spring mechanisms at the legs of the polishing device as per the requirement of the floor/ polishing surface.

Due to the supportive structure for load bearing, there was significant reduction of muscular effort (% MVC) for polishing activities in case of redesigned device. The strength required for the redesigned device was lower than the existing device by 62.73% (Deltoid), 79.72% (Bicep), 12.77% (FDS), and 82.25 %(ECR).The Wilcoxon signed-test showed a statistically significant change in muscular effort levels for Deltoid muscle ($Z = - 3.180$, $p<0.001$), Bicep muscle ($Z= - 3.180$, $p< 0.001$), ECR ($Z= -3.180$, $p<0.001$) while operating existing and redesign polishing device. This proves that the supportive/ weight-bearing mechanism helps avoid sustained load holding during the use of hand-held floor polishing device and thereby significantly reduce the muscular effort for polishing activities.

H3: Proper anthropometric and biomechanical compatibility of hand-held floor polishing device can significantly improve the usability of the device.

Handles of the existing polishing machine were not properly designed by due consideration of anthropometric and biomechanical compatibility of the targeted user population. The grip diameter of the existing device was 35 mm and it was hard plastic coated. In the redesigned device, handle grip diameter (42 mm) and length were decided as per hand anthropometry of the Indian male population (table 2.3) and there was soft-rubber coating on the handle for a comfortable grip. The addition of roller ball caster unit at the bottom of the 3 supportive legs along with the provision of two hand manoeuvrability helps in smooth movement of the redesigned device on the floor-surface. The redesigned polishing device has the provision of attaching the handle on both right and left side of the frame as per the requirement of the hand-dominance of the workers. Redesigned handle of the device improved the wrist posture during the polishing activities as was evident from the postural score of the wrist from REBA score (table 4.5).

Following usability evaluation using System Usability Scale (SUS), it was observed that the average SUS score for the redesign floor polishing device was 86.8 which meant ‘excellent’ and ‘acceptable’ level of usability. This was a great improvement is SUS score in comparison to existing device with the average score of 13.45.

Thus, it could be stated that the hypothesis- 3: ‘Proper anthropometric and biomechanical compatibility of hand-held floor polishing device can significantly improve the usability of the device’ is accepted. It implies that designers/engineers should concentrate on anthropometric and biomechanical data during design of the hand-held vibrating tool/equipment/device.

5.4 Novelties (key contributions) of the present research

The research work promotes the existing knowledge of the vibration mitigation strategies in the applied domain of the floor polishing work where the use of the vibrating polishing device is a part of the regular working life. The key novelties of this research are pinpointed hereunder.

- **Contribution to knowledge-base**

Following the current research, adoption of awkward working posture, repetitive forceful movement, prolonged work duration, and improper working tool have been identified as some of the ergonomic stressors associated with the floor polishing work. As there was not single literature in the Indian context, which deals with the ergonomic risk factors, thereby occupational health issues and their corresponding remedial measures including ergonomic design intervention, the present research has addressed this identified research gap by design modification of the existing hand-held floor-polishing device used by construction workers. The present research has successfully demonstrated how high level of exposure to vibration (due to use of the hand-held polishing device) in the construction sector affect the occupational health of the polishing-workers and how ergonomic design intervention can be adopted for reduction of vibration generation and transmission to the human hand-arm system for reduced vibrational exposure and thereby ameliorating the ill-impact on occupational health.

The current research has not only identified the ergonomic stressors in the unorganized sector of construction work but also addressed the issue through systematic research and development of a redesigned polishing device with its subsequent field trial for assessing usability and acceptance by the targeted users.

- **Contribution to methodological perspective**

Systematic research methodology has been followed in the present research staring from literature review and field survey for establishing the research need and problem statement to finally come up with innovative product design for addressing the identified problems through design, development and field-testing. Current research has demonstrated how to identify ergonomic stressors during field surveys using questionnaires and direct/ indirect (photography and videography) observations. Both qualitative and quantitative research methodologies were adopted as per the requirement of data collection. Pre-designed questionnaire to identify the drudgery of the polishing workers and standard Nordic body parts discomfort mapping for identifying pain/ discomfort were used to understand the requirement of appropriate ergonomic interventions. The REBA for postural load evaluation, quantification of vibrational exposure using Human- Vibration meter, EMG for quantification of the requirement of muscular effort, and SUS for usability evaluation were applied during polishing activities by both existing and redesigned device to demonstrate the effectiveness of the redesigned device in comparison to existing ones.

The research methodology followed in the present research work might be the foremost of its kind as regards exploration from an occupational health perspective in floor polishing work in the construction sector in India. Researchers, Designers and Engineers involved in design, development and manufacturing of hand-held vibrating equipment/ machine/ device, may adopt a similar strategy to come up with innovative product design. Thus, the standardized methodology as described and adopted in the present research could serve as the research manual for future researchers.

The complete methodology (starting from problem identification to providing appropriate solution) used in the present research may be reproduced by emulating similar exploration in various occupational sectors in order to recognize occupation specific ergonomic stressors and suggest suitable solutions, specifically for workers of unorganized sectors.

- **Perspective of intervention strategies**

The current research has demonstrated how to come up with an appropriate ergonomic design solution against a given problem. The detailed methodology of product design innovation has been followed here. It involves user study and market study for design limits selection; generation of product concepts following brainstorming and using Morphological chart; screening of final concept using Pugh chart; mock-ups development, prototype development; and user trial and feedback from real field condition. The intervention strategies to address each of the identified problems such as (a) use of planetary gear mechanism (by replacing compound gear) to reduce jerk and vibration; (b)use of supportive structure and vibration dampening material towards diminishing vibration transmission to hand-arm of the workers; (c) provision for the vertical adjustment of the device to accommodate polishing stone of different thickness; (d) proper casing of the device to ensure electrical safety; (e) changing the dimension and design of the handle for anthropometric and biomechanical compatibility; (f) provision of attaching the handle on both left and right side of the device for facilitating as per workers hand dominance and operational requirement; (g) supportive frame with 3 legs on the ground to avoid sustained load holding by hands; and (h) use of roller ball caster unit at the bottom of the 3 supportive legs for the smooth movement of the redesigned device on the floor-surface.

- **Contribution to the society**

The current research has addressed the real-life problems of occupational exposure to vibration of the floor polishing workers in the unorganised sectors of construction work. Appropriate ergonomic design intervention to ameliorate the drudgery of the unprivileged construction workers has been depicted here. The developed design intervention was tested in real field conditions to demonstrate its usability and acceptance among construction workers. The design intervention significantly reduced exposure to vibration as well as reduced the muscular effort for polishing activities along with improved perceived comfort due to better anthropometric and biomechanical compatibility. It is expected that the mass manufacturing and implementation of the device for the polishing activities in the construction sector would be very beneficial towards the reduction of the drudgery of the unprivileged construction workers to a great extent.

5.5 Limitation of the present research

Despite of extensive and profound attempt to attain the best outcome out of it, there are consistently a few concerns beyond the capacity of the researcher, leading a few seatbacks in the outcome. The displeasing and inextinguishable restrictions of this section of research, which could be taken for further exploration as future scope of the research.

1. With the redesigned polishing device is feasible to conduct polishing activities in horizontal surface. In future research intervention strategies for polishing in vertical surface can be explored.
2. The amount spent in fabricating the first concept prototype is much higher (Rs 15,442 approx.) than the existing floor-polishing device (Rs 4800 approx.). Once the design is optimized and fabricated in mass scale, the market price of the new machine will be reduced to a great extent.
3. The entire study involved male participants only, as they are the predominant user; yet evolution could be extended for female users also.
4. Muscular effort was studied for the polishing activities in terms of %MVC but impact on muscular fatigue was not studied separately.
5. Rubber coating was used as vibration dampening material. Effectiveness of other dampening materials could have been explored.
6. Effectiveness of the redesigned polishing device could have been studied in terms of other physiological variables like HR, EE etc.
7. The present thesis work was carried out in the city of Guwahati, which is one of the largest city of north-east India having high number of construction activities recent ties for the initiation of smart-city project by Government of India. To achieve the aim of the present thesis work and to test the formulated hypotheses, Guwahati city was selected as the locale of the study. It is possible to extend similar research in other parts of the country to understand the ground level scenario of sufferings of the construction workers working with vibration tool/ device in India.

5.6 Conclusion

In the unorganized sectors of construction activities, one important work is polishing of the floor/ stone using hand-held polishing device which is generally a modified drill-machine. Repetitive and prolonged use of hand-held vibrating polishing devices is an integral part of the daily lives of the workers engaged in construction sectors in India and other developing countries. The adoption of awkward working posture, repetitive forceful movement, prolonged work duration, and improper design of the polishing device are some of the prominent ergonomic stressors associated with the floor polishing work. There is not single literature, which deals with the ergonomic risk factors in floor-polishing activities, associated occupational health issues and their corresponding remedial measures including ergonomic design interventions. Thus, the present research has addressed a very noticeable research gap and has come up with an innovative design solutions to reduce the drudgery of the unprivileged workers engaged in floor-polishing activities in construction sectors.

Following appropriate design interventions against the identified ergonomics design issues/ problems present in the existing design of the polishing device; effectiveness and usability of the redesigned device was compared with the existing device in terms of vibration generation and transmission (using Human-Vibration Meter), wrist posture sustained load holding, ease of manoeuvrability, anthropometric compatibility and proper griping, requirement of muscular effort for polishing activities (using EMG analysis), and overall usability of the device (using SUS technique). It was observed that the redesigned floor-polishing device was superior than the existing one for all the aforesaid evaluation parameters.

The research work notably imparted to the existing knowledge base of occupational health evaluation in the context of the industrially developing countries like India in the field of occupational vibrations in construction sectors. Current research also demonstrated innovative design intervention as a mitigation strategy to the adverse impact of ergonomic stressors on workers’ health. The Research outcome of the thesis could be able to ameliorate the vibration exposure of the workers during the use of the vibrating device (the hand held floor polishing device) and this would also facilitate the improvement in quality and efficiency of the system as well as the life of the polishing workers in the unorganised construction sectors.

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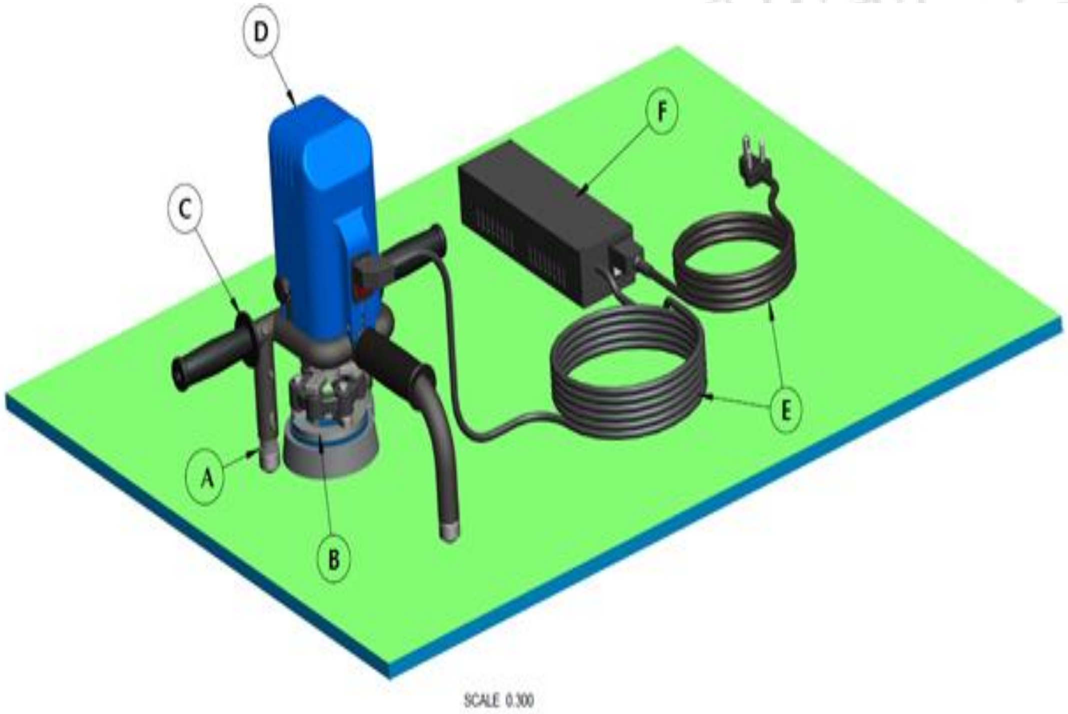
7. Appendix

7.1 Appendix A/Fig A: Full Assembly of the Polishing Machine

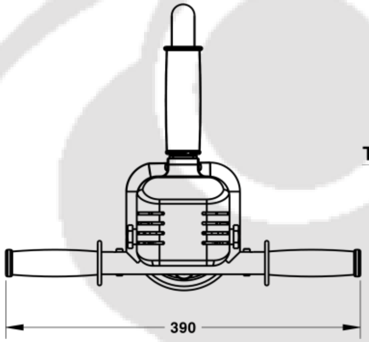


PART NO.	DESCRIPTION	QTY	MATERIAL
A	Ball caster and mounting unit	2	Steel
B	Motor and stone assembly	1	C. Iron
C	Main support frame and accessories	1	Steel tube
D	Plastic cover and accessories	1	Steel
E	Power supply cables	2	Insulated
F	Power supply unit with cover	1	Steel

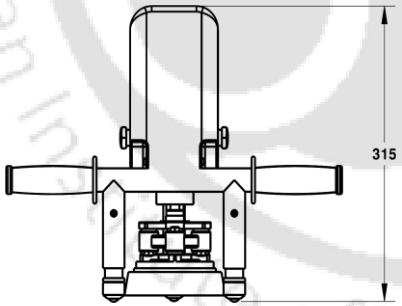
Scale- 1:1	All Dimensions are in Milimeter (mm)		
Sheet No.	Part No.	Date	
1	-	02/09/2018	
Departmant of Design, IIT GUWAHATI			Size: A3

Appendix A/Fig B: Assembly of Machine Components

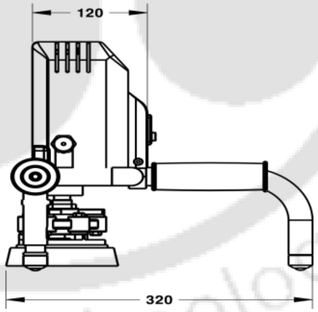
Isometric Views



Top View



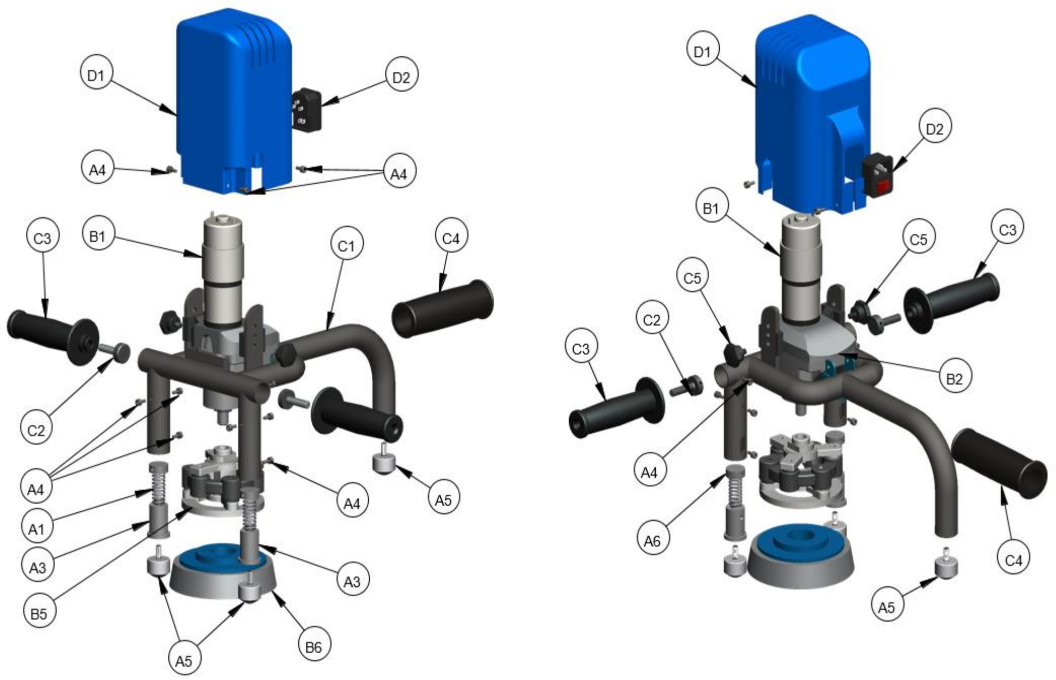
Front View



Side View

Scale- 1:4	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
2	SUB-ASM	02/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

Appendix A/Fig B-1: Exploded View of Machine Frame and Components

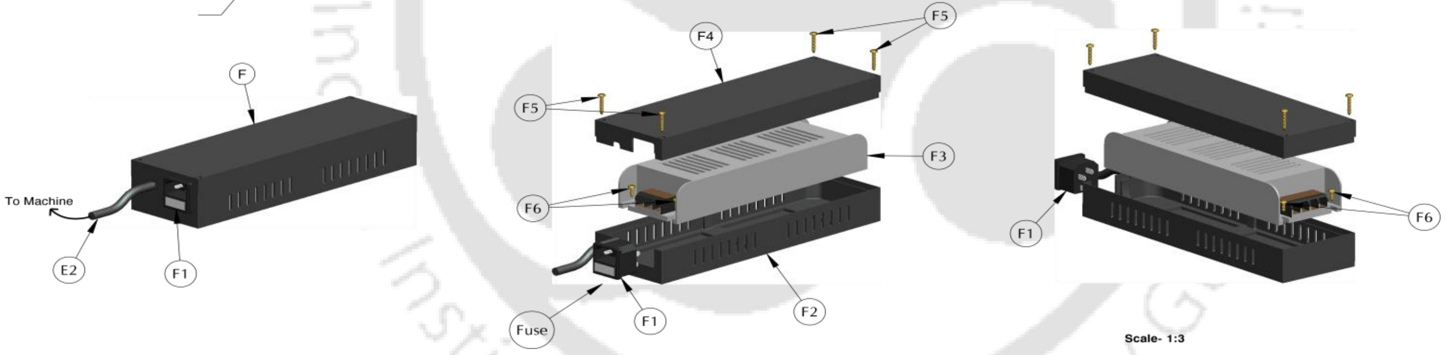


PART NO.	DESCRIPTION	QTY	MATERIAL
A1	Compression spring	2	Steel
A3	Ball Caster Mounting	2	Steel
A4	Allen Bolt-M4x8mm	8	Steel
A5	Ball Caster Unit	3	Steel
A6	Stopper	2	Steel
B1	Planetary geared DC motor	1	Steel
B2	Motor assembly hub	1	C. Iron
B5	Self-aligning stone assembly coupling	1	AL/Rubber
B6	Polishing stone	1	Steel
C1	Main support frame	1	Steel
C2	Handel assembly screw	2	Steel
C3	Side handle	2	Plastic
C4	Rear Handle	1	Rubber
C5	Clamping bolt knobs	2	Plastic grip
D1	3D printed plastic cover	1	PLA
D2	IEC male socket with switch	1	Plastic

Scale- 1:4	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
3	SUB-ASM	10/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

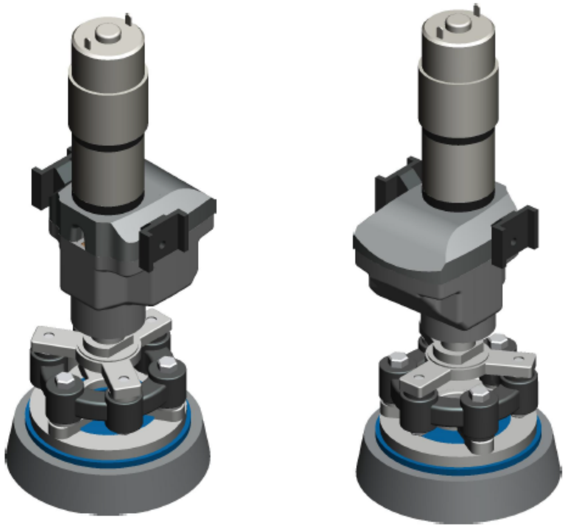
Appendix A/Fig B-2: Assembly of DC Power Supply Unit and Components

PART NO.	DESCRIPTION	QTY	MATERIAL
E1	IEC C13 female right angle 3 pin plug	1	Plastic
E2	Double core double insulated wire cable (Length = 5 meter)	1	Ins
E3	Double insulated 3 core power cord	1	Ins
E4	IEC Female Plug	1	Plastic
E5	3 Pin Power Plug	1	Plastic
F1	IEC male socket with fuse	1	Plastic
F2	Cover-Lower section	1	PLA
F3	DC Slim power supply unit	1	-
F4	Cover-Upper section	1	PLA
F5	Self taping screw-20mm	4	Brass
F6	Self tapping screw-10mm	4	Brass

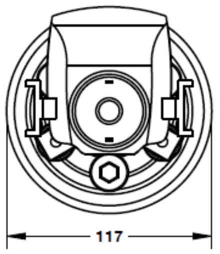


Scale- 1:3	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
4	SUB-ASM	10/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

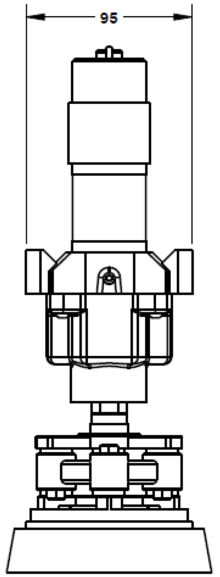
Appendix A/Fig B-3: Motor and Stone Mounting Sub-Assembly



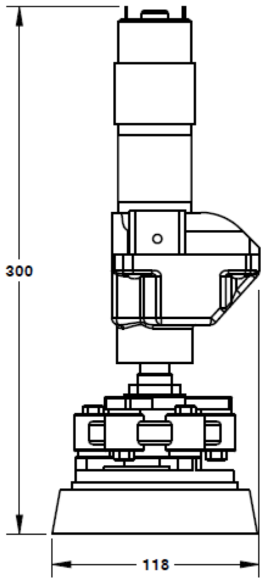
Isometric Views



Top View



Front View

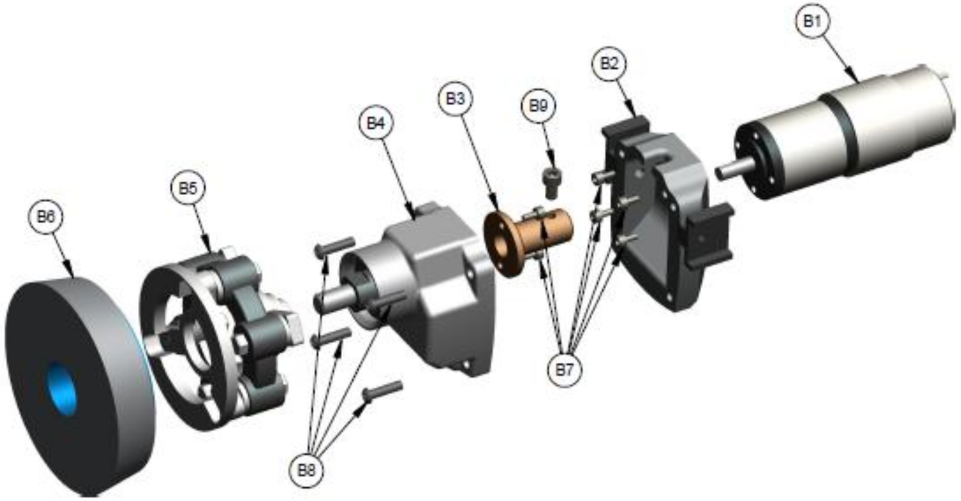


Side View

Scale- 1:2	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
5	SUB-ASM	10/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

Appendix A/Fig B-4: Exploded View of Motor and Stone Mounting Components-

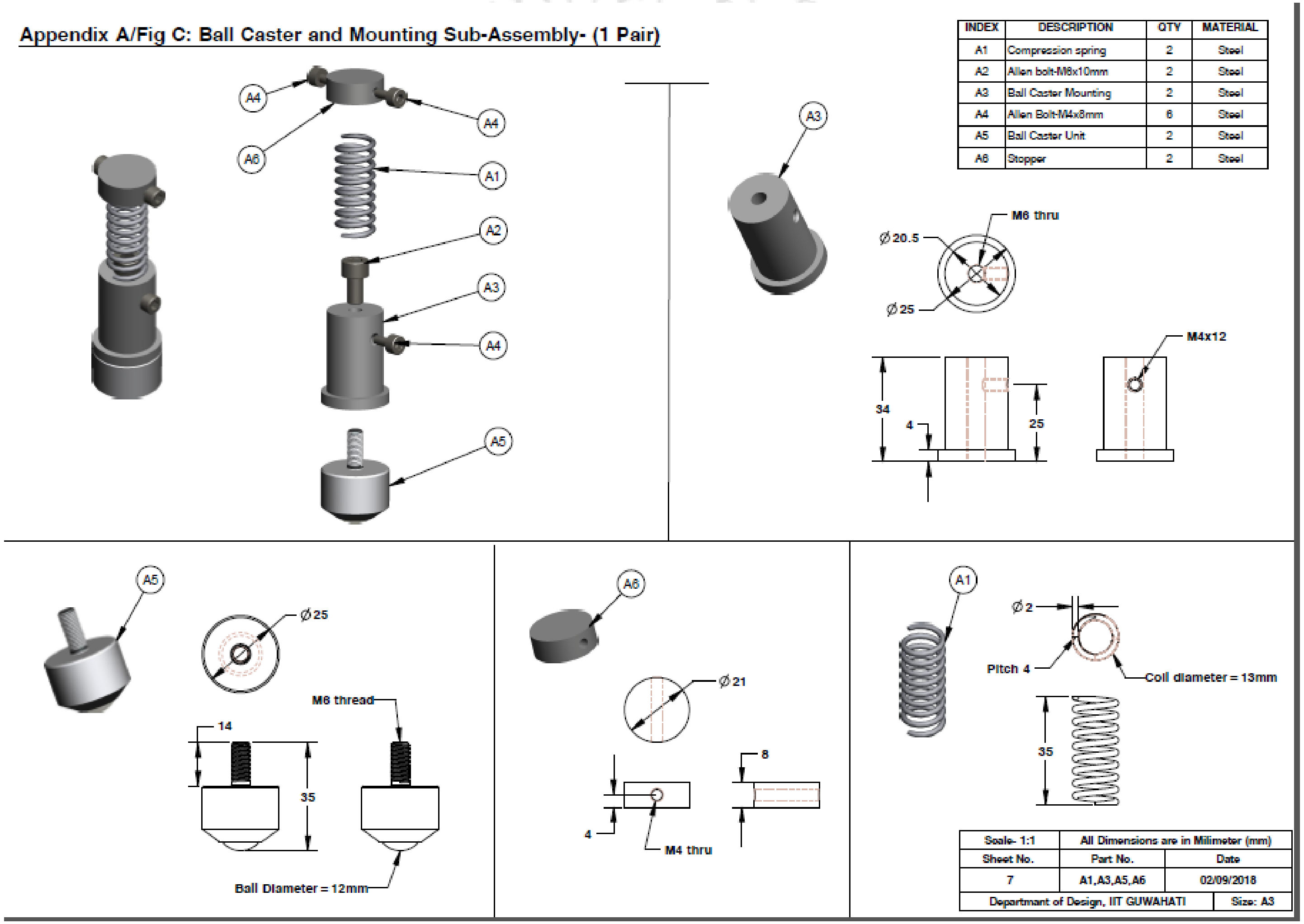
PART NO.	DESCRIPTION	QTY	MATERIAL
B1	Planetary geared DC motor	1	Steel
B2	Motor assembly hub	1	C. Iron
B3	Rigid flanged coupling	1	Steel
B4	Bearing hub	1	Steel
B5	Self-aligning stone assembly coupling	1	AL/Rubber
B6	Polishing stone	1	Steel
B7	Allen Bolts-M4x8mm	6	Steel
B8	Allen bolt buttonhead-M6x20mm	4	Steel
B9	Allen bolt-M6x10mm	1	Steel



Exploded View

Scale- 1:2	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
6	SUB-ASM	04/09/2018
Department of Design, IIT GUWAHATI		Size: A3

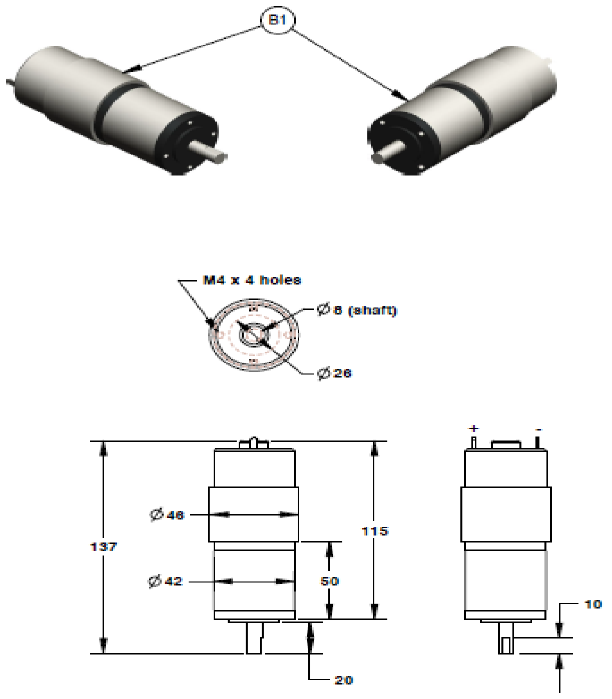
Appendix A/Fig C: Ball Caster and Mounting Sub-Assembly- (1 Pair)

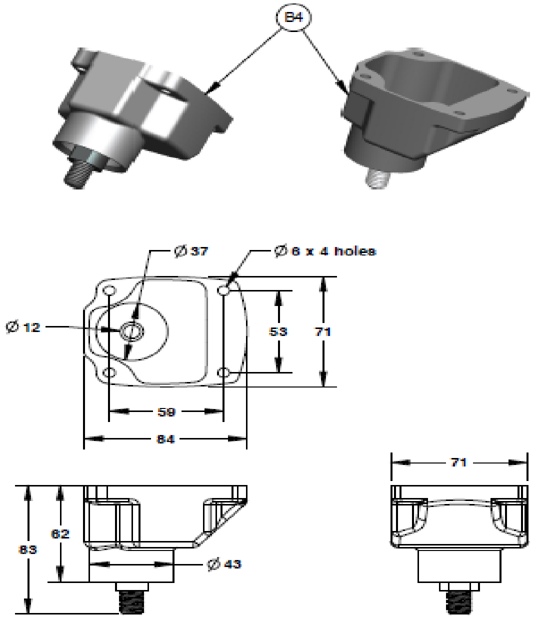


INDEX	DESCRIPTION	QTY	MATERIAL
A1	Compression spring	2	Steel
A2	Allen bolt-M6x10mm	2	Steel
A3	Ball Caster Mounting	2	Steel
A4	Allen Bolt-M4x8mm	6	Steel
A5	Ball Caster Unit	2	Steel
A6	Stopper	2	Steel

Scale- 1:1	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
7	A1,A3,A5,A6	02/09/2018
Department of Design, IIT GUWAHATI		Size: A3

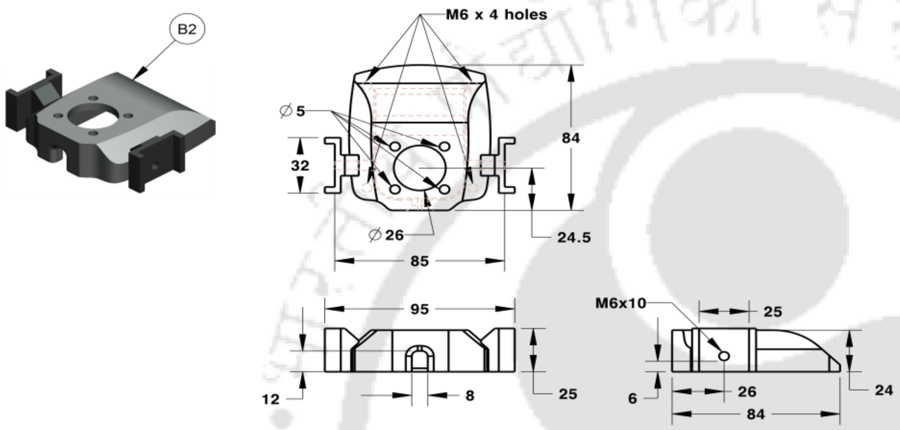
Appendix A/Fig D-1: DC Motor and Bearing Assembly Hub-

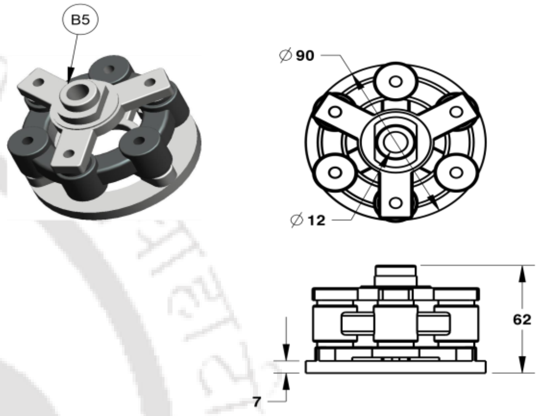


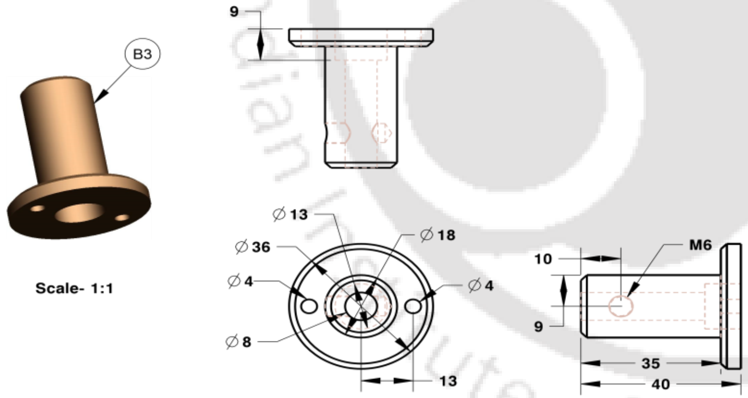


Scale- 1:2	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
8	B1, B4	10/09/2018
Department of Design, IIT GUWAHATI		Size: A3

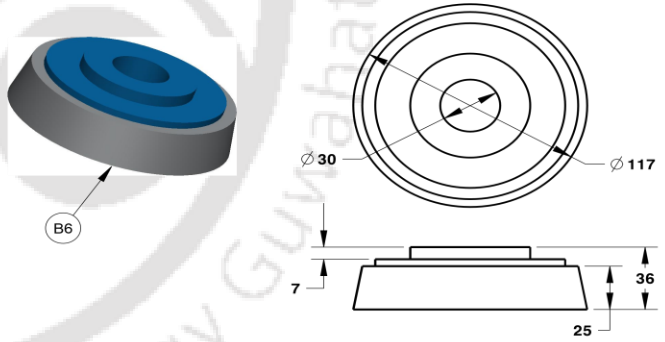
Appendix A/Fig D-2: Motor Assembly Block and Coupling-





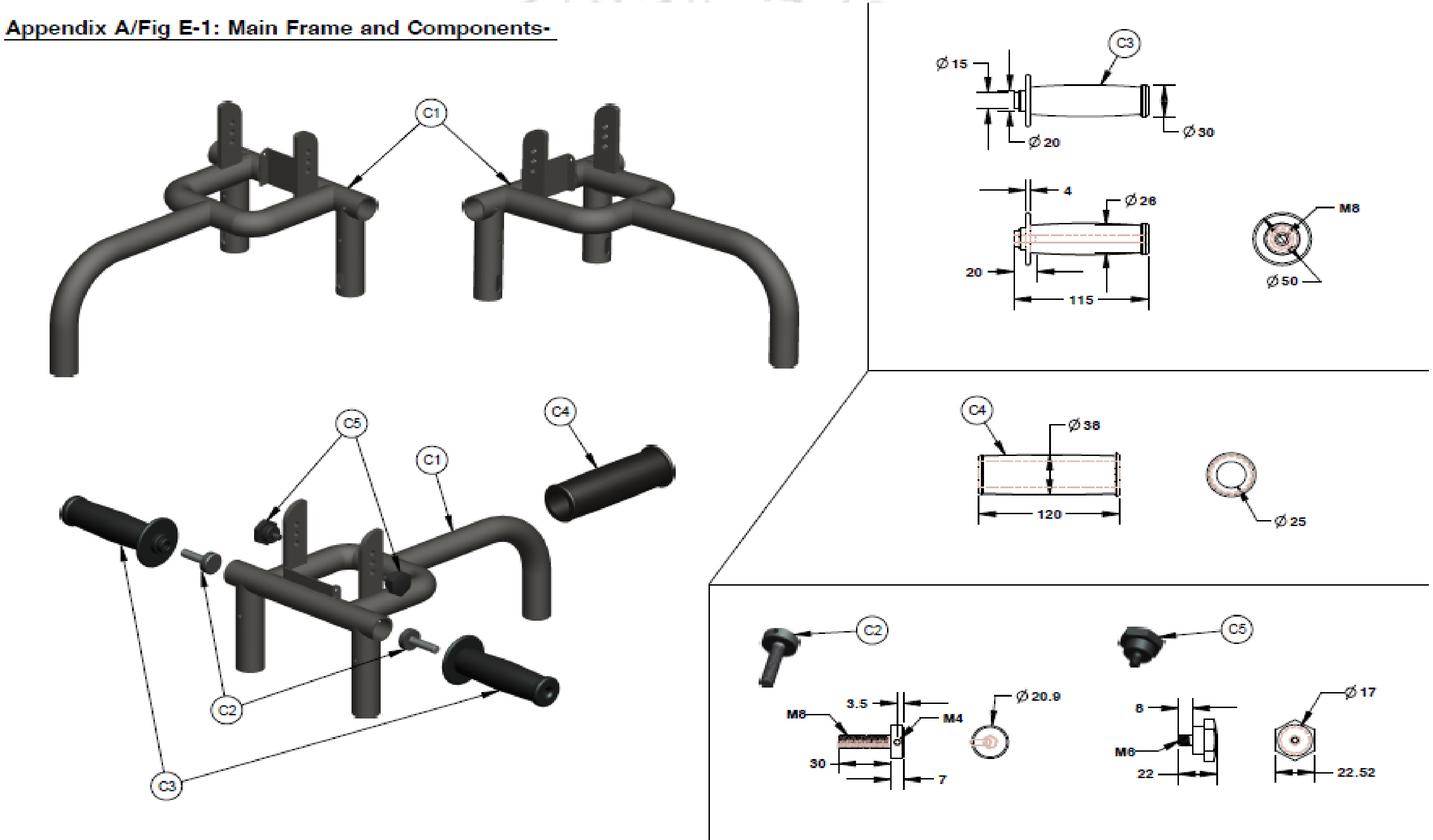


Scale- 1:1



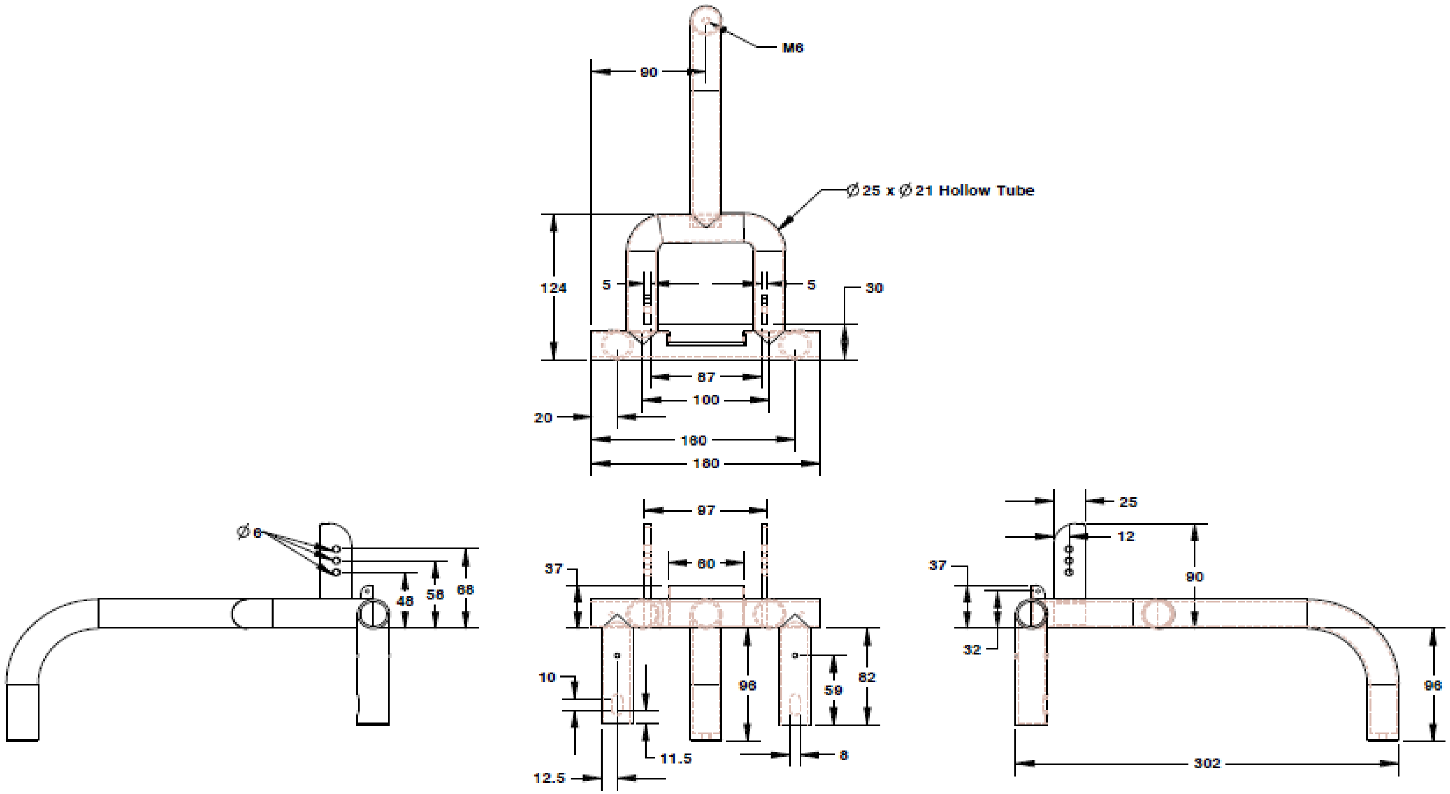
Scale- 1:2	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
9	B2, B3, B5, B6	10/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

Appendix A/Fig E-1: Main Frame and Components-



Scale- 1:1	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
10	C2, C3, C4, C5	10/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

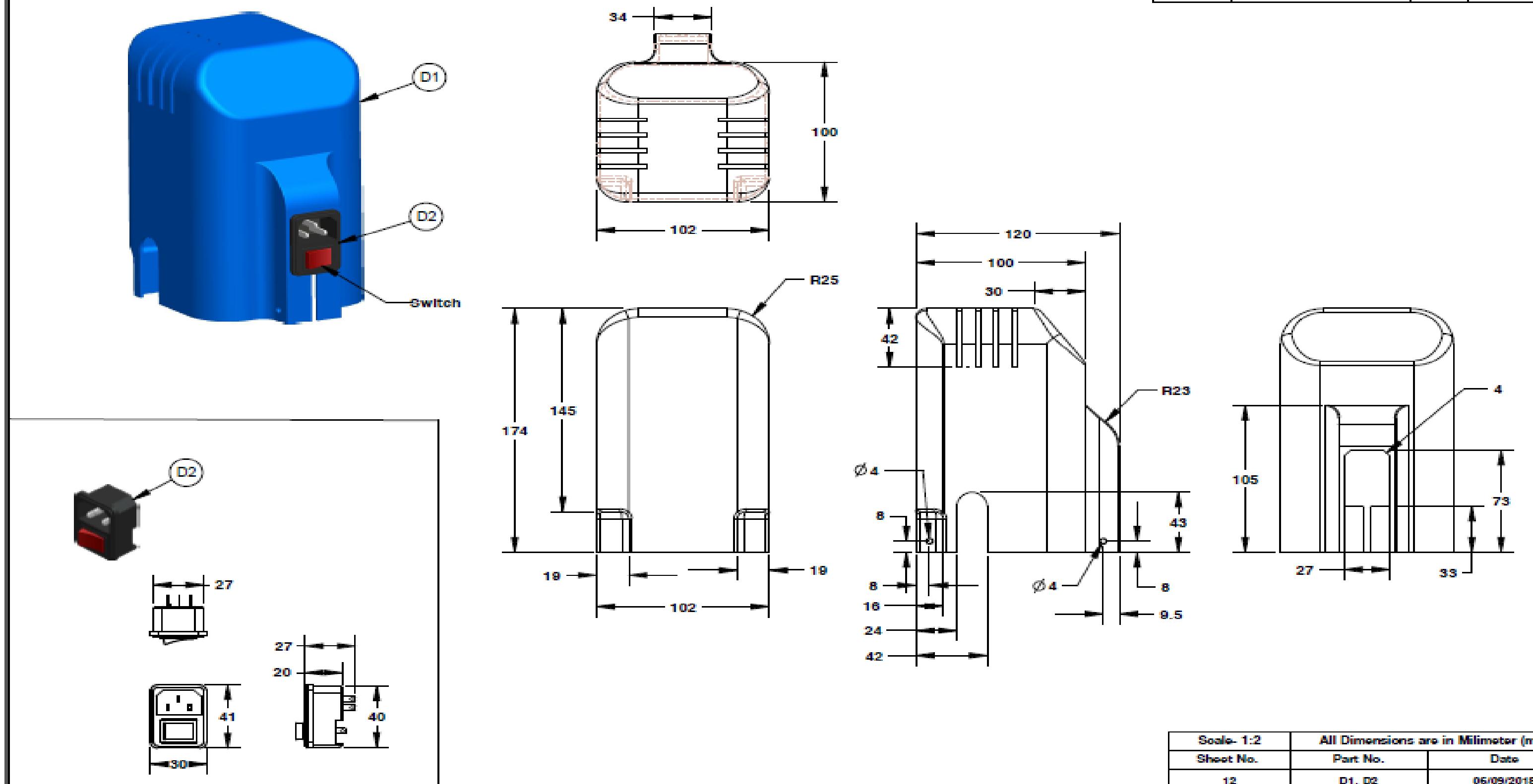
Appendix A/Fig E-2: Main Frame of Steel Tube-



Scale- 1:3	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
11	C1	10/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

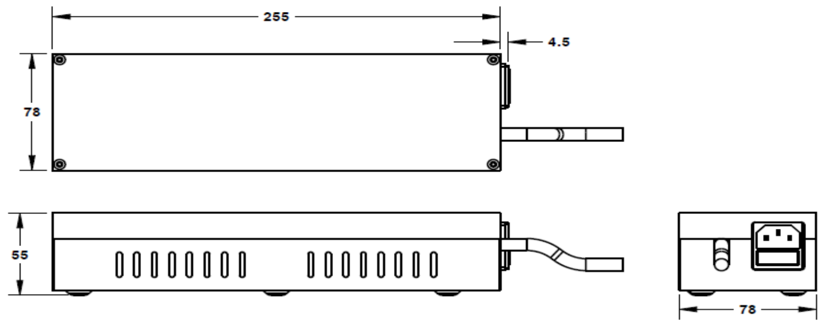
Appendix A/Fig F:Plastic Cover and Components-

PART NO.	DESCRIPTION	QTY	MATERIAL
D1	3D printed plastic cover	1	PLA
D2	C14 IEC male socket with rocker switch	1	Plastic

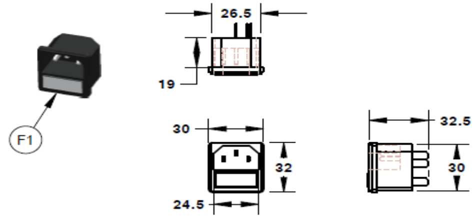


Scale- 1:2	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
12	D1, D2	06/09/2018
Department of Design, IIT GUWAHATI		Size: A3

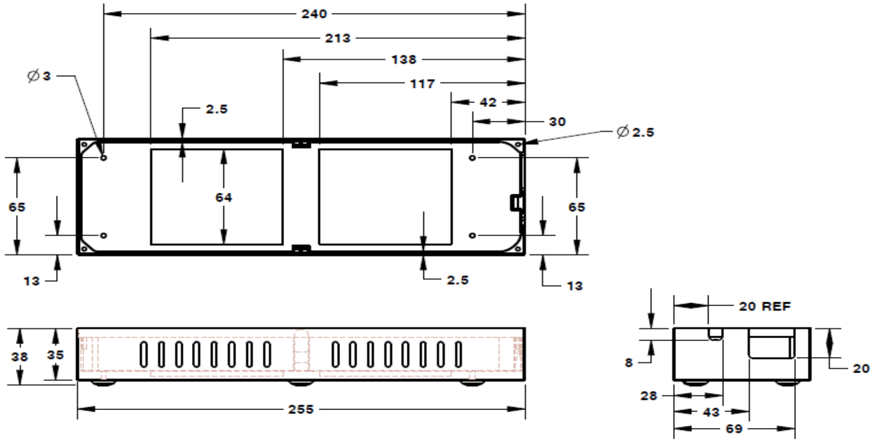
Appendix A/Fig G-1: DC Power Supply and Box:



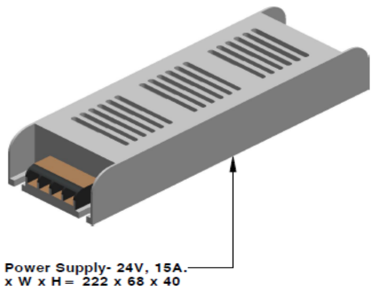
F1: IEC Male Socket with Fuse



F2: Cover-Lower Section

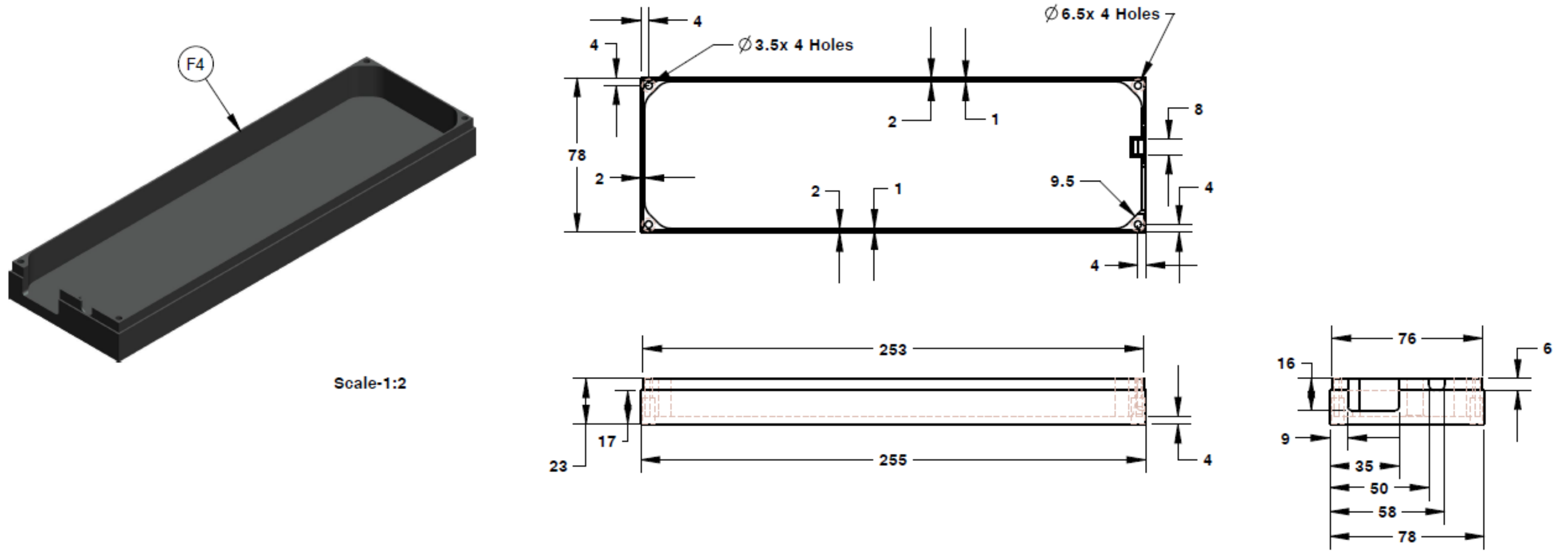


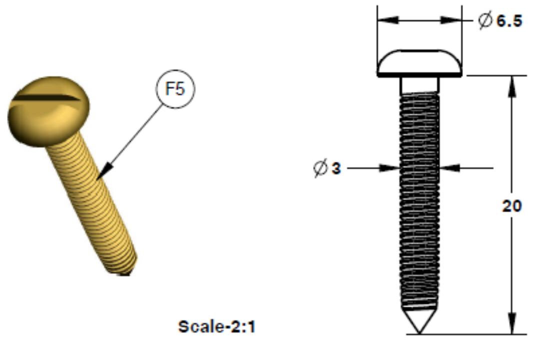
F3: Power Supply Unit

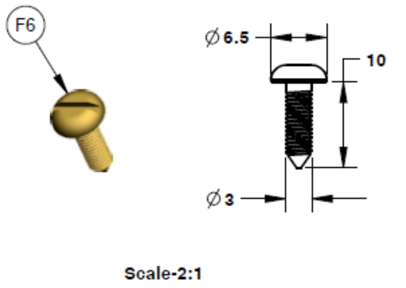


Scale- 1:2	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
13	F, F1, F2, F3	10/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

Appendix A/Fig G-2:Power Supply Unit with Cover







Scale-	All Dimensions are in Milimeter (mm)	
Sheet No.	Part No.	Date
14	F4, F5, F6	10/09/2018
Departmant of Design, IIT GUWAHATI		Size: A3

7.2 Appendix B

Adopted and modified from Nordic Questionnaire for Musculoskeletal sysmptotms (Kurnikova et al.,1986) and Medical in confidence health surveillance questionnaire assessment of hand-arm vibration syndrome.

Section 1: Personal and General Information

Name: Age (Sex):

Address:

Ethnicity: Education: Family Work History:

Height (cm): Weight (kg): BMI (kg/m^2):

Habits: Smoking Tobacco Drink Others

Physical Exercise (non-job):

Section 2: Work environment information

---

1. **How long have you been employed at your present job?**

   (1) 2 years (2) 5 years (3) 6 years (4) 9 years (5) more than 9 years

2. **Duration of working hours in a day.**

   (1) 4 hours (2) 5 hours (3) 6 hours (4) 7 hours (5) 8 hours

3. **Number of working days in a week.**

   (1) 3 days (2) 4 days (3) 5 days (4) 6 days (5) 7 days

4. **Total breaks taken during the working hours in a day.**

   (1) none (2) one (3) two (4) three (5) four

5. **Overall duration of breaks taken in a day.**

   (1) one hour (2) two hour (3) three hours (4) 4 hours

6. **What do you do during your breaks?**

   (1) walk around (2) sit (3) stand (4) sleep (5) do other thing

Section 3: Personal medical history

Please choose the scale that is most closely applicable for each statement for the body parts.

1. **Any trouble (ache, pain, discomfort) in the following body parts during the last 12 months and 7 days caused by your floor polishing work.**

Body Parts	(5) extremely		(4) quite a bit		(3) moderately		(2) a little		(1) not at all	
Neck										
Shoulder										
Wrists/Hand										
Elbow										
Ankles/Feet										
Knee										

2. **If there is pain, then to what degree your pain interfered with your work and your life outside of work during the last 12 months and 7 days.**

Body Parts	(5) to a very large extent		(4) to a large extent		(3) somewhat		(2) to a small extent		(1) to a very small extent	
Neck										
Shoulder										
Wrists/Hand										
Elbow										
Ankles/Feet										
Knee										

1. **During the last 12 months and 7 days how long, does the pain continue when it occurs?**

Body Parts	(5) every day		(4) more than 30 days, but not every day		(3) 8-30 days		(2) 1-7 days		(1) 0 days	
Neck										
Shoulder										
Wrists/Hand										
Elbow										
Ankles/Feet										
Knee										

Section 4: Vibration Discomfort

1. **Vibration discomfort felt during floor polishing work.**

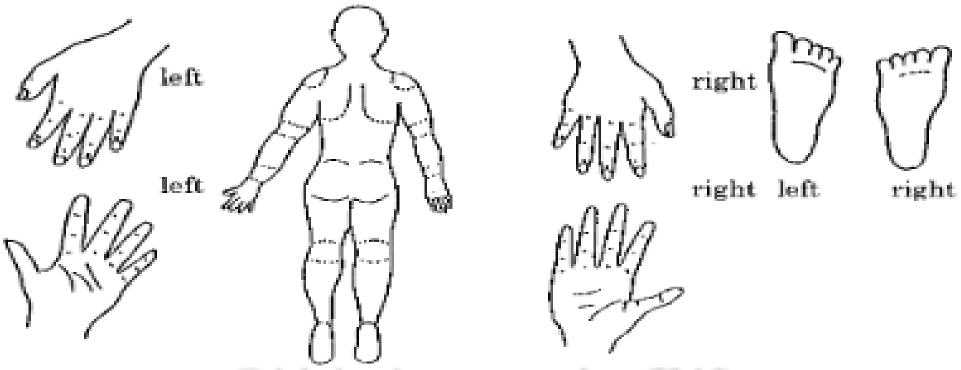
(5) extreme (4) high (3) moderate (2) low (1) not at all

2. **Have you at any time had numbness, tingling or dullness in the fingers, palms or feet while working with the floor-polishing device?**

(2) yes (1) no

If yes, please answer the following questions.

i. Please fill in the area in the part of your body in which you have had numbness.



When has it had occurred? (..........years ago)

ii. In which season does it often occur?

1) spring 2) summer 3) winter 4) any time

iii. How long does it continue in the season when it often occurs?

1) every day 2) several times a week 3) several times a month 4) several times a year

iv. What is the present condition of the numbness, tingling or dullness in the fingers, palms or feet. Is it severer than before?

1)severer than before 2) better than before 3) no change

v. Are you experiencing any pain with the muscles and joints of your hands or arms?

(5) extreme (4) high (3) moderate (2) low (1) not at all

vi. Are you experiencing any swelling of the muscles and joints of your hands or arms?

(5) extreme (4) high (3) moderate (2) low (1) not at all

vii. Are you experiencing any stiffness with the muscles and joints of your hands or arms?

(5) extreme (4) high (3) moderate (2) low (1) not at all

ix. Are you suffering with weakness of grip?

(5) extreme (4) high (3) moderate (2) low (1) not at all

x. Do you have any problems with fine movements and dexterity of your fingers at room temperature?

(5) extreme (4) high (3) moderate (2) low (1) not at all

xi. Have you ever suffered your fingers going white on cold exposure?

(5) extreme (4) high (3) moderate (2) low (1) not at all

Section 5: Medical Treatment

1. **Visit to a physician for any pain or trauma**

   2) yes (1) no

2. **Kind of treatment doctor prescribed**

treatment	**Yes (2)**	**No (1)**
surgery		
injection		
physical therapy		
medicines		
other		

3. **Any of the following illness as told by a physician?**

   i. Rupture
   ii. Digestive disorder (specific stomach complaints, gastritis stomach, ulcer, intestinal complain)
   iii. Circulatory problems (haemorrhoids, heart complains)
   iv. Raynaud's phenomenon
   v. urinary disorders (prostatitis, renal disorders)
   vi. Vestibular disturbances (dizziness)

4. **Was it better, after the treatment?**

   a) Better b) No change c) Worse

Section 6: Work assessment on psychosocial factors

1. **How stressful do you find your work?**

   (5) extreme (4) high (3) medium (2) low (1) not at all

2. **Job involves a great deal of responsibility**

   (5) to a very large extent (4) to a large extent (3) somewhat (2) to a small extent

   (1) to a very small extent

3. **Satisfaction from job**

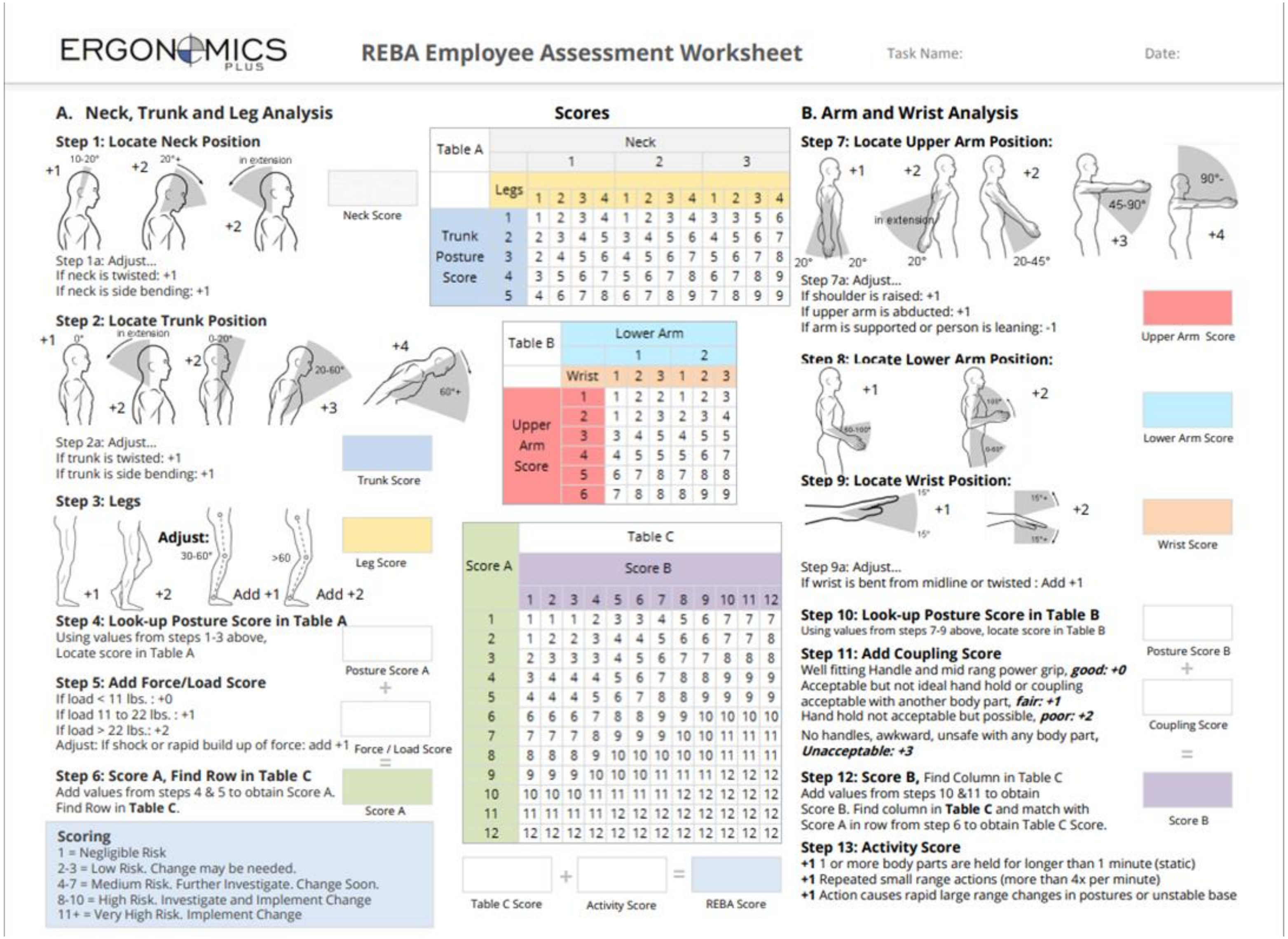
   (5) to a very large extent (4) to a large extent (3) somewhat (2) to a small extent

   (1) to a very small extent

7.3 Appendix C

Rapid Entire Body Assessment

(based on Technical note: Rapid Entire Body Assessment (REBA), hignett, McAtamney, Applied Ergonomics 31 (2000)201-205; Provided by practical Ergonomics, rbarker@ergosmart.com (816) 44-1667)



REBA Employee Assessment Worksheet

Task Name:

Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 2: Locate Trunk Position

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

Adjust:

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A

+

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score

=

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Score A	Table C											
	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

Lower Arm Score

Step 9: Locate Wrist Position:

Wrist Score

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B

+

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score

=

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

7.4 Appendix D

System Usability Scale (SUS)

Sr.No.	System Usability Scale questions	Ratings				
		Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1.	I think that I would like to use this product frequently.					
2.	I found the product unnecessarily complex.					
3.	I thought the product was easy to use.					
4.	I think that I would need the support of a technical person to be able to use this product.					
5.	I found the various functions in the Product very well integrated.					
6.	I thought there was too much inconsistency in the Product.					
7.	I would imagine that most people would learn to use the Product very quickly.					
8.	I found the Product very cumbersome to use.					
9.	I felt very confident using the Product.					
10.	I need to learn many things before I could get going with this Product.					

7.5 Appendix E

Publications

1. Nath, S., Verma, I., Tiwari, R., Karmakar, S.,2016.Impact of vibration and design intervention strategies adopted in Indian informal sectors. In Proceedings of International Ergonomics Conference (HWWE: December, 8-11), National Institute of Technology Jalandhar, Punjab, India, (p. 53-56), ISBN: 978-83006-81-6.
2. Nath, S., Kalita, T., Chatterjee, A., Tiwari, R. Karmakar, S., 2017. Occupation imposed postural discomfort among the stone polishing workers from Guwahati, Assam: A systematic ergonomic evaluation. The Japanese Journal of Ergonomics, Vol. 53 (Supplement-2 p. S438-S441. [http://doi.org/10.5100/jje.53.S438]
3. Nath, S., Kalita, T., Chatterjee, A., Tiwari, R. Karmakar, S., 2017. Occurrence of musculoskeletal disorders among the stone polishing workers of Guwahati (India). International Ergonomics Conference (HWWE: December 8-11), Aligarh Muslim University, Aligarh, India.
4. Nath, S., Kalita, A., Tiwari, R. Karmakar, S., 2018. Ergonomic design intervention to ameliorate exposure to vibration during use of hand-held vibrating tool for stone-polishing activities in unorganised sector. Occupational and Environment Medicine,75, A518-A519.
5. Verma, I., Nath, S. and Karmakar, S., 2018. Research in Driver-Vehicle Interaction: Indian Scenario. In: Ergonomics in Caring for People, (p. 353-361), ISBN 978-981-10-4980-4[Springer, Singapore].
6. Nath, S., Kalita, T., Arunachalam, M., Tiwari, R. Karmakar, S., 2019. Association Between Adopted Posture and Perceived Vibrational Discomfort Among Stone Polishing Workers. In Research into Design for a Connected World (pp. 549-561). Springer, Singapore
7. Nath, S., Tiwari, R., Karmakar, S., 2020. Prevalence of Musculoskeletal Disorders among stone polishing workers using Stone Polishing Device in unorganized sector of Guwahati (India), International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol- 9(5), 2278-3075.