

Design Intervention for Mechanisation of Tealeaf Harvesting to Improve Productivity and Efficiency

(A case study of an improved harvesting device in the context of Assam, India)

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

Doctor of Philosophy

by

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Indian Institute of Technology Guwahati

Guwahati - 781039, INDIA

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Under the Supervision of
Prof. Amarendra Kumar Das



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April 2017

DECLARATION

I hereby declare that the work contained in this thesis entitled “**Improve productivity & efficiency of tea plucking process through design intervention: A case study for an improved plucking device for tea gardens of Assam, India**” is my own work done under the supervision of Professor Amarendra Kumar Das, at the Department of Design, Indian Institute of Technology Guwahati (IITG), Assam. I hereby declare that to the best of my knowledge, it contains no materials previously published or written by another person, or a substantial proportion of material which have been accepted for the award of any other degree or diploma at IITG or any other educational institute, except where the due acknowledgement is made in this thesis. Any contribution made to the research made by others, with whom I have worked at IITG or elsewhere, is explicitly acknowledged in the thesis. I also hereby declare that the intellectual content of this thesis is the product of my own work, and as per general norms of reporting research findings, due acknowledgements have been made wherever the research findings of other researchers have been cited in this thesis.

Place: Guwahati

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Vikramjit Kakati
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CERTIFICATE

This is to certify that the work contained in this thesis entitled “**Design Intervention for Mechanisation of Tealeaf Harvesting to Improve Productivity and Efficiency (A case study of an improved harvesting device in the context of Assam, India)**” submitted by Mr. Vikramjit Kakati to the Indian Institute of Technology Guwahati, for the award of the degree of Doctor of Philosophy has been carried out under my supervision. This work has not been submitted elsewhere for the award of any other degree or diploma.

Place: Guwahati

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Dedication

I would like to dedicate this thesis to my wife, Dr. Bobby Sharma Kakati, Mr. Shajumon M.S, Jr. Technical Officer, and Mr. Haren Das, Technician, Department of Design, IIT Guwahati.

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Place: Guwahati

Date: 19th April 2017

Vikramjit Kakati



Abstract

The Indian tea industry is one of the major foreign revenue earners for the country. It is one of the major employers of women. Many of the activities, especially the tea-leaf plucking activity (constituting 40 percent of the total cost of production of tea leaves) performed by the women workers.

The tea industries of Assam, in are facing revenue losses during recent times. One of the main factors is shortage of workforce engaged in field operations. Studies have shown that acute shortage of workforce takes place in the tea plucking activities during peak season due to various socio-economic reasons. Due to the manpower shortage, a considerable quantity of available tea leaves for tea making remains unplucked. This directly affects the overall production of made tea and hence on the revenue earnings by the tea gardens. In this scenario, the only suitable solution to the problem appears to be the adaptation of mechanised harvesting.

The purpose of this research is to formulate a solution for mechanised harvesting which should be economical and suitable for tea gardens of Assam. To accomplish the stated purpose; a combination of research methods featuring literature survey, questionnaire, direct observation, one to one interview for data collection; statistical analysis of the gathered data, work study technique, virtual human modelling and simulation, prototype development and testing has been used.

After gathering necessary information, it was felt that for tea gardens of Assam, a single operator handheld battery-powered rotary type tea harvesting machine with high productivity in comparison to presently available machines with a similar mode of operation will be the best solution.

The prototype of the proposed machine was developed at Department of Design, IIT Guwahati and field trials were carried out at Dolaguri Tea Estate located in Numoligarh, Assam with a participatory approach. Through these field trials, it was found that the newly designed machine was efficient and had higher productivity compared to hand plucking.

While the field trials were carried out, it was also found that the machine was safe for operation from the point of view of safety, user-friendly and design was thus efficient.

Keywords: Product design, tea-harvesting, agricultural engineering, tea plucking,



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Abbreviations used in this thesis

AASTGA	All Assam Small Tea Growers' Association
Ah	Ampere hour
CFM	Continuous Fermenting Machine
CTC	Cut, Tear, Curl processing
d.c.	Direct Current
GPF	General Provident Fund
HDPE	High-density polyethylene
ILO	International Labour Organisation
LOS	Level Off Skiff
LP	Light Prune
LS	Light Skiff
kg	Kilogram
m	Meter
m ²	Square Meter
mAh	Mille ampere hour
NBPDM	Nordic Body Parts Discomfort Mapping
PSCC	Parliamentary Standing Committee on Commerce
r/min	Revolution Per Minute
s	Second
SGDD	Small Growers' Development Directorate
STG	Small Tea Growers
TBI	Tea Board of India
TF	Theaflavin
TR	Thearubigin
TRA	Tea Research Association
TRI	Tea Research Institute
UP	Unpruned
V	Volt
YTD	Young Tea Doge

Chapter 1 Tea Industry in Assam: Present Context

Tea is a widely consumed drink in the world as a beverage. Tea originated in China and later on the British popularised it in most of the European & Asian countries (Dutta A. K., 1992). Tradition ascribes the discovery of tea to Chinese people. The word tea is derived from 'The' - in Amoy language. Since 2000 years ago the use of tea was known (Mary & Heiss, 2007) to the Chinese. In the beginning, tea was used for medicinal purpose in China. Moreover, the natives of Tibet, Burma, and Assam were using tea for centuries. People during that time used tea to neutralise depression, headache, eye pain, joint pains, and several other pains of the same nature (Willson & Clifford, 1992).

Health benefits of tea - Tea is having antioxidant properties. This helps to neutralise the oxidising elements present in human body. Due to presence of polyphenols in tea, it is claimed that consuming tea in regular manner helps to prevent specific types of cancer by inducing Phase-I and Phase-II metabolic enzymes which increases the formation and excretion of detoxified metabolites of carcinogens (Sharma et al., 2007).

Dutch Merchants introduced tea to Europe during the early part of the 17th Century. Garraway's Coffee House in London first publicly served tea in 1657, and it became one of the popular drinks in England. Import of tea from China by the British East India Company began in 1689. By 1700, tea had become one of the great non-alcoholic drinks in several countries (Willson & Clifford, 1992).

For next few decades, tea was imported from China to various European markets.

1.1 The Indian tea plantations

The history of tea cultivation in India is quite old. In India, cultivation of tea was meant for consuming it as a stimulating beverage and as well as an ingredient in the traditional system of medicine (Tea Board, 2013). The commercial production of tea in India began with the arrival of the East India Company in Assam. Presently, tea is a major beverage and India along with China is the highest producer of tea. A major portion of tea (around 82%) produced in India is consumed locally (Tea Board, 2016).

The higher demand for tea in Britain and the unsteady trade relations between China and Great Britain were two major reasons for Britain's initiatives to establish a steady tea business in India. During 1780 A.D., the trade relation between Great Britain and China weakened and due to these reason initiatives were taken to find out alternative

sources for tea and this led to the discovery of tea plants in India. Britain started to concentrate towards British India for the cultivation of tea on a commercial basis (Baildon, 1881).

After 1850 the quantities of tea export from China beginning to fall mainly due to emerging tea plantations in the Indian state of Assam. In the year 1887, Britain imported more tea from Sri Lanka & India than China (Willson & Clifford, 1992).

Table 1.1: UK Import of tea from 1883 to 1889 (Source: Willson K.C 1992)

Year	UK imports of China Tea (kg)	UK imports of Indian Tea (kg)	UK imports of Ceylon Tea (kg)
1883	50702514	26308336	453592
1884	50277498	28221133	907184
1885	51489042	29791015	1459205
1886	47276080	31034765	2832682
1887	41053705	37698938	4509158
1888	36583556	39104166	8415492
1889	27714471	43544832	12927372

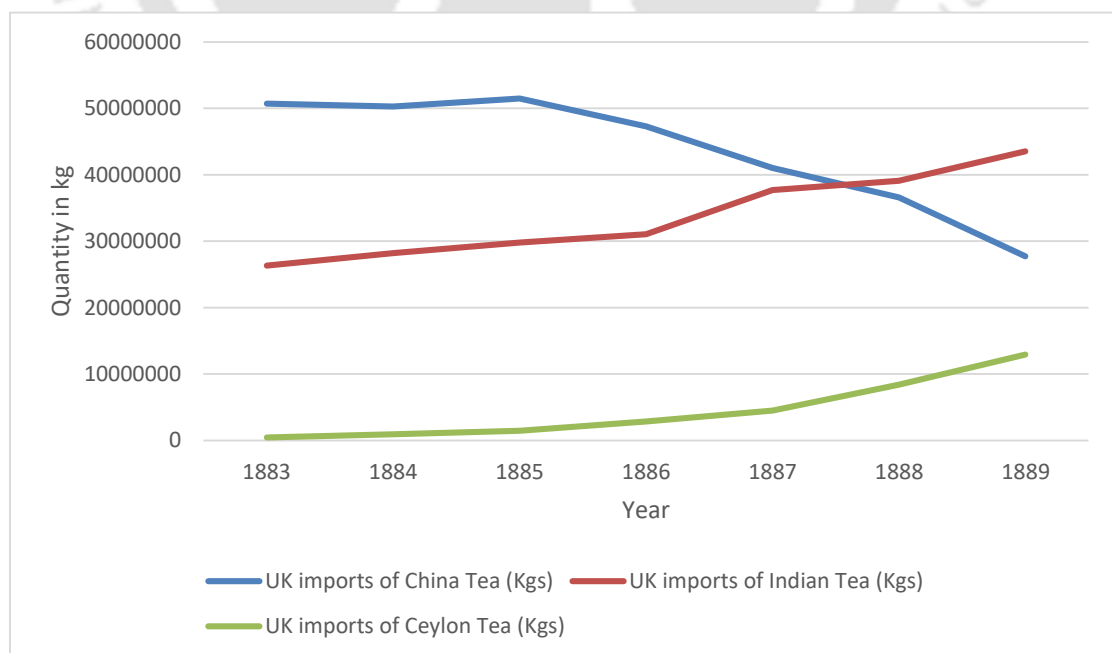


Fig. 1.1: United Kingdom's import of tea from 1883 to 1889. (Source: Willson K.C 1992)

The tea industry in India is one of the most efficiently organised agricultural enterprises (Arya, 2013). The credit for the growth in tea industry goes to the entrepreneurs from the Great Britain, who invested a huge capital during the initial days of the plantation. After the Yandabo Treaty in 1826, King of Ava (now in Myanmar) handed over Assam to the British and thus the latter gained absolute control over entire Assam (Dutta A. K., 1992). This treaty provided incentives to the British traders for expanding their area under tea cultivation as they acquired government lands in favourable term and after losing legal monopoly of the tea trade between Britain and China in 1833, the then British East India Company began looking for another origin of supply in the newly conquered regions. Upper Assam was selected as the preferred region for tea cultivation because, in the early 19th century, tea was first discovered growing in the wild in many places around the Brahmaputra valley.

In 1836, the first experimental tea cultivation in Assam began, and for the first time in 1839, tea from Assam was sent to London Auction, which received very positive feedback (Akhtar, 1939). Thus, this was the beginning of the tea industry of Assam. In tea plantation, the regulations placed into observing by the then colonial rulers (British) were extraordinarily favourable for the European entrepreneurs. Due to the lack of knowledge of tea cultivation and dealing capital, local entrepreneurs have shown very little interest and initiatives in tea cultivation throughout the initial days. Even entrepreneurs have shown very little interest and initiatives in tea cultivation throughout the initial days. Even after the independence, the situation was somewhat same as British firms were confiscated by the non-public organisations from the mainland of India. Therefore, it is rightly aforementioned that “the plantation sector in Assam thieved on alien interest, employed capital, labourers from outside the region and catered to the needs of external market” (Borah, 2013). From the uncertain starting, tea industry of Assam, as per the year 2014 -15 data Assam is having 307.08 hectares of land under tea plantation with a total production of 606.8 million kg (Tea Board, 2016). India is the second largest producer of tea in the world (1197 Million kg in 2014-15) and fourth in global export (Tea Board, 2016). Tea (chai) has become a common beverage of India, and it consumes around 82 % of her total production. It is one among the oldest organised industries in India and one among the largest employment generator in the organised sector. Over 12, 00,000 permanent and virtually the same numbers of casual and seasonal staff area unit utilised by the tea industry (Gothoskar,

2012). The growth of this industry in India has helped to develop regional economy and infrastructure of the many backward regions like Assam.

The British played the leading role in rearranging the export oriented agriculture in the first half of the nineteenth century. Britishers were responsible for the creation of a replacement, colonial order re-shaping the state, and society in such a way that the most English agriculturist could begin cultivating those crops that were very much profit making in the markets controlled by English trading houses. The transfer of political power to British East India companies dawned the beginning of the new agricultural policy.

The credit of establishing tea plantations in India largely goes to Britain. Northeast India was the pioneering area, where the government's first experiments in the cultivation of tea plant were carried out with both Chinese and Assam indigenous plants. As superintendent of tea culture, Bruce established nurseries and manufactured tea with the help of Chinese tea makers. In the early years of jungle clearance and planting, the first generation planters had to undergo tremendous hardships, like- living in primitive mud huts and fighting with wild animals and diseases. The government, having ascertained that cultivation of tea plants in India was a feasible proposition, started handing over all its experimental tea lands to private enterprise. Early in 1840, two-thirds of the East India Company's tea lands were handed over to the newly formed Assam Company rent-free for a ten-year period. The Assam Tea Company also took out leases on various other wild tea tracts. Thus, it can be said that this was beginning of the tea plantation system in India (Dutta A. K., 1992).

The industry, since the beginning of the 1850s, began to expand rapidly, and vast areas of land were consumed for tea plantations, and gradually Assam became the leading tea producing region in the world.

1.2 Origin of tea in Assam

The tea plant belongs to the botanical family of *Camellia Sinensis*. It belongs to the genus *Camellia*, which has eighty-two species (Wilson, 1992, P 25). Commercially and taxonomically tea is the most famous of all *Camellia* species. *Camellia* was named in honour of a Moravian Jesuit called (1660-1706) 'Came' (*Camillus* in Latin), who wrote about plants in Asia. The tea plant is placed in the polymorphic species '*Camellia*

Sinensis'. According to recent findings, it was found that this plant of commerce in India is derived from two species (Jat) viz.

- i. Small-leaved China variety (*Camellia Sinensis* ver. *Sinensis* (L.))
- ii. Large-leaved Assam variety (*Camellia Sinensis* ver. *Assamica*).

The Chinese variety is a Dwarf, slow growing and shrub-like whereas Assam variety is tall, quick growing tree (Wilson, 1992, P 31).

However, it is observed that due to hybridisation presently more than these two species are involved in the evolution of the present day tea plant in India. Considerable interspecific hybridisation has taken place in nature. Hence the taxonomy of tea is compounded. However, tea today is botanically in general referred as *Camellia Sinensis* (L), O. Kuntze.

Camellia Sinensis is indigenous to Assam, and it was discovered in the 1820's. In 1823 Major Robert Bruce, who was posted in Assam, was told about the existence of tea plants in northeast Assam adjacent to Burma (Dutta A. K., 1992).

In India, tea is planted in the Eastern and Southern sector. Assam dominates the country's tea map by manufacturing more than 50% (Figure-1.1) of total tea production (Tea Board, 2016).

In recent years, tea industry of Assam has witnessed several structural changes, which includes the emergence of tea cultivation on a small holding, rising competition in the domestic market, the introduction of Bought Leaf Factories (BLFs), (Das, 2010). Tea production in Assam takes place in each big and small scale. Cultivation of tea on the small holding of land is a new thought in India. As per the guideline of Tea Board of India (TBI), small tea growers (STGs) have been outlined as a person or group, who has plantation space up to 10.12 hectares (Hazarika & Borah, 2013). At the present STGs area unit became an awfully vital constituent of tea production because as per the data of 2013, in Assam around 67,179 hectares of tea plantation land under small tea growers' possession (Directorate of Economics and Statistics, 2015).

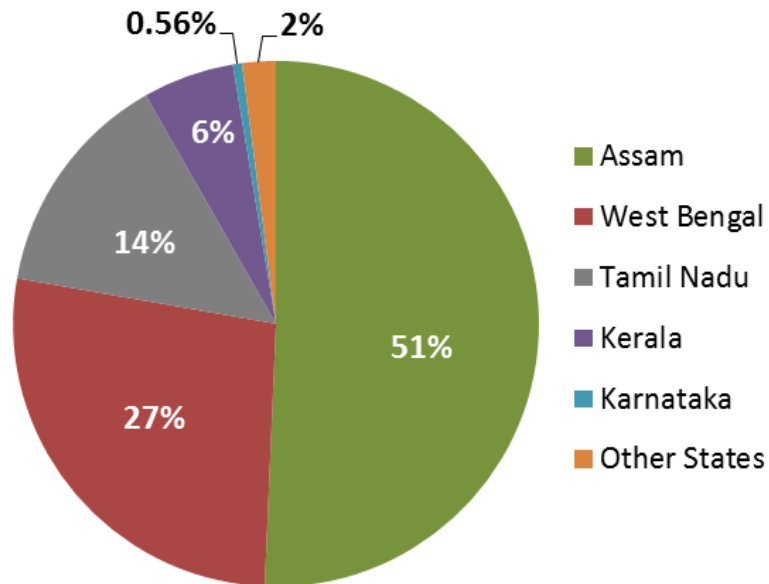


Figure 1.2: State wise tea production percentage in India 2014-15 (Source: TBI)

1.3 Background of the research

Tea, unofficially, is said to be the national drink of India. India is the major producer and exporter of tea (Tea Board, 2016). The Indian tea industry is one of the key foreign revenue earners for the country. Processing of tea includes different activities; among those plucking of tea costs forty percentages (40%) of the total value of production of tea (Bhattacharyya, 2011). A major part of the workforce in tea business is deployed in plucking activity (pre-processing of tea). During the season time, work mainly suffers throughout pre-processing of tea due to a shortage of labour force.

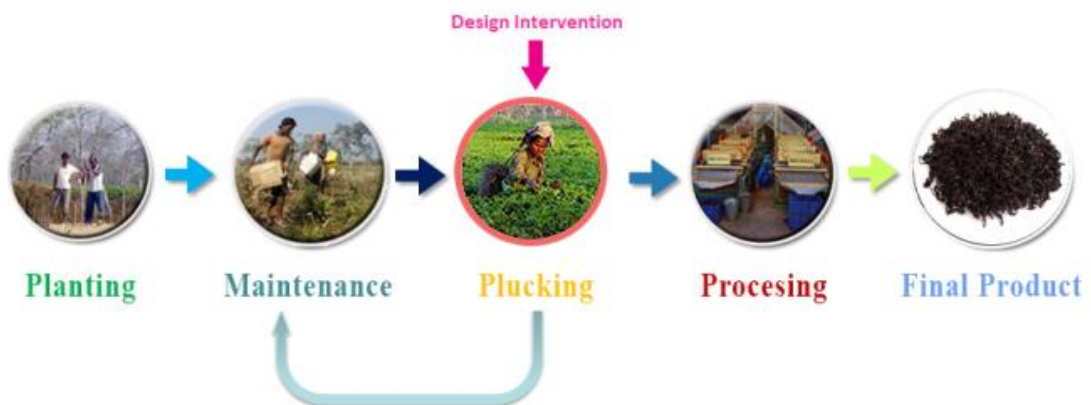


Fig. 1.3: Process of tea manufacturing

In the process of tea manufacturing, there are completely different steps are to be followed and which are planting, maintenance, plucking, processing and final product. Tea leaves harvesting requires experienced eyes and dexterous hands. From the plant *Camellia Sinensis*, tea leaves are plucked and then taken to the manufacturing plant for processing. The best quality of tea is manufactured solely from single bud along with next two leaves. In Assam, the tea plucking is mainly done by female workers (Bhattacharyya, 2011). It has been observed that an experienced plucker can pluck around 20 to 24 kg of green tea leaves per day.

The cost of labour is the prime input element in the tea industry. However, the wages of the tea garden labourers were not high (Dutta A. K., 1992). The problem of labourer shortage has aggravated in the recent times. Migration of the new generation of tea community youths with higher education and job prospects with higher pay in a different domain is leading to a shortage of employees in the harvesting of tea. Due to the establishment of new small tea gardens, the demand for manpower is increasing day by day, but there is no new source of supply of workforce. Management of the tea gardens is not able to engage adequate numbers of employees for plucking during peak season (Mitra, 2012) (Rajya Sabha Secretariat, 2012).

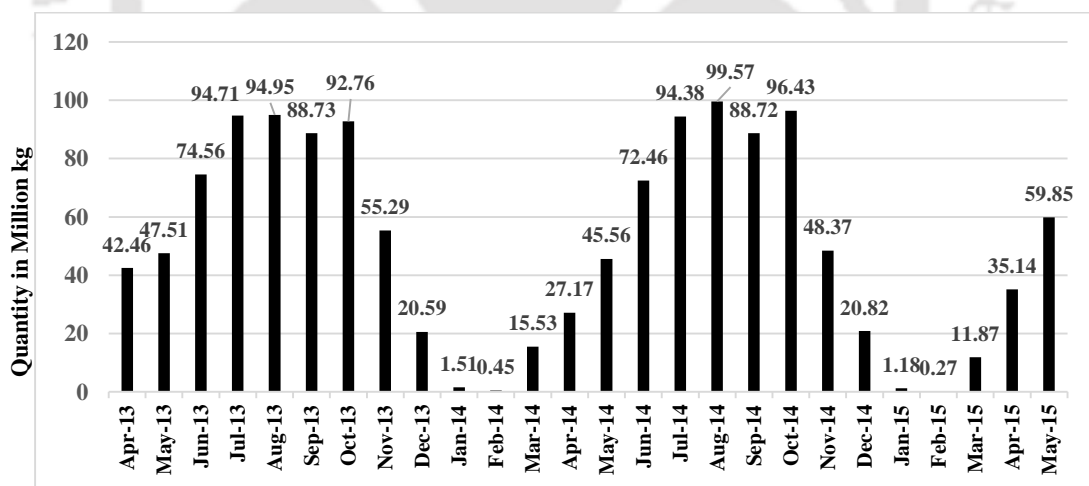


Fig. 1.4: Month-wise Tea Production in India. Quantity in Million kg (Source TBI)

Tea Companies are acquiring huge losses since they are unable to pluck the tea leaves on time. This problem becomes severe during peak season from May to November (Tea Board, 2016). In this scenario; the tea corporations are probing for various effective solutions, and as a result, mechanisation of tea leaf harvesting appeared to be inevitable (Rajya Sabha Secretariat, 2012).

In Assam to harvest one acre of tea plantation, it takes around forty man-hours (Trace et al., 1990).

Above situation has been aggravated by another socio-economic phenomenon. This is creation and expansion of small tea gardens in Assam. The then Agriculture Minister of Assam in 1978 took initiative and encouraged the youths from the rural areas of Assam to take up tea plantations in the farmhouse and unused land for improving the economic conditions (Bora, 2008). Since then, plantations in the small sector have shown a considerable rise and have spread over various districts- particularly in the Northern and Eastern Assam (Barua P., 2015). As per Tea Board of India, a small tea grower is one who holds land for tea cultivation up to 25 acres.

Several factors helped in consolidating the Small Tea Growers (STG) in Assam. Some of these factors were- (i) skilled workforce from the nearby plantation estates, (ii) available market to sell green tea leaves in the estate tea factories and (iii) advantages of plantation crops over the seasonal agriculture crops.

Setting up of tea plants, popularly known as bought leaf tea factories (BLTFs), by a wealthy section of investors was a part of the expansion of the small tea sector. Currently, there are 177 BLTFs across nine districts of Assam (Government of Assam, 2011). The new BLTFs along with the existing tea factories, however, could not help the STGs as it could not create a fair ground to absorb their produce. The discontents of the STGs over the pricing of green tea leaves reflect this. The high fluctuation of price of tea leaves throughout the year, usually un-remunerative, results in the form of dependency condition to sell the green tea leaves (Barua P., 2015).

Data of the survey conducted by Assam government in 2011 reveals that the processing capacity of Assam's 177 BLTFs is around 260 million kg and total production in the small tea gardens was 391.5 million kg in 2008. Due to this, there was a crisis-like situation for selling leaves. The numbers of STGs are increasing day by day. As per the data collected from Small growers' development directorate (SGDD), Dibrugarh, Assam as on 31st November 2016 the number of STGs has in Assam has reached to 84, 577 numbers (SGDD 2016). The STGs have covered around 78203.35 hectares of land (SGDD 2016).

The members of All Assam STGs' Association (AASTGA) have been contributing about 29% of the total tea produced in Assam, and this is approximately 14% of the total tea production of India.

In this scenario, due to less availability of workforce, some of the regular workers from the big and medium tea gardens work at small tea gardens at a higher wage rate and this increases the absenteeism in the medium & big tea gardens during season time.

Due to above mentioned reasons the parliamentary standing committee on commerce (PSCC), has strongly suggested that mechanisation in the tea harvesting is essential to sustain the tea industry in the coming years (Rajya Sabha Secretariat, 2012).

Various tea producers' associations of the region have appealed to the chairperson and members of the PSCC to initiate measures that will cause full mechanisation within their business to beat the shortage of labour in the sector (Mitra, 2012). Moreover, Assam Tea Planters' Association, North Eastern Tea Association and Bharatiya Cha Parishad submitted a memo to the chairperson of PSCC stating that automation is the only solution to overcome this labourer shortage problem (Mitra, 2012) (Meghalaya Times, 2012).

If the situation remains unchanged, in the coming years, tea industries of the region may be compelled to wind up their business. Due to this problem, design intervention throughout pre-processing of tea is essential so that effective, efficient & error free devices can be developed to pluck tea (Baisya et al., 2014) (Barkakoty, 2011) (Rajya Sabha Secretariat, 2012).

1.4 Problem identification

Assam is one of the leading tea producers in the world, and Assam tea is best-known for its quality. However, due to numerous reasons as mentioned earlier, the tea industries of this state are facing a workforce shortage, and this is directly affecting the production. During person-to-person interviews with the professionals from the tea industry, several factors that have led to this workforce shortage were evident to the researchers. Factors like, various government employment generation schemes like MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act), where the daily wage of a worker is Rs. 181.69 in comparison to Rs. 169.00 of tea industry, have been attracting garden workers to enrol under the different schemes other than the tea

industry. Conjointly, today education is also playing a significant role in declining of the workforce (IANS, 2015). In brief, due to low wages and less facility, low standards of living in garden labour lines, youth of the new generation of tea tribe are no longer interested in working as a garden labourer (Rajya Sabha Secretariat, 2012).

During the pilot study, it was observed that most of the Small Tea Growers do not have a permanent workforce. During tea leaf plucking season, they hire pluckers from other big gardens at a higher wage rate.

Because of this, the problem of labourer shortage is rising and has become a significant problem faced by the tea industries. Due to a shortage of workforce throughout peak season, production cannot still be increased in spite of availability of pluckable tea leaves in their plantation, and a substantial area under tea cultivation remains unplucked, and this directly affects productivity. A similar situation was faced by tea plantations in other parts of the world too, and this condition was overcome through mechanisation. For sustaining the tea industries of the state, mechanisation appears to be the only suitable solution (Rajya Sabha Secretariat, 2012).

1.5 Pilot study to understand requirement of the tea industries regarding tea plucking activities

A pilot study was carried out in selected tea gardens of Assam with the different stakeholders of tea industry from top management to field workers to explore the possible areas of design intervention in the area of plucking of tea. During this study, it was learned that in Assam, various measures to enhance tea plucking efficiency had been explored both by the research institutes and industry. It was informed that shearing devices (Fig.1.5) and engine powered mechanised tea harvesting machines (Fig.1.6) and battery operated tea plucking machines (Fig. 1.7) were used as pilot projects in the tea gardens of Assam.



Fig. 1.5: Harvesting of tea with the help of mechanical shear. Source: alarmy.com



Fig. 1.6: Engine powered mechanised tea harvesting machine. Source: alarmy.com



Fig. 1.7: Battery powered tea harvesting machine. Source: tradeindia.com

The opinions of various persons from tea industry of Assam regarding these machines are:

1.5.1 Shear plucking

- a. Shear plucking results in lower yields at the same harvest interval as compared to manual plucking. Quantities of broken shoots are higher in shear plucking than manual plucking, and this affects the quality of made tea (Burgess, 2006).
- b. It has been observed that continuous use of shear affects the bush health and reduce yield at the end of the season. (Saikia, J., & Dutta, 2012).
- c. Shear plucking increases productivity only in unpruned fields, not in all areas (Saikia, J., & Dutta, 2012).

1.5.2 Engine powered mechanised tea harvesting machines

During this study, it was found that the industry has reservations about using gasoline powered machines because of - high noise and vibration, pollution, complicated operation, possible pilferage of fuel for using in personal vehicles, two strokes engines where lubricating oil is mixed with the fuel to the extent of 20 – 40 ml/litre. These lubricants do not burn and comes out with exhaust gas and can deposit on the tea leaves and this can deteriorate the quality of made tea, and these machines requiring more than

one operator (Fig. 1.6). Two operators to carry the machine and another helper is necessary to handle the plucked tea collection bag.

1.5.3 Battery powered mechanised tea harvesting machines

In some gardens of Assam, battery powered tea harvesting machines were used on a pilot project basis. During the study, it was learned that, though the battery operated tea harvesters are noiseless and non-polluting but their plucking capacity very less in comparison to engine operated machines.

As per the information obtained from this study, it was learned that there is a high demand for an efficient battery operated hand held plucking machine which can be operated by a single worker.

1.6 Research justification

This research becomes relevant due to the shortage of the workforce in the tea sector at present and its trend is rising rapidly. From the pilot study, it was evident that the tea industry in Assam is acquiring losses since the industry is unable to harvest the tea leaves on time due to the acute labour shortage. For the tea industry in Assam to sustain economically, it is essential to increase productivity without requiring increasing workforce, which is dwindling. This will help in containing increasing production cost. In this scenario the tea industry is probing for various effective solutions to tackle the situation. As a result, mechanisation of tea leaf harvesting appeared to be inevitable (Rajya Sabha Secretariat, 2012). Considering this and various contexts of tea gardens in Assam, appropriate design intervention is justified and this research work was undertaken as a response to the call given by various stakeholders.

1.7 Research questions (RQ)

From the pilot study and interactions with various stakeholders in the tea industry, it was found that industry wants design intervention for tea leaves harvesting that can solve the shortage of plucking workforce in the gardens, acceptable to the stakeholders, socially relevant to Assam. Thus, it was found that there exists a scope within the field of tea processing for design intervention. For this following questions were raised:

RQ1: What is the state of mechanisation in the tea harvesting in Assam?

RQ2: Why stakeholders are not using available machines for tea harvesting

or

What are the shortcomings of existing tea harvesting machines in the context of Assam?

RQ3: How design intervention can impact the tea productivity?

RQ4: How design intervention can be initiated in the tea harvesting?

The answers to these could offer full justification for the research focus in this critical but less investigated subject.

1.8 State of the art review on mechanical harvesting of tea

During literature review, it has been observed that there are limited studies carried out on mechanical tea harvesting in context of tea industries of Assam. However, in other tea producing regions, people have carried out studies on mechanical harvesting of tea. Since this study is in context of tea garden workers and their workplace in Assam, the literature review has been split into two categories as mentioned below:

- a) Socio-economic studies on the origin of the tea tribes in the state, which can throw lights to present shortage of tea workers.
- b) Tea harvesting Machine and Method related studies.

Findings from both the studies are elaborately discussed in Chapter 2, Chapter 3 and Chapter 4 with relevant references.

1.9 Hypothesis

Design intervention through the introduction of an efficient mechanised tea harvesting device will lead to enhanced productivity in harvesting of tea leaves to meet the challenges of shortage of tea garden workers engaged in plucking.

1.10 Aim & Objectives of research

1.10.1 Aim

Aim of this research is the design and development of an appropriate tea harvesting machine in the context of the tea gardens of Assam to compensate the labour

shortage throughout peak tea harvesting season. This can lead enhanced productivity and efficiency of tea harvesting process.

1.10.2 Objectives

Objective 1: To explore the possible areas of design intervention in the field of mechanised tea harvesting.

Objective 2: To carry out field study with the stakeholders of selected tea gardens to understand their requirement related to mechanised tea harvesting process.

Objective 3: To design and develop an appropriate tea harvesting machine based on the need of the tea industry as a part of mechanisation of tea harvesting process.

Objective 4: Testing of the newly designed and developed machine to assess its performance and thereby validate it in terms of efficiency etc.

This research becomes relevant due to the shortage of the workforce in the tea sector at present and its trend is rising rapidly. For the tea industry in Assam to sustain economically, it is essential to increase productivity without requiring to increase workforce, which is dwindling. This will help in containing increasing production cost.

1.11 Research paradigm adopted

Research paradigm, in general, is known as a framework of perception, understanding, and belief within one's world or reality (Shrestha, 2009). Bassey, (1990) defined it as "A network of coherent concepts regarding the nature of the world and also the functions of researchers, adhered to by a group of researchers, conditions their thinking, and underpins their research actions." This is crucial because it determines the event and execution of research. It also affects how the research findings can be analysed (Guba & Lincoln, 1994).

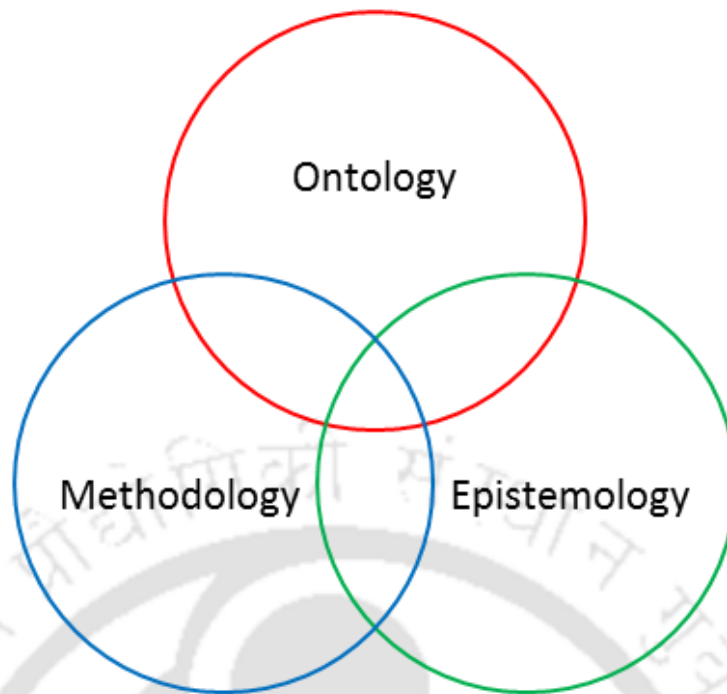


Fig. 1.8: Research Paradigm (Adopted from eLearn Centre, UO de Catalunya)

1.11.1 Ontology, epistemology, methodology

Ontology, Epistemology, and methodology are interrelated in the research process.

1.11.2 Ontology

Ontology is the beginning of all research. It is mainly associated with belief about reality. “What is true?” or “what is there to know?” philosophy. Ontologically research can be divided into two subgroups: Realism and Relativism.

Realism is based on ‘one truth’ concept. There is only one truth exists and with measurable objectives.

In relativism, it is a belief that there are multiple realities exists and the truth evolves and changes. Ontologically this research is positioned in “relativism.”

1.11.3 Epistemology

It is derived from the Greek words episteme (knowledge) and logos (reasons), it helps in how to know it or how to get the knowledge on the subject of research or how to discover new things related to the researched topic. Here knowledge is discovered through objective measures. Ontological beliefs will dictate epistemological beliefs.

Epistemology can be divided into further two sub-classes: ethic approach and emic approach.

In ethic approach, truth can be found from the study of the subject or system from the observations/information collected from the observations/studies carried out from the outside of the system.

The emic approach is the subjective approach for knowing the reality. In this method, inside view of the research problem is taken into account; in brief, it is an interactive approach. Personal interviews, questionnaire etc. are carried out in this approach (Shrestha, 2009).

This research is designed with this approach. Information will be collected through interviews, feedback, questionnaires, field observations and so forth to get a realistic view to know the requirement of the tea industries of Assam to overcome the production loss during the harvesting season and to find out a suitable solution to solve the problem.

1.11.4 Methodology

Methodology deals with “how the knowledge can be discovered in a systematic way”. People often misinterpret “Methodology” with method; but both are different in nature. Methodology guides in data gathering techniques like interviews, survey, document review and so forth.

This research will be based on Mixed Methods where there will be a combination of qualitative and quantitative research. According to Erica Loop (2014), this type of methodology uses several different measures, which include both contextual understanding like interviews or observations along with facts or statistics. By adopting this method, we will be able to investigate our research problem on multiple levels. This will help to gain different views and a comprehensive look at the research topic. A mixed methodology knits more than one philosophical perspective, allowing for the integration of various theories and ideas (Loop, 2014).

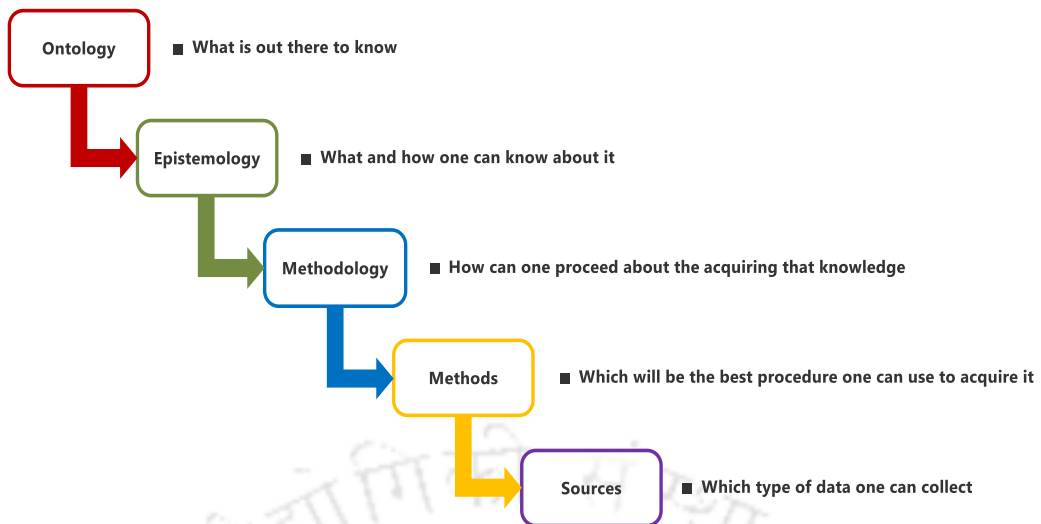


Fig. 1.9: Building blocks of research paradigm and their interrelation. Source: Hay, 2002

Ontology	Epistemology	Methodology	Methods
[What there to know]	[How we know that we know]	[How to acquire the knowledge]	[What Procedure to use]
<u>Objectivism</u> Existence of independent of researchers	<u>Positivism</u> Truth out there to be discovered	<u>Deductive</u> General to specific	<u>Quantitative</u> Interpretation of phenomena
<u>Constructivism</u> Phenomena continually accomplished by researchers	<u>Interpretivism</u> Develop truth based on social interaction	<u>Inductive</u> Observations to theory	<u>Qualitative</u> Empirical Assessment

Fig. 1.10: Research Strategies

1.12 Research approach

As mentioned earlier, the aim of analysis is to work out how the productivity of tea harvesting can increase without increasing the production cost and deploying additional workforce through design intervention.

The research can be administered with a pragmatic approach in seeking out an acceptable solution to the matter.

This study adopts the human-centred design approach, for design and development and implementation of appropriate technology in harvesting of tea.

1.13 The product development lifecycle

Various stages which will be adopted during the development of the tea harvesting machine are as follows:

1.13.1 Analysis

To design and develop this new tea harvesting machine, a proper product development approach is to be adopted.

In any organisation, there may exist plenty of ideas for a new product, but once it has selected the best among the ones available, the next step is to start researching the market. This will help the organisation to see if there is any likelihood that this type of product will be in demand, and also of the fact as what specific features need to be developed for meeting the needs of a potential market. The various stages of product development processes are discussed below.

1.13.2 Concept generation

Any product, before introduced or developed, begins with an idea. In some cases, this might be very simple, as the new product may be based on something similar that already exists. In other situations, the product may turn out to be something revolutionary and unique. In fact, many of the leading manufacturers will have a separate department that focuses only on the task of coming up with new innovative design.



Fig. 1.11: New product development stages. Source: Product lifecycle stages, 2013

1.13.3 Design

In this phase, the product is first designed as per the most suitable concept available. This involves 3D modelling, Virtual testing, technical feasibility study, material selection and so forth.

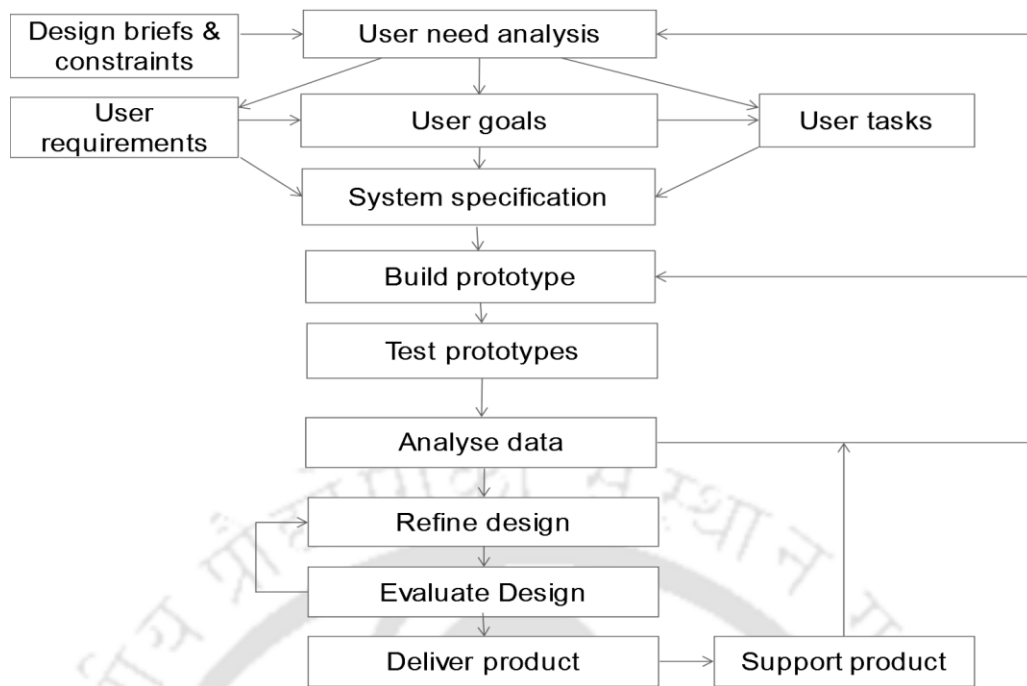


Fig. 1.12: Different phases in human-centred design. Adopted from (Nielsen, 1994)

1.13.4 Development

After concept generation, next comes product development. The first models or the prototypes are gradually modified through different stages of designing and manufacturing before the finished product, which the customers will eventually buy, is zeroed down.

1.13.5 Testing

The testing phase is a critical phase. Most manufacturers and companies prior to the official launch of any new product in the market by investing a significant sum of money on production and promotion will test the same with a small group of prospective consumers/users. This will help them in making it sure that they have a viable product that will be profitable, and any further changes that need to be made prior to its launch are also made.

In this research once the design is completed, it will be prototyped and the newly designed machine will be tested functionally. Its performance and efficiency will be required to be evaluated through actual field trials. For this, five numbers of tests are planned to find out:

- i. Difference in area harvested using the designed tea harvesting machine in unit time and area harvested by hand plucking by the same worker in the same time.
- ii. Difference in time required to harvest a unit area of 100 m² by a worker using the machine and by hand plucking.
- iii. Difference in quantity of tea leaves plucked in unit time using the machine and by hand plucking.
- iv. Hand grip strength testing to understand the effect of using the tea plucking machine on the workers.
- v. Documentation of feedback from workers, who will be exposed to the machine to understand their experiences while operating the machine through a questionnaire and then to carry out Nordic body parts discomfort mapping. A questionnaire will be provided to each worker for this purpose and the sample questionnaire is provided at Appendix C.

To interpret the data collected with the help of proposed tests, statistical methods will be used to calculate mean, standard deviation and variance for group statistics. Levene's test for equality and 't'-test for equality of mean for independent samples will be conducted.

Some common statistical procedures assume that variances of the populations from which different samples are drawn are equal. Levene's test assesses this assumption. It tests the null hypothesis that the population variances are equal (called homogeneity of variance or homoscedasticity). In the other word this test is used to test whether two or more population variances are equal. For each scenario that is set up, two simulations are run. One simulation estimates the significance level and the other estimates the power (NCSS, 2014).

A t-test is an analysis of two populations means through the use of statistical examination; a t-test with two samples is commonly used with small sample sizes, testing the difference between the samples when the variances of two normal distributions are not known (University of Connecticut, 2014).

The objective of any statistical test is to determine the likelihood of a value in a sample, given that the null hypothesis is true. A t-test is typically used in case of small samples

and when the test statistic of the population follows a normal distribution (Research Optimus, 2013).

1.13.6 Modification / analysis

Testing of the product with prospective customers will provide the company/manufacturer certain feedbacks and based on these feedbacks the manufacturers make necessary adjustments to the product. They further decide on the ways they are going to launch it in the market. With ‘real’ customers, providing genuine feedback to the companies about the product, these companies, on the other hand, will be able to make some strategic decisions that will turn out to be crucial to the product’s success. The price of the product and marketing strategies are some of the important decisions that these feedbacks will help the companies to take.

1.13.7 Retesting

During initial testing in the real environment, there may be some unforeseen problems which may arise, and in this phase, these problems are taken care of and then the product is tested again.

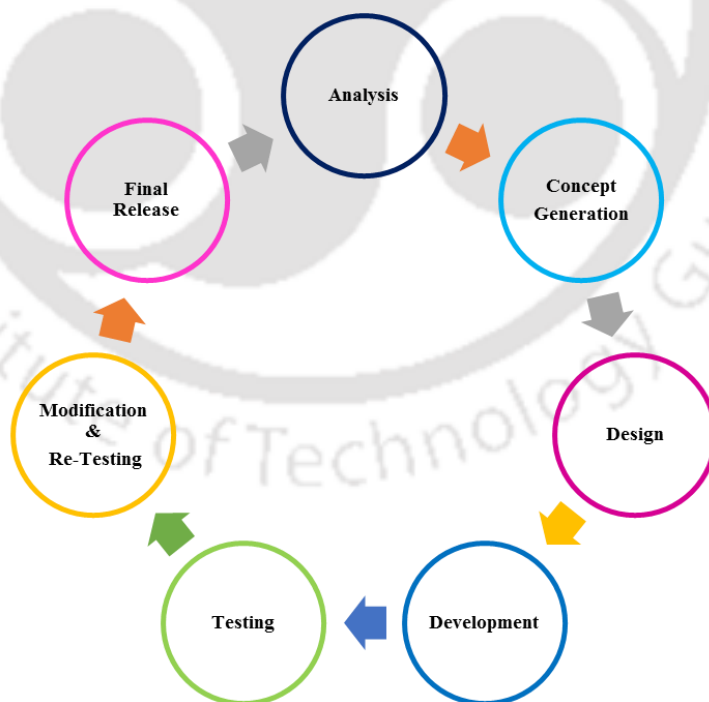


Fig. 1.13: The product development lifecycle (Nielsen, 1994)

1.13.8 Final release

Going through all the stages above, when a product makes its way to the new product development stage, the most important step left is successful introduction of it to the market. Moreover, once this is done, good product lifecycle management will ensure the manufacturer makes the most of all their effort and investment.

1.14 The outline of the thesis framework

The thesis is structured into the following chapters.

Chapter 1 titled *Tea Industry in Assam: Present Context*, introduces the background and motivation behind this research work. The research issues were discussed and placed in the content of their multidisciplinary background of tea industries in Assam. Aims and objectives of the thesis are highlighted. The boundaries and scope of the research are laid out along with definitions and taxonomy. Summaries of all the chapters are outlined.

Chapter 2 titled *Tea Industry in Assam: Socio-economic and Demographic Situation* provides state of the art review on the origin and socio-cultural elements of tea tribe, present problems related to manpower in tea industries.

Chapter 3 titled *Tea Plantation and Tea Manufacturing Process* describes tea plantation and production system in Assam. Different stages of tea cultivation and various types of tea are covered in this chapter.

Chapter 4 titled *Mechanical Harvesting of Tea*, covers study of various types of tea harvesting machines, mechanical harvesting methodology, advantages and drawback of the currently available tea harvesting machines etc. to arrive at requirement of an appropriate tea harvesting machine in the context of tea gardens of Assam.

Chapter 5 titled *Concept Generation, Design and Prototyping* covers concept generation of an appropriate battery powered single operator tea harvesting machine, its detail design and final prototyping including functionality test. Different components of the proposed machine were designed and manufactured and assembled to construct the prototype.

Chapter 6 titled *Design Validation of the Newly Designed Machine* covers operational testing of the prototype through actual field trial in a tea garden for validation of the design and research hypothesis through the results of field trials. Details of various test conducted is also covered here. Statistical Analysis data collected in the experiments and discussion on the field experiments and the methodology adopted are described in details.

Chapter 7 titled *Discussions, Conclusion and Recommendations* covers consolidated findings of the research, contribution and limitations of the current research. Future scope of work- too have been presented which opens up avenues of future work for further development of the concept and it's more applications. Recommendation for application of the findings of the research in the tea insdutry of Assam is part of this chapter.



Chapter 2 Tea Industry of Assam: Socio-economic and Demographic Situation

Assam's tea industry plays a greater role in the economy of the state than other plantation crops. As tea is cultivated in the valley as well as hill tracts of the state, it prevents soil erosion and maintains ecological balance. Promotion of the industry enables the state government to maintain regional balance in development planning. The tea garden labour community of Assam represents around 17 percent (Telegraph, 2016) of the total population of Assam and is one of the major contributors to the organised workforce as well as to the economy of Assam (Vedanti, 2014). It is only in the tea industry that 50 percent of the cost of production is related to labour wages and benefits while urban concentration and environment pollution are non-existent.

2.1 Plantations

Plantations refer to a large scale agricultural entity, mostly specialised in one specific crop, grown for distant markets, employing an extensive range of wage labourers operating under close supervision in a very strict gradable organisation. Specifically, a plantation can be outlined as an institution for the production of cash crops for export purposes.

International Labour Organisation (ILO) defines plantations as “an agricultural endeavour, employing hired employees, situated in the tropical or sub-tropical regions that are principally involved in the cultivation or production for the commercial purpose of tea, rubber, sugarcane, coffee, bananas, cocoa, groundnuts, cotton, tobacco, citrus, and coconuts etc. It does not embody family or small scale holdings cultivating for native consumption and not often using hired employees”. Regarding global coverage, ILO acknowledges fifteen commodities that belong to the plantation class (Lincoln, 2010).

2.2 Characteristics of plantations

Unlike alternative agricultural sectors, the plantation sector has continued with the similar cropping for an extended period. It takes 4 to 7 years of the plantation crops to yield rich dividends. Once the gestation period is over, then production may continue for many years, even more than 100 years as is the case with tea. Maintenance of a permanent labour force is required for this and providing them with various facilities

like housing, medical care, education for children and other welfare measures (Lincoln, 2010).

The plantations have a continual nature of operations, which imposes a long-term commitment of monetary investments and land resources. It is a labour intensive agro-industry, where land is the largest resource input of the production process, and each plantation has self-contained units for output and process additionally (Lincoln, 2010).

The corporate structure of process with managerial and technical expertise is another specific feature of the plantation segment. In Indian situation, the plantation business is principally export oriented. Hence, fluctuations in global value, supply and demand have an effect on the industry's prospects. Considering above factors, plantations resemble associate business instead of agriculture.

The plantation locations are remote places not conducive to easy mechanisation. Unlike alternative industrial sectors, plantations have little scope for area-wise growth as there are restrictive land laws. Plantations are characterised by a closely demarcated territory, an isolated labour force that lives in plantation area and an overseas market. The plantation firms themselves handle manufacturing, transport, and marketing of the crops. They tend to develop their own monetary, social, ethnic and political affiliations and identities.

Plantations' production has certain uniqueness regarding its origin, the use of the labour force, the type of the work undertaken, the harvests produced, its effects on the local society and the local economy.

Unlike the plantations, in peasant farming, the crop raised is sustenance crops which form the most food items of the peasant raising it. The peasant may either sell the surplus or at times part of his reserves to fulfil his cash necessities. Hired labour use is not the very characteristic of peasant farming. In commercial agriculture or contract farming, each labour engaged is employed, and modern technology might be used. However, they differ from those of plantations.

2.3 Plantations in India

In India, the plantation concept is mainly applicable to tea, coffee, rubber, and cardamom. Cardamom is the oldest Indian spice which was produced through the plantation. References to the medicinal properties of cardamom can be found in ancient

Indian Ayurveda books. Coffee has a historical reference in the manuscripts of the seventeenth century.

Crops like cardamom, rubber, and tea which are under plantation has been declared as such under constitutional provisions following the commodity acts of rubber, tea, coffee, and cardamom that have been enacted to facilitate their development. This has been done because of the importance of these crops as major foreign exchange earners, and these being national industries adjoining entirely different states. In India, the major cash crops are indigo (Bihar), jute (Assam and West Bengal), tea (Assam, West Bengal, Tamilnadu, and Kerala), cotton (Western and Southern states of India), coffee (Tamil Nadu, Karnataka, and Kerala), tobacco (Andhra Pradesh) and rubber (Kerala, Tripura). These crops have been the major cash crops since the late 19th and the early 20th century until other new cash crops was introduced. In some sectors of India, sugar, cotton, pepper and cardamom, were produced in a way similar to plantation system.

2.4 Emergence of the corporate firm

The Companies Act of 1862 in Britain encouraged massive undertakings in the corporate sector, replacing old family firms by limited liability companies run by salaried managers. These developments were not reflected in the changing conditions of the tea plantation industry in South India, where proprietary planters continued to be in the majority. The plantations moved towards organised resource mobilisation and a stable professional management of the enterprise (George, 2002).

2.5 Size of tea estates

Tea estate is a standard unit of production in a tea plantation and includes the place where tea is grown and the factory where it is processed. There are mainly three types of tea estates: (a) Small growers (b) Medium and marginal estate (c) Big estates (George, 2002).

2.5.1 Small growers

Estates having less than 50 hectares and no separate factory of its own are regarded as small producers. Estate rules are not applicable to these gardens.

2.5.2 Medium and marginal estates

Estates having less than 200 hectares, with or without a factory of their own are treated as medium estates. Their yield is lesser compared to the big units and is governed by normal estate regulations.

2.5.3 Big estates

Estates having an area of 200 hectares or more are classified in this category. Owned by large enterprises, these big estates are the producers, exporters, and retailers of tea in India and abroad. In South India, large estates account for 64.58 % of the total area (George, 2002).

2.6 Economic size

The size of an economic holding is determined by various Agro-economic factors such as climate, elevation, soil availability, cost of labour, transportation facilities, capital, management, and equipment. Costs and yields vary according to geographical location. The Plantation Inquiry Commission (1956) on tea points out that an estate of at least 300 acres would be required to feed a factory of the smallest size throughout the year. Larger estates facilitate the adoption of improved cultivation techniques and thereby benefitted through increase in productivity. A small estate cannot raise adequate green leaf to justify the construction and operation of a factory economically and has to depend on bought leaves factories.

A survey conducted by the Tea Board in this regard covering 135 single- estate tea companies in India over the years 1958-1962 revealed that estates between 3000 and 4000 hectares had the highest productivity per unit area and also the lowest unit costs of production. Neither the area nor the yield per unit represents a valid criterion to determine, whether an estate of a given size could achieve an adequate economic return. For regulatory purposes, the Tea Board considers estates below 150 acres owned by an individual and estates below 300 acres owned by a company as uneconomical (George, 2002).

2.7 Estate management

An average estate having 400 hectares will have a manager and is usually divided into three divisions. Each division may have one assistant manager under whom there will

be three to four field officers. These officers will have assistants under whom there will be 15 to 25 supervisors. These supervisors will have 30 to 40 pluckers or 10-20 field workers under him. In some cases, there will also be a visiting agent under the general manager. The person is generally an experienced manager and acts as a super manager (George, 2002).

2.8 Origin and growth

Unlike other agricultural or industrial enterprise, plantation management has certain unique features which owe much to the British for its style and functioning. The management system largely evolved before the emergence of organised labour and enactment of different legislative measures. In the recent past, considerable research on adoption of modern management practices in tea plantations has been carried out, but there is little impact on the plantation industry (George, 2002).

In the beginning, forms of organisation in tea industry were proprietary in nature and based on partnership. The joint stock companies, which came on the scene with extensive holdings of estates, altered the form and style of management (George, 2002).

In tea plantations, 95.1 percent of the workers are engaged in manual jobs such as plantation labourers, field workers, supervisors and so forth. The proportion of male, female and adolescents are 45 percent, 54.3 percent, and 0.7 percent respectively. In tea plantation, 4.9 percent workers are employed in the non-manual category. Male workers are doing the majority of the non-manual jobs (Labour Bureau, 2008).

In tea plantations, 86 percent male workers and 94.4 percent female workers are engaged as labourers. In Assam, Tamil Nadu and West Bengal almost all the women workers are employed as plantation labourers (Labour Bureau, 2008).

2.9 Role of managing agencies

Managing Agencies were business firms developed to provide managerial, financial and technical services to estates whose owners were away from the properties. These agents provided service in budget control, cultivation, manufacturing, taxation, foreign exchange control and staff recruitment. The managing agencies were organised in the form of a company with many of the functions of the present estate manager transferred to the managing agents. Small estate owners, unable to afford the services of managing

agencies were soon taken into the larger fold and were given exposure to the developed market of London.

In the beginning, the typical unit of the tea industry in South India took the shape of a sterling company (very good in quality) in Britain. The agency houses, many of which were situated in Britain, started their own ventures and took over some of the sterling estates to look after the interests of sterling companies. In the course of time, the early individual planters became associated with agency houses that managed several tea plantations and became incorporated into the firm structure of managing agency system. Thus the capital of managing agents and managerial experience of the early planters provided a sound foundation for the growth of tea industry in South India. Harrison & Crosfield, James Finley, Brook Bond, Peirce Leslie and so forth, were some of the leading managing agents in the field till the system was abolished (George, 2002).

The link between the agency and the estate manager was the visiting agent. The visiting agent was an experienced practising planter holding a relatively senior position. He used to visit the estate and give a report to the managing agents. He was expected to provide advice to the manager. Gradually he got more power and authority in the managing agency system. With the passing of the managing agency system, this position was assumed by the managing director of the companies. However, the functions of managing director were entirely different and were more concerned with the general administration of the company (George, 2002).

2.10 Plantation system and human resource structure in tea plantations of Assam

Tea Plantation system is the institutional arrangements related to production and marketing of crops which are methodically planted to generate revenue.

Plantations are the largest single employer of labour in the private sector in India. Among them, tea plantations are the most labour intensive and the largest employer of organised labour. In a tea estate, the hierarchy followed is as shown in Fig.2.1.

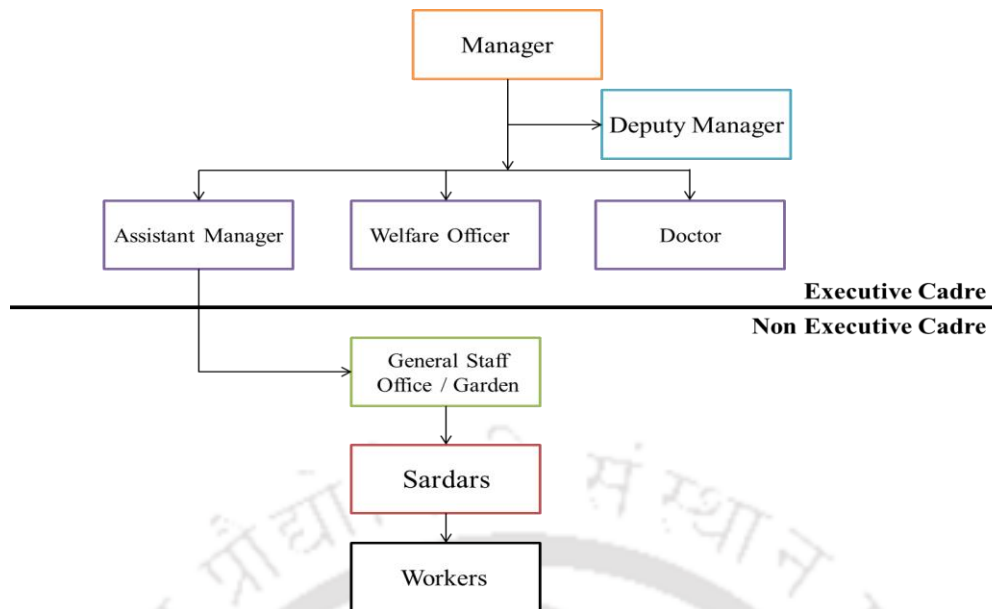


Fig. 2.1: Organisation chart of Indian tea industry

The most important job at a tea estate is plucking of the tea leaves. The harvesting of tea leaves from the bushes is done by carefully plucking the tender shoot between the thumb and first finger. The harvest is a bud, and the two tender leaves below it as this is where the highest concentration of flavour-producing chemicals are found. Thus, plucking operations have to be timed according to the rate of growth of new shoots, which varies from season to season. Plucking, though looks apparently simple, requires a certain degree of skill and considerable attention. Two-thirds of the total numbers of labour days in a tea plantation are devoted to plucking (Bhattacharyya, 2011). Women are usually employed for this job (Fig. 2.2) as they are considered more efficient than men. Plucking of tea leaves is more of an exclusive job for women—a skilled leaf picker is usually a woman, requiring little supervision in her work.



Fig. 2.2: Manual tea plucking by women pluckers in Assam, India.

2.11 Classification of tea plantation employees

Manpower associated with tea industries can be classified mainly as workers, staff and managerial levels.

2.11.1 Workers

The term 'workmen' can mean all employees in an estate, male and female except persons who are members of the supervisory, medical and welfare establishment, clerks or motor vehicle drivers who are employed on a monthly basis. Both skilled and unskilled workers are included. According to standing orders of March 1951, there are only two classes of workers (George, 2002).

- i) Permanent worker: A permanent worker is one who has been declared fit for work and has been registered on the check roll for the period of the contract.
- ii) Casual workers: Casual workers are those who are engaged in work on a purely casual or temporary basis.

Permanent or casual workers further can be classified into three categories.

- i) Field workers: They work in the estate as pruners, weeding and spraying workers or employed in common household work within the estate. They are usually paid on an hourly basis.
- ii) Pluckers: Usually, women are employed in plucking the tender tea leaves. It is a piece-rated work and a major portion of the workforce in the tea gardens of Assam is pluckers (Bhattacharyya, 2011).
- iii) Factory workers: Skilled and unskilled workers working in the tea factory are included in this category. The wage rate is slightly different from the field workers (George, 2002).

In tea gardens of Assam, working hour starts at 8.00 a.m. and ends at 4.00 p.m. A pictorial activity diagram of a female tea garden worker engaged in plucking in the tea garden of Assam is provided at Appendix A.

2.11.2 Staff

Staff refers to those engaged in supervisory roles, medical and welfare establishment workers, clerks or motor vehicle drivers employed on monthly rates of pay and not

covered by individual contracts. The staff works under managerial personnel at administrative and supervisory levels. They are present in different departments of a plantation such as an office, field, factory and medical department. The staff members are classified as permanent, probationary and temporary (George, 2002).

There is another sub-category of people employed in the plantations known as the special category. Mechanics, electricians, wire-men, laboratory technicians, fitters, drivers, carpenters, masons, blacksmiths, midwives, Balsevikas, teachers in unaided schools, medical orderlies, plumbers, pump operators and others doing similar work fall in this category (George, 2002).

2.11.3 Managers and Assistant Managers

Managers and assistant managers are classified under the management cadre, and individual contracts determine their terms and conditions of work. In many North Indian plantations, human resources are categorised into four divisions - management, staff, sub-staff and workers. The management comprises of the manager, assistant manager, and factory supervisor. The staff consists of white-collar workers. The sub-staff consist of lower level supervisors and other monthly workers. All others are included in the category of workers (George, 2002).

A manager in an estate is a permanent employee and needs to be available throughout the day. Since all labourers reside within the plantation, the manager is responsible for every minute issue in the estate. The Plantation Labour Act prescribes facilities like housing, electricity, drinking water and hospital to be arranged for the workers. A plantation is often a closed community, and the workers have to depend on the estate manager for a variety of services. This has led to a paternalistic style of management in some cases and even a dictatorial style in some others.

Plantations employ more workers per unit of investment than most manufacturing processes. As the workers are spread out over a wide area ranging from 400 to 600 hectares, supervision, and control of employees are of special significance in a plantation. An efficient network of transport and communication and regular inspection is required in this area which makes the levels of management and span of control in a tea plantation distinct from other manufacturing concerns. (George, 2002)

The manager is mostly an agriculturist. Tea estate management necessarily involves the management of various agricultural processes. As such, the manager is expected to have

a thorough knowledge of multiplication of the plants, nurturing, manuring, weeding, leaf collection, down to the factory process. Knowledge of various sorts of plants and their culture, soil composition, ways of harvesting, pest and disease management, weed management, nursery management, shade for tea and its management is an indispensable and essential ingredient of managing a tea garden. Tea companies prefer people who have basic knowledge of the plant and agriculture for their managerial cadre.

Modern methods and practices in management cannot be applied with equal efficiency in a tea plantation. The unique work environment of the plantation industry presents a great test to the universal application of management principles, including taking the benefits of modern technology in business and non-business concerns (George, 2002).

Usually, big or medium size tea estate has a tea manufacturing factory under a factory manager. Some technical competence is required for this job. The factory manager should be well acquainted with the characteristics of different varieties of tea, marketing opportunities, and promotion methods. Employees under managerial level should know the various constitutional acts and rules that govern their work and service conditions (George, 2002).

2.12 Difference between plantation labour and other agricultural labour

Unlike in other industries, in tea plantation, labourers have to perform mainly outdoor activities and thus they constitute a special kind of agricultural employment. Hence, it is for this reason that women are mostly engaged in the tea estates and tea nurseries rather than in factories. The field work is suitable for unskilled workers, and so women are preferred in field work. However, some field duties are only allotted to male workers, which include digging pit, pruning, skiffing, spraying of pesticide and irrigation etc.

Another feature of plantation workers, especially in tea, coffee, and cardamom plantations, is that they are recruited on a family unit basis from distant places since most of the estates are located in remote places. In these locations, either local workers are not available, or locals are not interested in working in the plantation. Generally, due to the low wage rate in plantation as compared to other industries and also due to the poor economic condition of the tea workers' families, an entire family shows interests to work in the plantation industry. However, in recent times, education has

played a vital role in changing this scenario. Nowadays, educated members of the family of the plantation workers are showing interest to earn their livelihood through other professions.

A unique characteristic of the plantation workers, compared to other agricultural workers, is that they earn a regular income to support their families. Presently, they are the most organised labour force of the economy. In Assam, tea workers' trade unions like Assam Chah Mazdoor Sangha, Assam Sangrami Chah Shramik Sangh, and Cachar Chah Shramik Union plays a vital role in tea industry as well as in the political scenario of Assam. Moreover, in reality, the mechanisation of plantation work does not pose threats of unemployment to these female workers; this is because the scope of mechanisation is possible in only some processes. The socio-economic background of the workers engaged in plantation sector also differs from that of their counterparts in other crops. They come from an entirely different social-cultural environment and are keen on preserving their traditions.

2.13 The Plantations Labour Act, 1951

The living and working conditions of plantation employees are statutorily governed by the Plantations Labour Act, 1951. Several other acts, like ‘The Workmen’s Compensation Act, 1923’; ‘Payment of Wages Act, 1936’ and ‘The Minimum Wages Act, 1948’ are also applicable. The Plantation Labour Act, 1951 is a central legislation administered by state governments through rules framed by them. The Plantations Labour Act covers conditions of work as well as the provision for living in plantations. As per this Act, the following must be provided by the employer free of cost to the plantation labourers.

Table 2.1- Facilities to be provided under The Plantations Labour Act, 1951

Conditions of work	Conditions of living
Duration of work	Housing
Weekly rest days	Medical care
Employment of women	Crèche
Annual and sickness leave	Canteen
Overtime	Children’s Education, Protective Clothing, Conservancy,
	Drinking Water, Recreational facilities,

Initially, this Act applied to the workers of tea, coffee, rubber and cinchona plantations, but in later stages, plantation workers of cardamom, cocoa, and oil palms were also included.

2.14 Other legal provisions

Along with the provisions of the Plantations Labour Act, all labour enactments applicable to industrial workers shall also apply to plantation labour force.

2.14.1 Maternity benefits

Besides the above mentioned acts, for the welfare and the benefits of the women employees in the plantation, the Maternity Benefit Act, 1961 entitles female workers in plantations to maternity benefit for a total of twelve weeks paid leaves maternity leaves.

2.14.2 Provident fund

The Provident Fund Act, 1952 offers security to workers after retirement. Employer and worker have to contribute at the rate of 10% of the wages. Assam government is pays 8.7% (changes as per amendments from time to time) interest rate on GPF for tea workers (PTI, 2015). Besides, some other schemes are also available for the tea garden workers; these are Pension Scheme, 1967; Family Pension Scheme. 1972, Assam Tea Plantations Provident Fund Scheme, 1955 and Deposit Linked Insurance, Scheme, 1984 (Pio, 2006).

2.14.3 Gratuity

As per the Payment of Gratuity Act, 1972, the employer has to pay 15 days' wages for every completed year of service subject to a ceiling of Rs.50, 000/- at the rate of last drawn wages.

2.14.4 Bonus

Also, there are provisions in the Payment of Bonus Act, 1965 to provide a bonus to the workers. The minimum annual bonus is fixed at 8.33 %. The maximum is 20%.

2.15 Present production scenario of Assam Tea

As per data from the TBI, in Assam, 304.40 thousand hectares of land are under tea cultivation and produced 629.05 million kg (as of 2013). In India during 2015-16,

around 951 Million kg of tea has been produced. Assam presently has around 793 registered tea gardens.

In the tea gardens of Assam, an average of 4, 18,434 persons are employed on a daily basis among which 2,01,507 are male and 2,16,927 females. The percentage of women workers employed is about 52 percent. (Indian labour yearbook, 2016)

Most of the existing Assam's tea companies are part of the earliest plantation which spread in the Brahmaputra valley and Barak valley in Assam. After independence, many tea gardens changed hands, and today most are owned by Indian companies.

2.16 Background of tea plantation workers of Assam

Assam tea's history is around 200 years old. The Treaty of Yandaboo, signed after the first Anglo-Burmese War ended the most expensive and the longest war in British Indian history. After the annexation of Assam from Burma (Myanmar) as a result of this treaty to India, the British colonial administration began tea plantations on a large scale in the region (Dutta A. K., 1992).

The year was 1834 when the first tea committee was formed, and this followed the establishment of first tea garden 1837. By 1900, total 804 tea gardens covered an area of 337,000 acres (1 hectare = 2.47 acres). The industry soon faced a shortage of labourers. With the native Assamese engaged in independent farming, a labour class seeking wage-based employment on a regular basis was not available locally. Moreover, the residents were not much efficient and punctual. During the early years, the English tea planters used experienced Chinese workers in the tea estates of Assam, but their wages were very high, and they were very problematic in nature. So the East India Company stopped the inflow of labourers from China. Then they recruited workers from the native Kachari tribe, but after some years they had started to create problem and tea garden management were no longer interested in recruiting them as workers (Varma, 2011). In this long process, different tribes of people were associated with this industry. As per Saikia (2008) in the initial years of tea plantation in Assam, workers from Chinese, Ahoms, Sonowals, Singphou, Phakiyal, Kacharies, Garo, Tiwa, Kuki, Karbi and Kashi communities have worked in the tea garden. Due to various factors in later part, people from those communities lost their interest in working at a tea garden as labourers. In some cases, the tea garden management also lost interest in people from some tribes due to their inefficiency.

With a bid to mitigate the problem of labour shortage, the then British government decided to bring in workers from various parts of India. Accordingly, the Tea District Labour Association (constituted under the Tea District Emigrant Labour Act of 1932) began recruiting labourers from six labour-surplus provinces of India. These provinces were – Bengal, Bihar, Orissa, Madras, Central and United Provinces (Govt. of Assam, 2007). The Assam Company recruited the first batch of tea garden labourer in 1841 from Bihar's Chotanagpur area. Other tea garden owners from Assam brought labourers from communities like Munda, Saotals, Orang, Saura, Kandh, Majhi, Dhanuwa, Kurmi, Tanti, Tasa, Nayak, etc. who are from outside Assam. At present, there are around 108 tribes who are working in the tea garden as labourers (Saikia M., 2008). The process of migration of labourers facilitated by the tea industry to Assam continued until 1960.

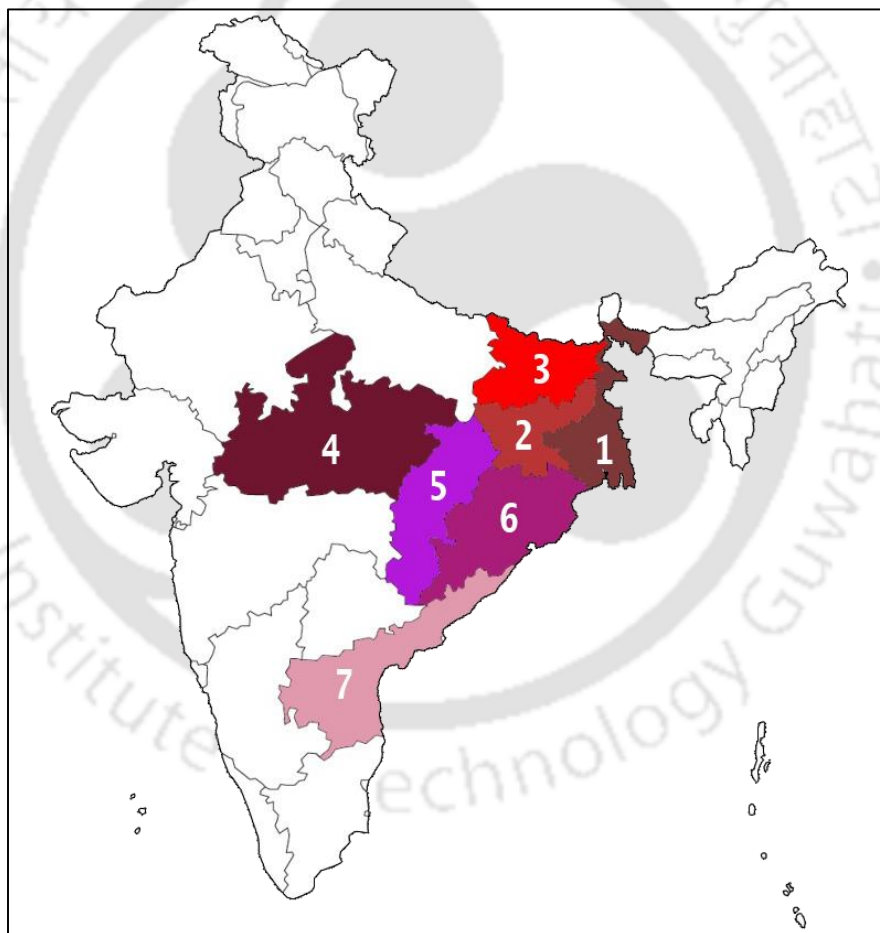


Fig. 2.3: Map of India showing the origin of current tea tribes of Assam: 1. West Bengal, 2. Jharkhand, 3. Bihar, 4. Madhya Pradesh, 5. Chhattisgarh, 6. Odisha, 7. Andhra Pradesh. Adopted from (Saikia M., 2008)

2.17 Migration process

The labourer, who came to Assam, had a trying time. The agents, also known as independent (free) contractors, enticed the labourers with secure employment, decent wages and healthy habitation. However, in reality, the labourer received a raw deal. The mortality rate among them was high, and the abuse of the contractors was so grave that it was protested in various quarters (Talukdar, 2007).

Initially, Rangpur district was the main collection centre for the labourer, and the company opened up some transit camps which were known as labourer depot. There were two types of depots, viz Debarking Depots & Inspection Depots (Akhtar, 1939).

Debarking depots

Those depots are mainly used as labourer collection camps. There were around thirteen such depots across Assam.

Inspection depots

Those depots are primarily used as government inspection and health inspection point for labourer during transit. There were around five such depots in Assam.

2.18 Survival of migrating labourer vs. economía of migration

Many of the labourers died during transit due to poor living conditions. Initially, the collection agents promised the labourer for good food, house & wages during their stay in Assam. However, in reality, the picture was entirely different.

For example, In between 1863-66 around 84,915 labourers migrated to Assam and within this period 30,000 labourers expired due to poor living condition and lack of medical facility. They were treated as Semi-Slaves (Hazorika, 2016) (Akhtar, 1939).

Three stages may be observed in the process of migration to Assam Tea Gardens (Akhtar, 1939):

Recruitment

This is the time from the prospective immigrant is induced to leave his native place to the time when he is brought before the forwarding agency.

Forwarding

This is the system through which the labourers are transshipped to tea gardens in Assam—their collection in the depots and transport by railway or steamer, as the case may be, and proper supervision of their needs and comforts during this stage.

At gardens

This stage lasts as long as a labourer continues working in the tea gardens. This raises problems of his wages, conditions of work and payment, housing, water supply, medical aid, general welfare, and finally repatriation if he wants to return to his native place.

2.19 Governmental intervention

Governmental intervention has influenced each of the above mentioned stages and solved the problem involved in each stage. Before Act III of 1863 was passed, recruitment and forwarding were entirely free. The result was the emergence of an unscrupulous class of contractors who profited by the pressing needs of the industry on the one hand and the ignorance of the labour class on the other. Ultimately the viciousness of this system attracted the attention of the government, and following the investigations and recommendations of the Committee of 1862, Act III of 1863 was passed. This Act provided for compulsory licensing of contractors and recruiters, medical examination of the immigrant, licensing and inspection of steamers. The licensed contractor, however, was no better than the unlicensed one, nor were his recruiters any better. Medical inspection only certified that the labourer was fit to go to Assam, irrespective of the fact, whether he was fit to work there. The prime necessity was to prohibit recruitment through contractors and his recruiters. This desirable reform took a long time to come and was only made effective in 1915. In the meantime, old labourer or gardens' Sardars were recognised as a recruiting agency, side by side, with the contractors' agency. This was done first by Act II of 1870 and was further confirmed and regulated by Act VII of 1873. Act VII of 1873 introduced another innovation of encouraging free immigration to Assam by recognising a class of free labourers under contract not exceeding one year (Akhtar, 1939).



Fig. 2.4: Tea garden workers with Sardars in Indian tea estate during the 19th century. Source: Royal Geographical Society, London

However, it was definitely more encouraged by the measure that followed, i.e., Act-I of 1882, which allowed immigrants to go to labour districts without entering into any contract and allowed them to enter into contracts there, either under the Act or without it. The garden Sardar and the contractors still continued, but successive legislative measures tended to relax the restriction on the garden Sardar while tightening them up in the case of the contractors. The abuses of this migration, however, led at first to the amendment of the Act of 1882 by Act VII of 1893, and later its replacement by a new measure. Act VI of 1901 Act VI of 1901 allowed local governments to prohibit unlicensed recruitment and placed several restrictions on licensed recruitment. Spontaneous immigration, especially in Surma Valley, didn't interfere with, though some control was exercised on garden Sardars securing recruits, outside the provisions of the Act. This Act was in operation for nearly 30 years and it was amended and altered several times making fundamental changes in its functioning.

After the prohibition of recruitment by contractors in 1915, the only recognised agency for assisted recruitment came to be the garden Sardar. The position became so anomalous that on the recommendation of the Royal Commission on Labour, a new Act (XXII of 1932) had to be passed. Under the present Act, recruitment before the

forwarding stage has been freed of restrictions. As regards forwarding each Act repeated with modifications, wherever required, the provisions about constituting depots for forwarding of recruits and medical and food arrangements in them and throughout the journey to Assam. The result was that the mortality en route to Assam which was enormously high when first it attracted the attention of the government has become negligible later (Hazorika, 2016).

As regards conditions of life and work in the gardens, the fundamental problem to be solved was how to ensure a decent remuneration to the labourer on the one hand, and how to satisfy the employer on the other that the expensive recruiter worker would stick to his garden on arrival in Assam. To attain the former, minimum wage rates was provided first by Act VI of 1865 and subsequently by the measures that followed. These rates were flat monthly rates (in some case varying with the increase of the period of stay) to be paid contingent on the performance of work for the period. The rates, however, were rather low and thus did not much benefit the worker. The only thing that helped disorganised labour force was that he was the pressing demands of the industry for labour. The provision for minimum wage disappeared with the disappearance of the penal contract. This was the method by which the employer was made secure against the labourer deserting him. The breaking of contract by labour was a criminal offence under this system. If the employer broke it, it was only a civil offence. This system was responsible more than all the other factors put together for the great prejudice that prevailed against the labours of the tea industry in Assam for over half a century. The system finally disappeared in 1926 with the repeal of Act XIII of 1859. As far as Act VI of 1901 was concerned, the penal contract had disappeared since 1915, when the chapter containing the Labour Districts Provisions ceased to apply to the remaining four districts of Assam (Akhtar, 1939).

Along with the penal contract as already mentioned the provision of the minimum wage disappeared. The new Act contains no such provision. Fixing of a minimum wage has become more essential now than ever before, because, due to depression in the industry and growth of local labour supply, the demand for immigrated labour has been considerably reduced. This one factor that used to help the unorganised labourers—the factor of keen competition among employers has also disappeared. The serious fall in the wage level seems to confirm this view. The necessity of evolving a wage fixing machinery on the lines laid down by the Royal Commission is, therefore, indicated.

As regards the other factors, on which depends the general welfare of the labourers on gardens, the various legislative enactments have succeeded in compelling the planters at least those who required compulsion—to provide various facilities for the health and happiness of their labour force.

The labour commissions recognising the above fact initiated admirable attempts for the welfare of the labour class that suited best for the gardens. Thus, further emphasis was given to the necessity of the followings:

- i. Keeping records of births and deaths;
- ii. More generous allocation of land for grazing and cultivation;
- iii. More active policy regarding anti- malarial work;
- iv. Better spacing of houses and improved construction;
- v. Construction of bathing and washing places;
- vi. Annual mass treatment for hookworm disease;
- vii. Adequate latrine arrangements;
- viii. Appointment of women doctors for training and supervision of midwives;
- ix. Legislative enforcement of maternity benefits;
- x. General adoption of the practice of feeding non-working children;
- xi. Appointment of health visitors;
- xii. Prohibition of employment of children below the age of ten;
- xiii. Provision for the education of children;
- xiv. Provision for inspection of gardens;
- xv. Constitution of Boards of health and welfare;

As already mentioned, most of the above facilities and provisions existed in varying degrees on different tea estates. A general equalisation and rising of standards, however, is imperative. Moreover, one can do no more than endorsing the expert advice of the Royal Commission.



Fig. 2.5: A 19th Century Tea Garden in India. Source: Royal Geographical Society

2.20 Cultural background

2.20.1 Evolution of Ex-Tea tribe

Initially, those labourers were under a bond period of five years. However, after the expiry of the bond period, they did not show their willingness to return to their homeland. This is because they were given land near the tea garden by the garden administration to settle down; moreover, liquor & opium were readily available in and around tea gardens. They settled in government “Khas land” or unused tea garden land in the vicinity of the tea estates so that they could earn their living as casual labourers in the tea gardens and also they can use those lands for cultivation. This created the Ex-Tea Garden tribe (Talukdar, 2007).



Fig. 2.6: A 19th Century Tea Garden worker depot in India. Source: Royal Geographical Society.

2.20.2 Present scenario: Assimilation with native culture and societies

Tea tribes of Assam are placed among the most backward and highly exploited tribes in India, even though the present generation is comparatively educated and even has intellectuals and professionals in various fields. Members of the tea tribes, being labourer, live in villages, inside tea estates (established by tea planters). These estates are located in interior places, and this contributes to their backwardness and exploitation by the tea planters. The workers, in a way, are forced to live with the basic facilities provided by the tea planters. The tea planters usually exploit the tea tribes in every possible way. Violence and agitation of labourer against the management are very common, and here the state machinery normally protects the tea planters. Lack of education, addiction of males to country-liquor, poverty, poor standard of living and health facilities are the core problems of their lives. There are instances where it had been witnessed that tea planters did not even supply life-saving drugs to workers when they were dying in epidemics. Every tea estate has a government of India appointed 'welfare officer,' but in most cases this is just a showpiece appointment (Sarma G., 2013).



Fig. 2.7: View of Chinamora Tea Garden Workers colony

2.20.3 Social bonding, merger with main stream

Over time, the tea tribes gradually adopted the Assamese culture. Majority of them became the followers of Srimanta Sankardeva, and some of them converted to Christianity.



Fig. 2.8: Naam Ghar (Traditional prayer hall) at Chinamora tea garden workers colony

After a long journey of 200 years, the people from the tea community is suffering from identity crisis, though they were trying to merge themselves with the mainstream of Assamese culture, but still they have to face resistance time to time from various sources.

2.20.4 Recent turmoil

An ethnic clash between Bodo tribe (one of the largest tribes in Assam and North East India) and Santhals (the descendants of indentured tea labourer have migrated from the erstwhile Bihar's Santhal Pargana district) erupted in early 1996. The reason for this ethnic clash was the ban imposed on the Santhals from entering into the forest, which caused a severe blow to the economy of the Santhals. The tea tribes are demanding for Scheduled Tribe status for their upliftment to which the Indian government has not given its consent and creating discontent among the tea tribes (Sarma G., 2013).

All the above factors are creating a new challenge to the tea industry and there is no single solution is evident in future.

In the next chapter, various aspects of tea plantation and tea manufacturing have been discussed.

Chapter 3 Tea Plantation and Tea Manufacturing Process

Camellia Sinensis commonly known as tea is a plantation and commercial crop, considered to be one of the top revenue generators in the world. Capable of self-sustenance, the tea plant is found mostly in tropical and sub-tropical regions.

Tea processing, starting from germination of tea seeds (or growth of saplings) to the finished product is a delicate process and takes into account many factors like economic, geographical, demographical, socio-cultural and more. Managing a tea garden involves a continuous daily effort, both by the labour force and the organisation.

The process requires a significant amount of investment, both in terms of time and money (TRA, Tocklai, 2014). The tea production process can be divided into two parts, viz. Field operations and manufacturing process. The field operations or field management covers tea nursery related activities, pruning, tipping, plucking, leaf handling, shade management in plantation, application of fertilisers, pest control and weed control. After plucking the tea leaves, these are transported to tea factories where processing of the tea starts. To obtain the final product green tea leaves are subjected to various sub-processes in the tea factories.

3.1 Nursery

The tea nursery or 'Seed Bari' is an essential part of a tea estate. In the nursery, tea plants are cultivated from seed or from grafting/cloning. In some small tea gardens, the tea nursery is not present.

3.1.1 Propagation from seed

Seeds from tea plants are placed on galvanised iron sheets under sunlight. 16-18 hours are required for seeds to crack when placed on the sheets. For selecting good seeds, they are first placed in water. The seeds which remain on top are discarded while the rest is used for plantation. The eye of the seed, also known as micropyle, is the little pore in the seed that lets water to enter for beginning the germination process. The seed is to be oxidised for germination, and it takes 9-10 days for the leaves to come out of the seed. Polyethylene bags are used which can hold about 2.5 kg of soil. Some holes are punched in the bags for excess water to drain out. It takes around 30-40 days for the soil to settle down (Willson & Clifford, 1992). In Assam, the soil has to be first tested in Tea Research Association, Jorhat before it is put in polythene bags. Both micro

and macro nutrients are required, of which micronutrients are of more importance. Nitrogen is necessary for the growth and potassium necessary for flowering (TRA, Tocklai, 2009).



Fig. 3.1: Seeds being raised in polythene bags in a tea estate of Assam. Photo by Dr.Pradip Baruah

3.1.2 Propagation from leaf

The leaf is grounded at an angle in the bed after dipping it in a 1 % solution of $ZnSO_4$ (Zinc Sulphate) and adding Rootex paste to its cut end for the growth of roots within 4-6 months. Saplings are grown in soil having pH in the range of 4.5-5.5 and organic nutrients. In the case of mother bushes, manure is added to the young tea dose (YTD) mixture in the ratio 2:1:2 @ 150 kg wet/ha in two shifts:

- i. April to July
- ii. August to September

In clone plants, rooting bed is introduced and in this method roots develop in 4-6 months. In this approach, leaves are cut in the middle. The newly cloned tea plants were called V.P. tea bushes. Rootex-root hormone powder is used for early growth of the root, Zinc Sulphate ($ZnSO_4$), an antibacterial, is also added. Leaves are kept erect so it is not done in a straight way, the shoot is not covered, and the process of photosynthesis goes on. The leaves are put in a certain area (Hazarika, M, 2005).



Fig. 3.2: Workers at Seed Bari



Fig. 3.3: Propagation of tea plant from leaf at a Seed Bari

3.2 Pruning

Pruning is the selective removal of parts of a tea plant like branches, roots, and buds. In tea cultivation, pruning is a widely used horticultural practice which helps to get rid

of any diseased, damaged, unproductive, unwanted or dead tissues from the tea plant. This helps in maintaining and improving the health of the plants. Proper pruning also results in a level plucking table. (Sarma A. C., 2012).

Pruning is one of the most critical operations of tea production and directly determines the productivity of tea bushes. If pruning is delayed, the size and weight of growing shoots on the plucking surface decrease. There is a preponderance of *banji* (Dormancy) shoots on the plucking table, as more and more buds fail to multiply with the loss of vigour. Pruning is, hence, necessary to maintain vegetative growth. (TRA, Tocklai, 2013).

3.2.1 Objectives of pruning

Young tea plants are pruned for the following purposes. (TRA, Tocklai, 2013)

- i. For quick ground coverage by producing a low, spreading frame.
- ii. For facilitating harvesting, both manual and mechanical.
- iii. For developing a robust framework that can sustain luxuriant vegetative growth.
- iv. For harvesting a maximum crop yield.

Pruning is a necessary operation for diverting the energy of the plant towards the production of leaves. Mature bushes are pruned at regular intervals to renovate the branch system and to keep the tea bushes in the vegetative phase. The operation triggers the production of fresh sets of robustly growing branches, replacing the old set. Pruning therefore not only controls but also triggers new growth.

3.2.2 Procedure of pruning

Pruning is carried out by using a knife with long blade and quick cope (known as pruning knife) or secateurs (clippers). Secateurs could have short blades to cut small branches or long blades for larger branches. While using secateurs, it must be ensured that it remains sharp; otherwise, they will overwhelm the stem and slow the boom of the plant. It is also advisable to 'polish' the cuts with a sharp knife so that water cannot stick to the cut surface. (If the cut remains wet, it is much more likely to get diseases).

For mild pruning of young tea plant, a 15 cm blade is used while for cleaning a smaller knife of 7.5-10 cm is used. The minimum weight of knife used for light pruning is 450gm as lighter knives cause wood splitting.

Wounds are formed at an angle of 45° to permit any water to empty with branches always from the inside to the outside. A high side of every wound facing outwards on the bush. When high sides of the cut branches are outwards, then the new shoot will also grow to the outwards of the plant and this will create bigger plucking surface.

Reduction of the tops of the tree kept parallel with the slope of the land (Fig.3.4). Without this, the part of the tea bush on the better give up of the slope will increase slowly than the component on the lower quit (Lesser number of new leaves and shoots will increase on the higher quit). There may be one small exception to the rule of thumb of pruning parallel to the slope. Prune the middle of each bush a bit greater than the out of Doors, developing a 'hollow' form of the bush. The reason for this is that the centre of the tea plant always grows faster than the out of Doors.

The frame of the bush can be covered with the branches and leaves eliminated through pruning to lessen harm from sun scorch. If the tea plant has fungus sicknesses, or if the bush body is heavily overgrown with lichens or algae, it is advisable to clean the body with lime or caustic soda combined with water (Michael & Braber, 2001), (Tushar, 2014).

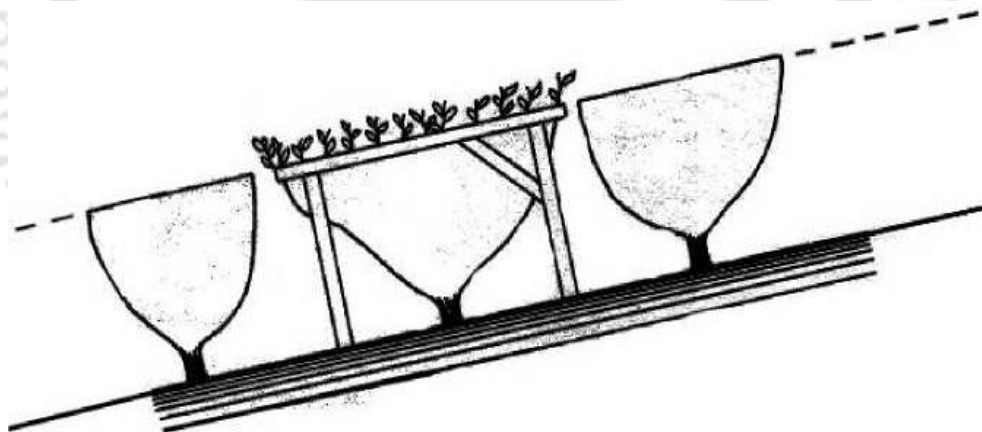


Fig. 3.4: Schematic diagram of tea plant's height in relation to ground level for pruning. Adapted from Bonheur, D. 1990

The thickness of branches should be the criterion for figuring out the height of pruning. Usually, a 4-12 month pruning cycle is observed in mid-elevation areas and five-year cycle at extreme altitudes.

3.2.3 The procedure of checking plant readiness for pruning

As suggested by Sarma (2012), the procedures of checking plant readiness are as follows:

- i. A hole, 15 cm deep and 10 cm from the stem of the young tea plant are to be dug.
- ii. Roots, which are at least half a centimetre in diameter, should be used while the larger roots exposed by the hole, cut off.
- iii. Roots to be held vertically and make smooth cuts across the ends.
- iv. A drop or two of iodine solution to be applied to the end of each root, It should be held vertically for five minutes, then iodine to be shaken off.
- v. The amount of blue colour produced to be observed. A deep blue colour spread throughout the surface of the root suggests an excessive concentration of starch. These plants have enough strength to get over pruning.
- vi. If the roots are very pale or do not show any colour, the amount of starch is low and would possibly need to hold off the first pruning.

For tea grown from seeds, three annual prunes are required to shape the frame of the bush.

First pruning is done at the height of 12-15 cm from the ground at the end of year two or beginning of year three (mid-December to January). In this prune, the central stem is cut. Branches are not cut even if the tips grow higher than 15 cm above the ground.

Second pruning is carried out after an interval of 12 months when tea leaves reach a height of 30-35 cm.

Similarly, third pruning is done 12 months after the second prune, at the height of 40-45 cm. Pruning is carried out from December to January.

In tea grown from cuttings, side stems grow more than the tea grown from seeds. Moreover, tea grown from cuttings tends to have more and bigger stems. For these reasons, only two formative pruning are required (Sarma A. C., 2012).

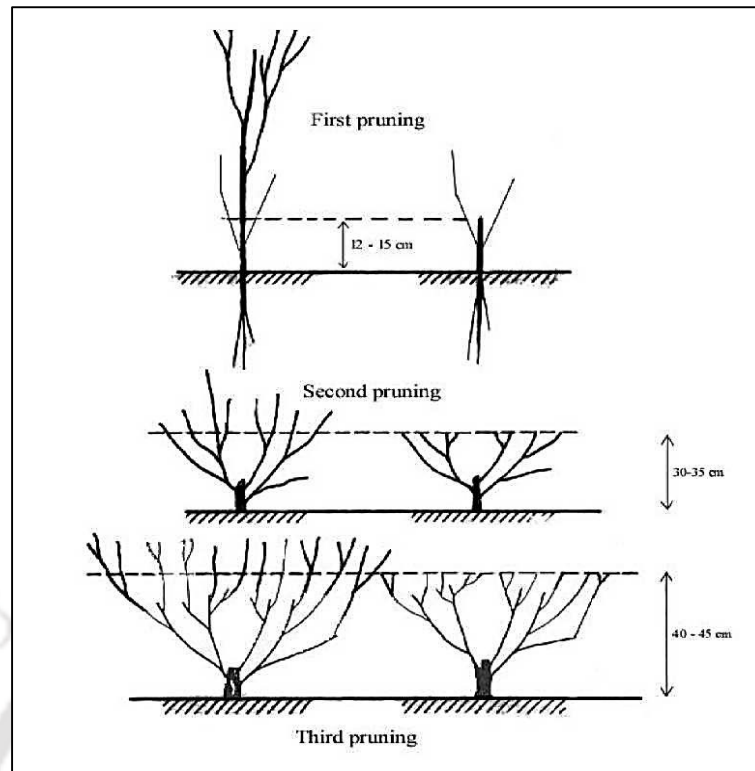


Fig. 3.5: Pruning for young plants growing from seeds. Adapted from Bonheure, D. 1990

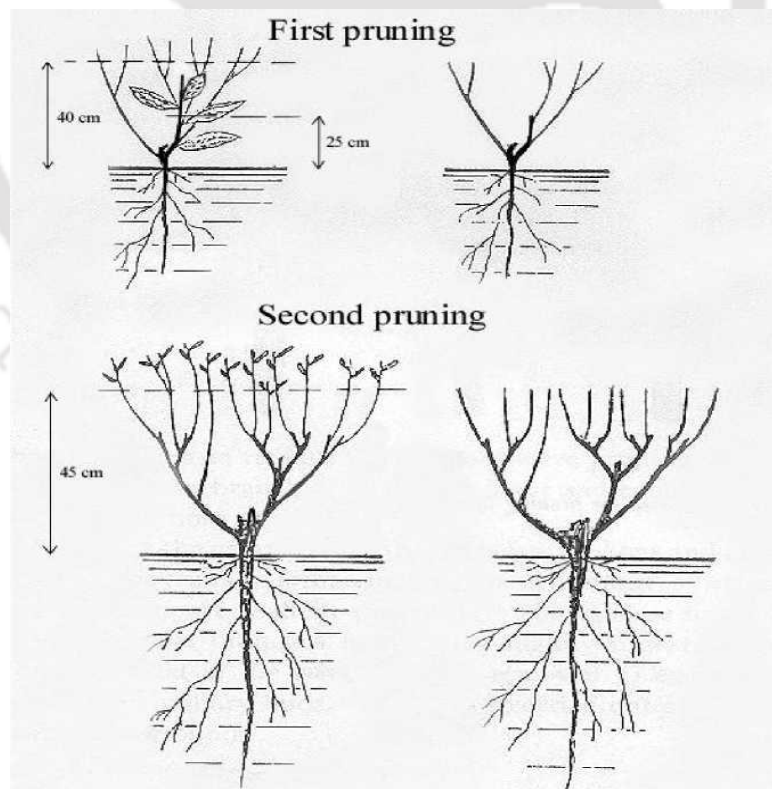


Fig. 3.6: Pruning for young plants grown from cuttings. Source: Bonheure, D. 1990

3.2.4 *Types of pruning*

Pruning activities can be mainly classified as under (Dutta 2005):

i. Unpruned (UP)

Untouched or levelled by hand.

ii. Heavy prune / Rejuvenation prune (RP)

Hybrids in the hill areas are cut leaving only up to a maximum of 15-37 cm above ground. In the plains, entire portion above ground is cut leaving only up to a maximum of 40-45 cm above ground.

iii. Medium prune (MP)

Used for top frame renewal and height reduction. Entire portion above ground is cut, leaving only up to a maximum 50-65 cm in plains and 35-50 cm in the hills.

iv. Height reduction prune (HRP)

The entire portion above ground is cut leaving only up to a maximum of 70-75 cm in plains.

v. Light prune (LP) or cut across

The entire portion above ground is cut leaving only up to a maximum 4-5 cm above the last prune. The wood is renewed for the growth of new branches and bushes are cleaned out.

3.2.5 *Pruning time*

The time of pruning depends on several factors like soil, climate, and topographic conditions. The optimum time to prune is when the plant's carbohydrate reserves are high, and it is dormant, or its growth rate is the slowest. The exact time, however, depends on climate, locality, crop and quality requirements, diseases, seasonal crop distribution and susceptibility to pests.

In Assam pruning is done during the plucking off-season i.e. between December and February is regarded as the ideal period for pruning in the North East, considering the starch reserve in the roots of tea bushes. While the content of root starch was found to

be maximum in February, light pruning during this month produces a later season crop compared to the pruning of December-January.

According to the Tea Research Association, Tocklai, pruning operation should be carried out during branch formation stage, with the best season being mid-December to January. It must be ensured before the first pruning (at the end of year two), that the young bushes have a sufficient storage of energy (starch) in their roots. For checking, an iodine solution is applied to the cut end of roots, and any colour change is noted. When iodine touches starch, the starch turns blue (Dutta, Saikia, & Sarma, 2005).

Pruning is not recommended during the first year, although for a thin and lanky young plant, it is useful to fold over the tip of the plant without completely breaking it off. This directs the plant's energy at its lower parts, making it grow stronger and thicker, thus preventing it from falling over.

The first pruning is carried out when the main stem has a diameter of over 0.7 cm, and the plants height is over 70 cm (Michael & Braber, 2001).

This first pruning is performed in between mid-December to January at the start of year two. During the first pruning, the main stem is reduced to a height of 12 to 15 cm above the floor, and other stems at the height of 15 cm above the floor are not to be touched. The second pruning is executed a year later and is done at the height of 30 to 35 cm above the floor. The third pruning to be carried out after twelve months from the second pruning at 40 to 45 cm (Michael & Braber, 2001).

3.2.6 Factors affecting pruning time (Tea Research Institute (TRI), Sri Lanka, 2013)

- i. Sun scorch
- ii. Drought and blisters
- iii. Desired regrowth time
- iv. Required rest period
- v. Crop requirement
- vi. Kind of tea
- vii. Age and vigour
- viii. Frame height
- ix. Knotty horizon
- x. Busy hygiene

- xi. Shade status
- xii. Irrigation facilities

3.2.7 Cycles of tea pruning

A pruning cycle consists of a prune observed through lighter styles of reducing or unpruned, till the bushes are pruned once again. Tea productiveness increases when the annual pruning is substituted with longer cycles through the introduction of skiff or unpruned. The duration of pruning must ensure that the branches of the bush continue to be uniformly thick, leading to the most quantity of pruning sticks on the frame.

For plain areas, the pruning cycle may be 3-4 years while for the hill areas like Darjeeling, etc. the span may be 4-5 years depending on the elevation (Dutta et al., 2005).

3.2.8 Procedure of choosing correct pruning cycle

Studies show that sustainability is lost after 2-3 repeats, irrespective of the span of the cycle. This indicates that a pruning cycle of fixed duration is not conducive for crop optimisation.

Main reasons for this could be the age of the bush and wood, vigour, bush frame, and hygiene. However, a 3-year cycle of LP - Deep Skiff (DS) – Unpruned (UP) or LP-UP-UP is ideal in comparison to any other cycle in mature young tea, after final frame forming prune and in old tea after bush frame rectification. Studies have also indicated that three-year pruning cycle helps to sustain productivity better than a four-year cycle in plains of North East India. LP-DS-UP was found to be advantageous over other cycles both in terms of productivity and quality. Depending on vigour and bush age, four-year cycles could sustain 1-2 repeats while three-year cycles could sustain up to three repeats.

Some common pruning cycles are (Sarma A. C., 2012):

- a) 3-year cycles
 - LP-UP-UP- Crop oriented
 - LP-DS-UP- Quality oriented
 - LP-DS-MS- Quality oriented

b) 4-year cycles:

LP-UP-DS-UP

LP-UP-MS-UP

3.2.9 Conclusion on pruning

A practice followed from the beginning of tea cultivation, the height of the plucking table has to be kept within easy reach of pluckers. In Bangladesh, pruning or skiffing of the tea bushes are done every year due to geographical location and environmental fluctuations. Most of the tea growing countries prune once after an interval of 3-4 years. In India, tea is harvested for 9-10 months in a year. There is very less yield in tea gardens of Assam from the third week of December to the first week of March and is considered a lean period for Assam tea. This is the best time for pruning. A long rain free period, low temperature leads to the restriction of the standard growth of shoots. Pruning of the tea bushes during this time prohibit transpiration loss; pruning litter covers the soil surface and reduces evaporation loss. For these reasons, pruning in India has to be done to keep the bushes at a vegetative phase along with convenient height.

The basic aims of young and mature tea pruning are different. The main purposes of young tea pruning are to make a permanent frame, develop quick canopy coverage and to increase the number of active branches. Ali (1970) stated that considering the quality and growth of tea bushes, 3-4 year pruning cycle could be followed. Ali further opined that longer pruning cycle with lighter skiff resulted in a reduction of crop quality. Barbora (1994) suggested a four-year pruning cycle, LP-UP-DS-UP for the North East while Barua (1989) stated that a three-year pruning cycle is most satisfactory for plain areas, with proper adjustment of various skiff combinations. He also mentioned that in higher elevations, the pruning cycle might be extended up to six years. Biswas (1977) observed that at lower elevations, pruning cycles longer than three years are less productive.

3.3 Skiffing

Skiffing is the lightest pruning with foliage levelled off and only green stems eliminated. The top 5 – 8 cm new growth is removed to obtain a uniform degree of plucking surface. If the timber is pruned about 75cm, it is called skiffing. In the plains of North East India, tea plants are pruned every 12 months when trees enter the dormant segment.

Although this technique is not practised, trees are reduced gradually every year, and this is called skiffing. Nowadays, yearly skiffing is not done by many estates and the trees are left unpruned for two successive years. Bushes can be skiffed deep, medium, mild or degree. Skiffing may be repeated for 2-6 years (Hazarika, M, 2005).

Deep skiffing is given at a top, mid-way between pruning and tipping. In medium skiff, the cut is closer to the tipping height, about 5cm under the tipping level.

The introduction of skiffing in North Eastern India has led to growth in productivity. However, skiffed bushes are at an extra risk of drought and get heavily infested with pests including spider mite and tea mosquito bug (Hegde, N K; 2011).

Various forms of skiffing operation are as follows:

3.3.1 *Deep skiff (DS)*

Deep skiff is a cut given halfway among the pruning and tipping levels, performed after a mild prune. As an example, tea tipped at 20 cm might be deep skiffed at 10 cm above the preceding pruning stage. Deep skiffing done after a year or more of unpruned or degree skiffs is a cut halfway among the pruning stage and the height of the desk. It is done at the stop of the season, and the height comes at 12.5-15 cm from the ultimate LP mark.

3.3.2 *Level off skiff (LOS)*

Level off skiff is carried out to cut off the highest plucking point and for level up. LOS is done at 5 cm above present year's tipping level.

3.3.3 *Medium skiff (MS)*

Medium Skiff carried out after a LP; tea bushes are tipped at 20 cm while deep skiffed bushes are tipped at 10 cm. Plants might be cut at the top, 15 cm from the pruning mark

or five cm beneath the final tipping stage. Medium skiffing is done after one or more years of unpruned, light skiffed or stage skiffed years. It is given just under the “crow’s feet,” fashioned by the closing year’s plucking. It is carried out just below the majority of crow’s feet to remove blockage (Dutta et al., 2005).

3.3.4 Light skiff (LS)

Light skiff carried out at present year’s tipping level to re-establish the level.

3.4 Tipping

Tipping can be defined as the first stage of harvesting. Correct and proper tipping can help develop right frames in the bushes. Tipping is also the first round of plucking of recovering bushes. The aim is to establish a level plucking surface and to provide adequate maintenance foliage for faster production of secondary branches (Hegde, N K; 2011).

Primary shoots arise in a pruned bush from the dormant buds that are present on the sticks. These are beheaded or tipped at a planned height to take care of the depth of maintenance foliage and build a level plucking table. Maintenance foliage or dark leaves are the shoots below the plucking table which provide nourishment and sustenance to the pluckable leaves. The leaves left on the bush after tipping is the protection foliage. Tipping heights depend on the type of pruning and skiffing (Hazarika, M, 2005).

3.5 Plucking

Plucking refers to the harvesting of tender apical shoots growing above the predetermined plucking table. The sole purpose of plucking is harvesting of tea. Plucking can also affect the long-term health of plants and help manage insects and diseases. Planters should measure plant health and pest damage while deciding to choose the best method for plucking and not just tea yield and quality. Besides giving a crop, plucking encourages regeneration of new shoots, checks the vertical growth of bushes and keeps them in the vegetative phase.

Plucking is the primary economic activity in a tea garden and is the most labour intensive operation in tea cultivation. As per the Labour Bureau (2008), the majority of the workers in a tea garden are leaf pluckers.

In tea industries, plucking amounts to 40% of the total cost of production and 70% of total workdays (Bhattacharyya, 2011). Young and soft vegetative components or shoots from tea bushes are harvested. These are then used as substances for processing tea within the manufacturing facility. This happens at the expense of metabolites furnished with the aid of mature upkeep foliage underneath the plucking table. Willson and Clifford (1992) mentioned that the young and smooth leaves are capable of taking an active part in photosynthesis, though these leaf regions do not get an opportunity to supply metabolites due to tipping and continuous plucking. Hence a sufficient active photosynthesis area should be kept at the time of tipping.

In Assam, March–November is the ideal plucking season while August, September, and October constitute the top plucking months. A graphical representation of the same is provided in Fig. 3.7.

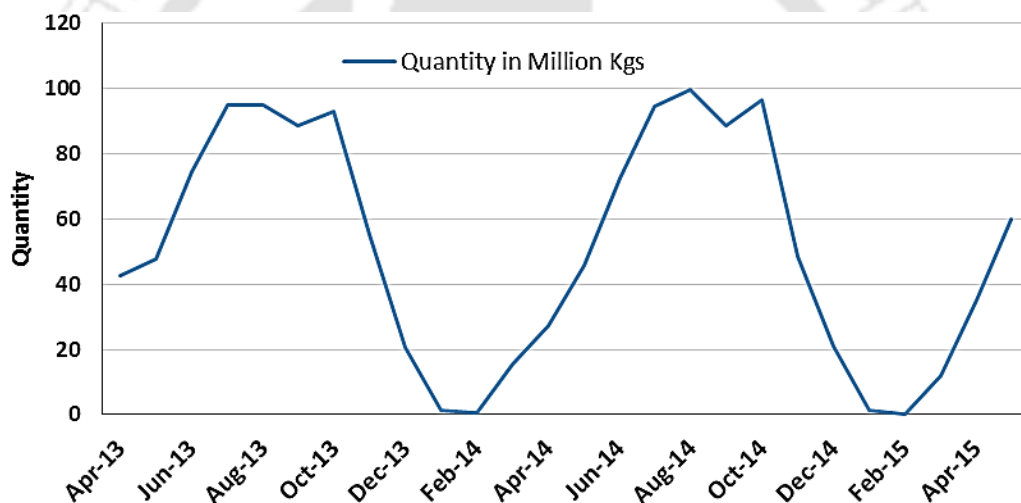


Fig. 3.7: Tea production cycle in Assam. Source: TBI

In India manual plucking operation is more widely used over mechanical means. Details on mechanical harvesting are discussed in Chapter 4.

3.5.1 Tea flushes

Periodic harvesting of new growth or different harvesting periods of tea is known as flushing. This operation consists of mainly plucking the top 2-3 newly grown leaves and buds at regular intervals. The shoots plucked this way are taken to the factory for manufacturing tea. These buds and leaves are commonly known as “flushes.” A tea plant will grow a new flush every seven to fifteen days during the growing season. This growing interval is dependent on some factors like climatic condition, quality of soil,

type of plant, etc. The best quality of tea is produced from the first two leaves and the bud (Maudu et al., 2012). Leaves that are slow in development always produce better flavoured teas (Barua P. K., 1970), (Barua D. N., 1989).

Flushes are significant periods of production for planters. There are typically four flushes in a year (Barua P. K., 1970), (Tea Monk, 2016):

i. First flush or Spring flush

It is the first harvests of the year which usually carried out during the month of March and April. This flush produces tea with the refreshing sweet aroma. The liquor is a pale yellow, and first flush tea is one of the most expensive teas in the market.

ii. Second flush or Summer flush

In between the month of May and June, the second flush is carried out. It is also known as summer flush the tea produces from this flushes have strong flavours. The best quality of Assam tea is produced from the second flush (Baruah, 2008). When brewed the tea turns a deep copper.

iii. Third flush or Monsoon flush

During the month of July to September, the Monsoon harvesting is carried out. This is also known as the third flush. The brewed teas from this flush are strong, addictive and amber in colour.

iv. Autumn flush or fourth flush

The Autumn flush or fourth flush is the end of the year harvest. In Darjeeling and Assam, this harvest takes place in October to December while in the southern hills of Nilgiris, the Autumn harvest happens between December and January.

Plucking operation is having a direct impact on the quality of the tea leaves and depends on temperature, time of year, day length, etc. In summer, production is more due to high temperature while it is low in winter. A plucking round is completed if harvesting is done in one section and repeated in the same section after seven days. 34-35 rounds of plucking are done in a year. Maintenance leaf has a life of 18 months and leaves at the height of 10cm from the level accounts for seventy-five percentage of the top crop.

3.5.2 *Method of plucking*

The method of plucking is almost similar in India; following types of plucking systems are adopted (Hazarika, M, 2005).

- i. *Janam* plucking: Done just above *Janam* leaves. (Suitable for North East India).
- ii. Fish Leaf plucking: Carried out above the fish leaf (Gol Pat) – this process is not suitable for the North East. The tea growing areas where plucking is done round the year or the plant growth is slow (Dutta, Saikia, & Sarma, 2005).
- iii. Step-Up plucking: Done by leaving one leaf on the plucking table. It is employed when maintenance foliage is damaged due to pests, hail or other biotic, abiotic stress.

3.5.3 *Standards of plucking*

- i. Standard plucking is the process when all new shoots that are above the plucking table are plucked leaving single buds and one leaf. It should be practised when growth conditions are optimum, from June to September. Here, plucking is done on leaves, buds and a small one and buds on the bush. The rest are plucked to tipping level (Hazarika, M, 2005).
- ii. Black plucking: In this process, everything above the plucking table is plucked. This is used to remove dormant shoots (Banjhi) and pest-infested shoots other than unopened buds, black plucking removes everything above tipping level.
- iii. Coarse plucking: In this process leaves, buds, one leaf and bud, small two leaves and bud on the bush are plucked. The remainder is plucked to tipping level.

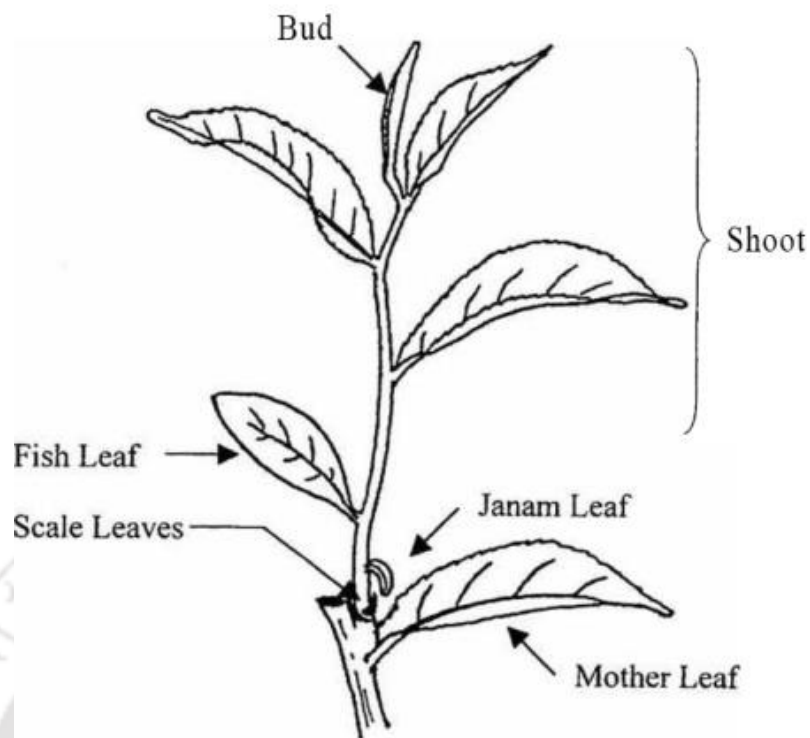


Fig. 3.8: Physiology of tea shoots. Source: Wilson K.C. (1992).

3.5.4 *Plucking interval*

The gap (in days) between two consecutive rounds of plucking in the same section is known as plucking interval. The standard interval is seven days but can vary between 5-6 days in peak growing season (June- September). However, during early and late seasons, plucking interval can be of 9-10 days. It is also known as plucking rounds (Dutta et al., 2005).

Recovery of the tea bushes from DS, LP, MS and LS helps in maintaining this ratio, improve the health of the bush and maximise yield. This is achieved by the 5, 3, 2 and 1 layers of maintenance leaf above the cut mark. The right time to start tipping is when 10-15 percent of the growing shoots reach tipping height in skiffed or pruned bushes. Tipping and plucking rounds of seven days are useful to increase generation numbers and boost crop production. A significant amount of crop is lost due to unwanted creep height. *Janam* and fish plucking are more efficient in controlling creep height. Light plucking is utilised when parallel developments dwindle and creep height increases at a fast rate. *Janam* plucking helps to control creep height in the light pruning and deep skiff sections while fish leaf plucking is utilised for light and medium skiff areas. During peak cropping season, a seven-day plucking round is preferred for attaining

high yield and crop quality. The soft three leaves and a bud (3, 1/2) are considered fine leaf in the peak season whereas it becomes coarse in the early and later parts of the season. Young growing shoots (1, 1/2) should be left off at the time of plucking, allowing them to attain physiological maturity and gain maximum weight for the next plucking round. A shoot with physiological maturity gains 40 percent of its weight than its immature stage (Hossain, 2014).

When harvesting is carried out by using mechanical shears, then 9 to 11 days plucking rounds are to be maintained. During mechanical harvesting, plucking interval should be in between 11 to 13 days (Dutta et al., 2005).

3.5.5 The correct time of the year for plucking

The process of plucking should begin only after the plants have grown enough to restock its energy reserves. After every plucking round, one should wait till new shoots have grown 20-30 cm above the pruning level (usually by early April). This is known as “tipping level” as shown in Fig.3.8. New shoots should be snapped using one’s finger, which completes the tipping level. Tipping has two purposes:

- i. To create a plucking table parallel to the slope.
- ii. To open buds on the sides of the shoots, resulting in more growth by the bush.

Shoots growing above the plucking table can be plucked lightly after tipping. The shoots should not be plucked before the "flushing period" because during this time the tea plant grows actively. The flushing period spans from spring to summer, with highest yields during June- September. It is also important to note that timings of flushing period are different for different varieties of tea. The tea plant remains dormant before and after flushing period and has to suffer levels of strain when plucked during the dormant state (Hegde, 2011).

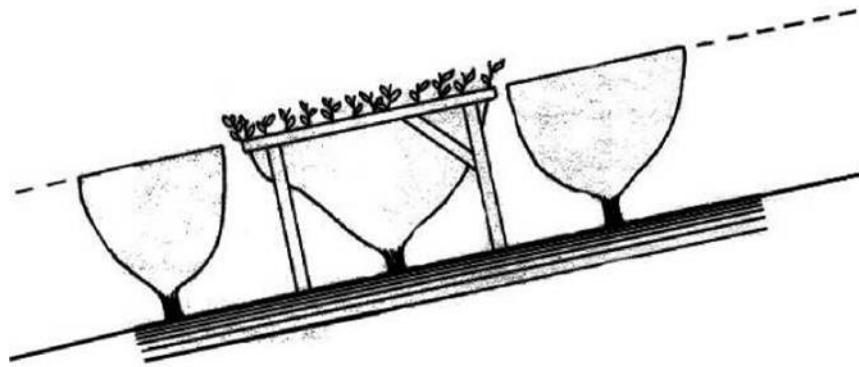


Fig. 3.9: Schematic diagram of tea plant's height in relation to ground level for tipping. Adapted from Bonheur, D. (1990)

3.5.6 Time of day and type of weather suitable for plucking

Plucking should be done in the morning as the plucked leaves can be then processed the same day. The quality of the tea also deteriorates if plucked leaves are kept overnight before processing. Another reason for plucking in the morning is that the quality or flavour of tea obtained from such shoots is superior to the leaves plucked during other part of the day because of having less soluble sugars and more catechins present in the leaves in the morning hours.

The growth of shoots and energy production of the plant is fastest and most efficient from about 8-11 hours in the morning. While labour demands may not make it feasible, tea production would be a bit higher if plucking starts late morning instead of early morning. Plucking should be avoided on rainy days as the tea takes longer to dry and loses its quality (Hegde, 2011).

3.5.7 Types of leaves suitable for plucking

Plucking is to be carried out on only the shoots growing above the flat canopy i.e. the plucking table. As per TRA, Tocklai, two kinds of shoots are to be plucked:

- i. Actively growing shoots that have at least two true foliage leaves above the rounded "fish leaf" (Fig. 3.10). Immature shoots (buds, or buds + 1 leaf) should not be plucked.
- ii. "Blind" or "Banjhi" buds should be plucked if they are growing above the tipping level. These are dormant buds that have stopped producing new leaves

and lies at the top of the shoots (Fig. 3.11). Plucking the Banjhi bud plus one young leaf revitalises buds, thus producing new shoots.



Fig. 3.10: Young 'shrimp' leaf.
Drawings by Wendy Gibbs

Fig. 3.11: Sleeping 'Banjhi' bud.
Drawings by Wendy Gibbs

If the shoots are above the plucking table, both actively growing and 'Banjhi' shoots should be plucked.

In Vietnam, some farmers as a norm pluck the shoot just above the rounded "fish leaf". The TRI, Sri Lanka however, recommends using different plucking heights according to the season (Hegde, 2011).

For spring harvest, there is a need to spare more leaves so that the plant can produce the energy it needs to recover from the stress of recently concluded pruning. Only those shoots should be plucked that are tall enough. The "shrimp leaf" and 2-3 young leaves should be plucked leaving behind two real leaves and the fish leaf.

For summer-autumn harvest, plucking should be done more often as due to the rapid growth of tea bushes, while plucking younger, shorter shoots are to be plucked during this period. If too many leaves are left on the bush, they may shade each other, and the yield may get reduced as the waiting period for plucking rounds will be longer. All tall shoots can be plucked including the "shrimp leaf" plus 2-3 young leaves. One real leaf plus the fish leaf are left behind on the bush.

For winter harvest, the climate is not favourable (temperature and humidity are both low) and tea buds grow slowly. Hence plucking should be done as soon as the buds are

ready. Otherwise, the buds will get old, reducing yield and quality. Nothing much needs to be left behind, as the bushes will soon be pruned. Plucking can be done on any shoots above the plucking table.

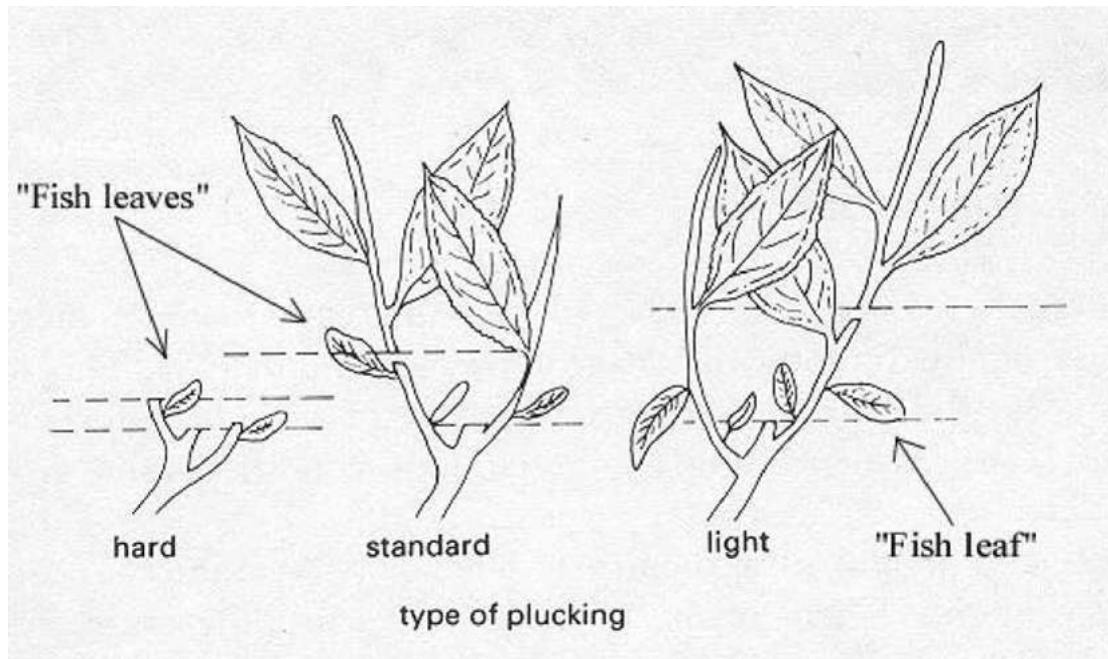


Fig. 3.12: Types of plucking, relative to the fish leaf. Source: Bonheure, (1990)

Planters in some countries always pluck above the first true leaf, or below the fish leaf (Hegde, 2011).

3.5.8 *Harvesting guidelines*

For high quality tea, only the bud and two (or at most three) - youngest leaves are tender and green enough and hence suitable for plucking. If the plucked shoot includes older leaves or stem, they should be discarded. If the shoot is plucked closer to the tip, leaving several leaves above the fish leaf, the height of the plucking table will increase too fast. Harvesting of older leaves (bud + 3 leaves) results in degradation of the quality of the tea. The third leaf has substantially less tannin and less soluble contents than the second leaf. However, the third leaf increases the weight of the harvest.

Care should be taken to ensure that the leaves are not crushed or bruised while plucking as it reduces the quality of the tea. For example, it is advised not to compress (pack down) the leaves in the plucking basket (Michael & Braber, 2001).

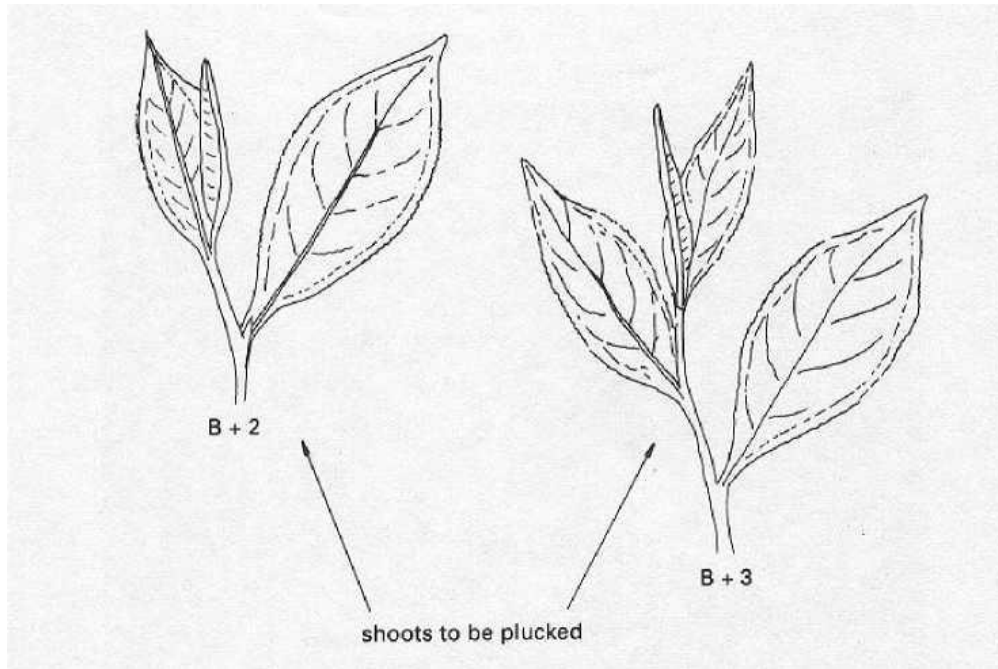


Fig. 3.13: Tea shoots suitable for plucking. Source: Hegde, (2011)

3.5.9 Guidelines for quality plucking

The R&D cell of Amalgamated Plantation, India, has recommended some guidelines for good plucking operation (Amalgamated Plantations, 2014):

- i. *Janam* Plucking should be adopted.
- ii. The small One Leaf (1L) + Bud (B) and single buds should be left on the plucking table.
- iii. Pluckers should not dip their hands below the plucking table.
- iv. Erect leaves of maintenance foliage should not be broken.
- v. Pluckers should not keep a lot of plucked shoots in their hands and shoots should frequently be transferred to the basket. Also, excess leaf should not be put in the same basket by applying pressure.

3.5.10 Fine leaf percentage

- i. Representative Green leaf weighing 100-gram shall be taken in several small quantities from random spots.
- ii. From this sample, unbruised green two leaves (2L) + bud (B) are considered fine leaf and separated by breaking from bigger shoots.
- iii. The weight of fine leaf portion to be taken. This denotes fine leaf percentage. (Amalgamated Plantations, 2014)



Fig. 3.14: A tea shoot suitable for plucking, Source: Amalgamated Plantation

3.5.11 Important aspects of plucking

Tea research institute of Sri Lanka suggested some important aspect of plucking as follows (TRI, Sri Lanka, 2003):

- i. Plucking table should be even and follow the slope of the land. The process of this should begin from the time of pruning and continue along with bush creep.
- ii. *Banji* and crow's-feet should be a routinely removed.
- iii. Arimbus or immature shoots are to be left unplucked so that they can be taken the next round as heavier units.
- iv. To maintain better leaf standard and even plucking table, coarse leaves and stalks should be removed.
- v. Shoots and hollows on side branches and the plucking table should not be plucked until they cover the open spaces.
- vi. Pluckers should not use force to put the flush into their baskets.
- vii. Pluckers should not retain an excessive number of plucked shoots in their hands.
- viii. Plucking on rested bushes and the lungs of pruned bushes should be avoided.
- ix. Damages to plucked shoots during weighing, bulking and transporting should be minimal.
- x. Education and careful supervision of pluckers will ensure the quality of made tea.

3.6 Pest controlling

The diseases incurred by tea plants in most of the gardens of Assam include blister blight (caused by *Exobasidium vexans*), black rot (*Ceratobasidium p.*), red rust (*Cephaleuras virescens*), charcoal stump rot (*Ustilina deusta*), brown root rot (*Phellinus noxius*) and violet root rot (*Sphaerostilbarepens*).

Red spider is the most problematic pest the crop cultivation in the tea gardens of Assam. Purple mite and pink mite fall under the less problematic varieties. Some other pests include common insects like Helo pelt, green fly, Thrips, Looper caterpillar, live wood and scavenging insects like termites and nematodes. (Hazarika, M, 2005)

3.6.1 Spraying

Spraying is one of the most important process for maintaining tea leaves and is done for the following reasons-

- i. Pest management
- ii. Disease management
- iii. Mineral management
- iv. Pruning and skiffing management
- v. Weed management
- vi. Shade management
- vii. Drainage and water management

Tea bushes are sprayed from time to time with chemical insecticides like Thiamethoxam, Thychloropid, Lambda-cyhalothrin and miticides like Propagule, Hexathyozon and Fenpyroxamate to prevent the crop from getting infested with insects and mites. Unwanted weed like Burweed and knotweed are either manually cleaned or sprayed with chemicals like Glyphosate. (Hazarika, M, 2005).

3.6.2 Types of machines used in spraying

Both manual and engine powered machines are used for spraying. A typical spraying machine can hold 13 litres of liquid, has a nozzle with a sixty percentage spot, can discharge 450 ml of liquid at the rate of 150 ml per minute and forty psi. Fertilisers are also used during spring when the soil is moist for spraying (Hazarika, M, 2005).



Fig. 3.15: A worker is spraying pesticide on tea bushes with the help of a spraying machine.

3.7 Transportation of green leaf

If the green leaves need to be stored before transporting to the factory, they should be spread out thinly under the shade of thatched roof in an airy and well-ventilated place.

The green leaves should be carried in baskets or bags instead of in big heaps and vehicles carrying them should have such facilities.

Care should be taken to ensure that the leaf is not damaged during transportation (Amalgamated Plantations, 2014).



Fig. 3.16: Transportation of green leaf to factory (Source: Amalgamated Plantation)

3.8 Processing of tea in factory

Tea processing or manufacture is a value addition process in which green shoots and leaves are converted to the finished product. Black tea is most widely prepared in the tea gardens of Assam. The diagrammatic representation of the manufacturing process of tea is shown in Fig.3.17.

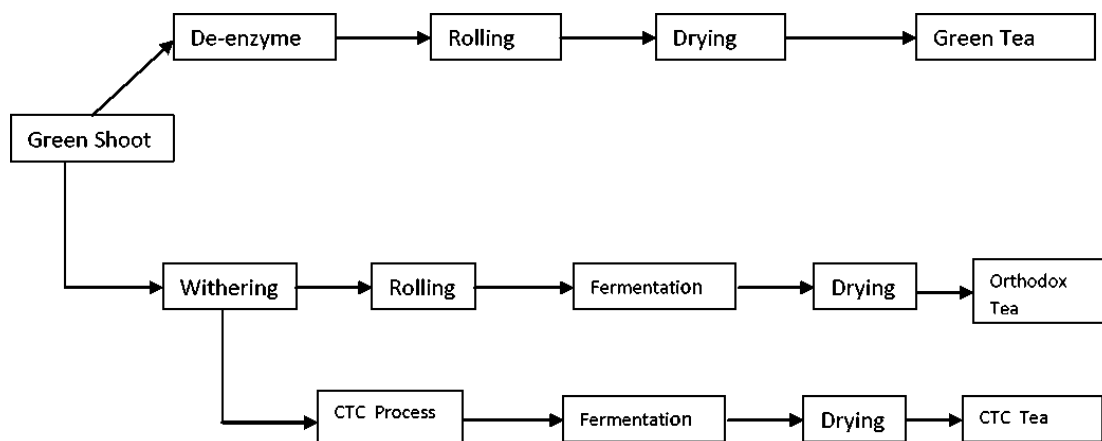


Fig. 3.17- Stages in manufacturing of different types of tea. Source: Planters' Handbook (2005)

3.8.1 Various types of tea processing

3.8.1.1 Cut, Tear, Curl (CTC) processing

The first step in CTC production is the withering process which involves passing the leaves through withering troughs. These troughs take away partial moisture from the leaves. A machine known as Rotor Vane is used to precondition the withered leaves before they are fed to the CTC machine. In this machine, initial crushing and a little bit of twisting take place, followed by C, T, and C i.e. crushing, tearing and curling. A machine called continuous fermenting machine carries out the oxidation process before the removal of moisture at the end of the drying process. Since tea is hygroscopic in nature, it is ensured by various processes that not more than 3 percent moisture is retained while the packaging is done.

3.8.1.2 Orthodox processing

In Orthodox tea manufacturing, the tea leaves are rolled with the help of Orthodox rollers after proper weathering. The Orthodox roller ruptures the tea cells by twisting and crushing the leaves. In comparison to CTC, in the Orthodox process, the maceration is less. The Orthodox types of teas are full of aroma (Tea Research Foundation Upasi, 2004).

3.8.1.3 Green tea processing

Green tea production involves no weathering processes, and the leaves are de-enzymed, i.e. hot steam passes through the leaves. This is followed by rolling over of the leaves using a device called the rolling table. The drying process follows it. The drying process involves removal of moisture from the rolled leaves with the finished product containing 2.5 to 3 percent moisture.

3.8.2 Withering

Withering is the first stage in tea processing for black tea. Green tea leaf contains a moisture amount of 78-84 percent, depending on the time of year. During withering, this moisture level is brought down to about 68-70 percent before processing in CTC manufacture. In the case of Orthodox tea, this moisture level is brought down to a level approximately 60-65 percent. The leaves become flaccid and rubbery in texture after withering. This partial removal of moisture is called withering or physical wither.

Tea leaves begin to wilt shortly after plucking, with a gradual onset of enzymatic oxidation. Withering is carried out to take out excess moisture from the leaves and also results in a very slight quantity of oxidation. The leaves are often put under the sun or left in a breezy room for removing the moisture. The leaves typically lose over a quarter of their weight in water throughout the withering process.

This method is also necessary for promoting the breakdown of leaf proteins into free amino acids and increasing the supply of freed caffeine, which changes the taste of the tea (Mazumdar, 2014).

Along with physical wither, chemical withers can also be done giving rise to some chemical changes. The process of chemical wither starts just after plucking of shoots as biochemical reactions are initiated along with the biological degradation of the shoots. Large molecules like cellulose, lignin, responsible for rigidity of the shoots degrade to make the shoots more flaccid. The ideal chemical withering process requires about 14 -16 hours (Willson & Clifford, 1992).

The major chemical changes during withering are listed below:

- a. Increase in caffeine content- this is responsible for the property of liquor.
- b. Growth in amino acid - tea shoots contains proteins which break down into amino acids and amides during the withering process. The concentration of

amino acids increases along with withering and are responsible for the flavour of the tea.

It can be thus established that green leaves withered artificially in 3-4 hours will only to be withered physically and not chemically. The tea made from this type of leaf will have lower amino acid content (Willson & Clifford, 1992).

3.8.3 Rotor Vane

The next important step after withering is maceration, primarily done by a Rotor Vane and CTC machine. The Rotor Vane is used as a preconditioner to CTC machine. Rolling tables can also be used for rolling in place of Rotor Vane before CTC operation.



Fig. 3.18: Rotor Vane machine. Source: The Aarkay Group



Fig. 3.19: A CTC machine. Source: China Tea Net

3.8.4 Fermentation

Fermentation is a necessary process to bring about changes to make the tea liquor palatable. Tea liquor has a raw and green taste before fermentation, and as the process progresses, the liquor becomes brisker and quality is improved (Verma, 2016).

3.8.4.1 Fermentation process

Fermentation takes place in separate rooms and the oxidation process that began during rolling continues. The room is sanitised and kept immaculate to avoid bacterial infection of the final product. Tea leaves are placed in a thick layer of 3.5 cm in big aluminium trays. The thickness of the layers depends on the room temperature. The right degree of fermentation is reached when the tea acquires a copper-red colour and the process must be halted by drying.

It is crucial to maintain the fermentation temperature between 80-84°F as beyond this temperature oxidation is halted. For optimum fermentation and to obtain desired briskness, strength, body and colour of the liquor, the temperature of the fermentation leaves must be maintained at two-degree difference between dry and wet bulb in the Fahrenheit scale (Verma, 2016).

3.8.4.2 Continuous fermenting machine (CFM)

The CFM was developed due to limitations of space, the spiralling cost of labour and the need for making tea processing a continuous one. It has resulted in the

mechanisation of the oxidative system and has been able to achieve the following objectives (TRA, Tocklai, 2014):

- i. To allow variability in thickness of bed, the period of oxidation and volume of air.
- ii. To achieve optimum ranges of temperature and humidity.
- iii. To sustain the quality of the end product.



Fig. 3.20: Continuous Fermentation Machine (CFM). Source: The Aarkay Group

3.8.5 Drying

The process of drying brings down the moisture content of tea particles from 60-70 percent after fermentation to a range of 2-3 percent. A machine called dryer is used for the purpose which makes it possible for the processed tea to be stored for further use. There are different types of drying machines used in the tea industry (Akhtaruzzaman et al., 2013). Some of them are as follows:

- i. Endless Chain Pressure Dryer
- ii. Continuous Tray Dryer (CTD)
- iii. Modern Vibro Fluidised Bed Dryer (VFBD)

3.8.6 Packaging and sorting

Sorting or grading is the final stage in tea. In this process, the leaves are sifted into different sizes and classified according to their appearance and type. The tea is packed

after sorting out a sufficient amount of leaves. Foil lined paper sacks are used for packing which provides a moisture barrier and keeps the tea dry. For large leaf teas, chests are used as they provide an extra degree of protection against the leaves being damaged during transit (Vintage Lace and Lavender, 2015).

3.9 Major classification of finished product

The final product of the crop, known commonly as tea, is divided mainly into following categories depending on processing techniques - Black tea (Orthodox and CTC), Oolong tea, White tea, Green tea, Fermented tea and Yellow tea (Jay Shree Tea, 2014).

3.9.1 Black tea

Black tea is processed in two ways - CTC (Weigh Down, Tear, and Curl) or Orthodox. The CTC technique is useful for generating a better product from medium and lower satisfactory leaves of consistently dark colour. Orthodox processing is done by applying manual techniques or by the use of machines. Generally, exquisite teas are processed by hand. Even as the techniques employed in conventional processing differ with the type of tea used, this style of processing outcomes in a variety of exceptional unfastened tea sought by many connoisseurs. Black tea is more oxidised than Oolong, green or white tea and its flavour is stronger than the less oxidised teas. Black tea also retains its taste for several years. (Chandan Bari Tea, 2013).



Fig. 3.21: CTC Tea. Source: estofainternational.com



Fig. 3.22: Orthodox Tea. Source: financialtribune.com

3.9.2 *Oolong tea*

Oolong is a traditional Chinese tea and is greatly popular among the tea connoisseurs of South China and Chinese expatriates in South East Asia. The Oolong tea is renowned for its fine quality; Oolong teas involve unique plant cultivars that are exclusively used for particular varieties. It is produced by a unique method, by withering the leaves below a strong sun and oxidation before curling and twisting. Oxidation degree ranges from 8 to 85 percentages, depending on the variety and production style (Jay Shree Tea, 2014).



Fig. 3.23: Oolong Tea- Rolled. Source: Erin Pehlivan.

3.9.3 *White tea*

White tea is a lightly oxidised tea, primarily grown and harvested in China, mostly in Fujian and Zhejiang province. White tea comes from the buds and leaves of the Chinese *Camellia Sinensis* plant, and the name is derived from the fine silvery-white hairs on the closed buds, which gives it a whitish appearance. The leaves and buds are decayed in sunlight and then processed lightly for preventing oxidation or further tea processing. The beverage, however, is not white or colourless but pale yellow. Production of white tea has also recently begun in Taiwan, India, Northern Thailand and Eastern Nepal (Jay Shree Tea, 2014).



Fig. 3.24: White Tea. Source: Lateas Quirrel.

3.9.4 *Green tea*

Green tea is manufactured from the *Camellia Sinensis* leaves that have undergone minimal oxidation during processing. This form of tea originated in China but has become associated with various cultures across Asia. Green tea is also the source of raw material for extracts used in dietary supplements, cosmetic items, and health food. Different green tea varieties have been manufactured in the countries where it is grown with varieties arising out of growing conditions, horticulture, production and harvesting time. (Jay Shree Tea, 2014).



Fig. 3.25: Green Tea. Source: Alessandro Martini

In Fig 3.26, three different stages of green tea are shown. From left to right: Infused leaves, Dry leaves, and liquid. The infused leaves look much greener than the dry leaves.

3.9.5 *Fermented tea*

Fermented tea is a type of tea that undergoes open-air fermentation which may continue for some months to several years. By exposing tea to humidity, micro flora and further air oxidises it through auto-oxidation fermentation process and also possibly through some reactivated oxidative enzymes found in the tea. This, in turn, alters the odour through typically mellowing the flavour of the tea. Astringent or sour teas are typically transformed into merchandise that is thick and unctuous, by large mouth feel and aftertaste. (Jay Shree Tea, 2014).



Fig. 3.26: Golden melon Pu-Erh fermented tea, Photo Credit: Jason Fasi

3.9.6 *Yellow tea*

Yellow tea is a special tea processed in a way similar to green tea, but with a slower drying phase, where the damp tea leaves per square measure are allowed to take a seat and yellow. The tea is typically yellow-green in appearance and smells entirely different from both white and green tea. This smell is usually mistaken for black tea if the tea is cured with alternative herbs. Yellow tea has some similarities in taste with green and white teas. The term Yellow tea can, however, be additionally used to describe high quality teas served at the Imperial court, though this may be applied to any variety of imperially-served tea. (Jay Shree Tea, 2014).



Fig. 3.27: Yellow Tea. Source: Junshan Yinzhen

Next chapter covers various aspects of mechanical harvesting based on findings from the current chapter.

Chapter 4 Mechanical Harvesting of Tea

Plucking is one of the most labour intensive operations in the production of tea and significantly affects production cost. Due to a shortage of workforce, traditional methods of hand plucking have become expensive and difficult to carry out in required time. It was found that mechanised harvesting was cheaper and time effective (Baisya et al., 2014).

The tea industry in North East India is traditionally labour intensive with plucking contributing about 60-70 percent of labour cost (Awasthi & Sarkar, 1983), (Barbora et al., 1998)

As a norm, manual plucking productivity (green leaf/plucker/day) is limited to 24 kg in the North East. There is nevertheless variation in this quantity, ranging from 18 - 40 kg depending upon the season, the yield of a section and incentive for extra leaf harvested (Baisya et al., 2014).

4.1 The necessity of mechanised harvesting

Mechanised harvesting deserves serious attention for the following reasons:

- i. To maintain plucking round during peak cropping season; this also coincides with a high rate of absenteeism of pluckers.
- ii. To control the increase in plucking cost.
- iii. As a mechanical aid for increasing pluckers' productivity maintaining profitability of the tea industry in the long run and also to making Indian tea more competitive in the international market (Barbora et al., 1998, Sharma et al., 1981).

Mechanical harvesting can be divided into the following categories:

- i. Shear Plucking
- ii. Machine Plucking

This study will mainly concentrate on machine plucking.

A plucking round is the number of days between successive plucking. An ideal plucking round is the number of days between successive growths of leaves on a shoot. It is known as leaf period or *phyllochron* (TRI, Sri Lanka, 2003).

Shoot growth is dependent on factors such as weather and the type of clone. Plucking rounds are shorter during wet weather while it is extended during dry weather.

A proper plucking round should be maintained which matches the rate of shoot growth, helps increase yield and minimises the drop in the quality of the tea.

- Haphazardly extended plucking rounds may not only lower tea quality but also reduce yield.
- Plucking rounds and plucking standards are independent factors.
- Due to the high percentage of over mature shoots, extended rounds may influence plucking standards (TRI, Sri Lanka, 2013).

4.2 Background of mechanical tea harvesting

Tea plucking machines were introduced for the first time in Japan. Beginning with a big scissor in 1910, Japan has researched self-propelled tea plucking machines; small engine operated tea plucking machines, tea pruning machines, ride-on tea plucking machines, etc. All of these were of the cutting and air-swept-collecting type, exemplified by tea plucking machine mount on CHA SHI II tractor, the LU DAO III tea plucking machine and the Corolla tea plucking machine. Travel performance of the Corolla machine showed good results with a clean plucking surface and lesser loss in tea leaf collection. Tea plucking scissors were imported by the former USSR from Japan in 1929. After 1930, some agricultural scientists began to study and design reciprocating type tea plucking machines. This led to the development of the self-propelled plucking machines. This type of machines was widely used in Japan after 1970 (Han et al., 2014).

The first tea plucking machine in the USSR was commissioned on May 13, 1958, at the collective farm of Chaniyeti village which was very much successful. The cause for inventing the tea plucking machine was a wish to get the better of the west, a strong driving force during Nikita Sergeyeovich Khrushchev's rule. Experts had declared that high quality mechanised tea plucking was an absolute impossibility and some banks also announced a prize of £100 000 for inventing the machine to pluck tea (Shumakov, 2006).

Tea harvesting machines were tested in Sri Lanka in the 1940s and also during the mid-1960s. In the late 1970s, TRI, Sri Lanka undertook detailed studies on portable tea harvesting machines (Wijeratne M. A., 2012). While tractor mounted, large self-

propelled machines are used in countries like Japan; China, and Indonesia, machines of those types are not suitable for use in the tea plantations of Assam. The main reason is that of the undulating and sloping terrain, the presence of shade trees, drains and terraces. One of the core features of these machines was the non-selective harvesting of shoots, which removed all shoots without leaving arimbus (young shoots).

The research on mechanised tea harvesting methods began in China in 1958. Until the 1970s, these researches resulted in the design and application of tea plucking machine of the manual, electrical and mechanical types. After 1980, China began cooperating with foreign companies for producing tea plucking machines. Several types were designed successfully including the reciprocating cutting type, the spiral hob type; horizontal circle blade type and the spiral roll folding type. Technologies like double-carried plucking machine (CS110) and double plucking machine (4CSW900) were introduced from abroad and replicated in China. In recent times, there are various tea plucking machines in the Chinese domestic market, all of which are the reciprocating cutting type. They are either propelled manually, by a motor or electric force and have the comparatively high quality of harvested tea sprouts and integrity rate. Among them, the most popular were one propelled by a gasoline engine as it had sufficient power source and better feasibility on slanting land (Han et al., 2014).

The principal operational effectiveness of some of these machines is as follows.

- Integrity rate of sprout and leaf is around 75 percent.
- Regulated sprout and leaf harvested reaches to 50 – 60 percent while the net rate of picking increases to 85-90 percent.

Some commonly used machine models are listed in Table 4.1. Meanwhile, research on small tea plucking machine are still continuing.

Table 4.1: Some of the commonly used engine operated tea harvesting machines

Sl No.	Manufacturer	Model Number	Power Input	Number of operator	Type	Country of origin
1	Ochiai cutlery Mfg. Co. Ltd	HV-10B	Engine, Gasoline/oil mix	One	Handheld	Japan
2	Ochiai cutlery Mfg. Co. Ltd	AM-120V 600	Engine, Gasoline/oil mix	One	Handheld	Japan
3	Ochiai cutlery Mfg. Co. Ltd	V8S-R3000	Engine, Gasoline/oil mix	Two	Handheld	Japan
4	Ochiai cutlery Mfg. Co. Ltd	V8 World2	Engine, Gasoline/oil mix	Two	Handheld	Japan
5	Ochiai cutlery Mfg. Co. Ltd	TFC-8	Engine, Gasoline/oil mix	One	Vehicle Mounted	Japan
6	Ochiai cutlery Mfg. Co. Ltd	OHL-5D3	Engine, Gasoline/oil mix	One	Vehicle Mounted	Japan
7	Ochiai cutlery Mfg. Co. Ltd	OHC-5VB	Engine, Gasoline/oil mix	One	Vehicle Mounted	Japan
8	Ochiai cutlery Mfg. Co. Ltd	OHC-5DVB	Engine, Gasoline/oil mix	One	Vehicle Mounted	Japan
9	Maax Engineering	TH 250	Engine, Gasoline/oil mix	One	Handheld	India
10	Xiamen sunny business co., Ltd.	EG2011A	DC Motor, Battery operated	One	Handheld	China
11	Xiamen sunny business co., Ltd.	BYEG-A1	DC Motor, Battery operated	One	Handheld	China
12	Zhejiang Kawasaki	BY-608	DC Motor, Battery operated	One	Handheld	China

There have been many research achievements in recent times. Examples can be cited of a Direct Current (DC) tea plucking machine designed in Zhejiang, China, by Grace Co. Ltd and an electrical tea plucking machine developed by Guo Sufang and his team.

The machine developed by Grace consists of a DC motor, speed reducer and picking system. This machine is convenient to use as it has small volume and a rechargeable battery (Han et al., 2014).

TRA, Tocklai has experimented with mechanised harvesting operations in the tea gardens of Assam from 1956, and intermittently after that during the 1980s and 1990s. There was no large scale adoption of mechanised operations in North East India. However, recent trends indicate that the tea industry is considering mechanised harvesting as an option for reducing production cost and cover more area under plucking (Baisya et al., 2014).

TRA, Tocklai, Assam signed one memorandum of understanding with Kawasaki Company, Japan for the development of one tea harvesting machine. To operate this machine six persons will be necessary (Bhattacharyya S., 2014). In one joint study carried out by TRA, Tocklai with Kawasaki, Japan on machine harvesting it was

learned that during rain flush period (July-September) there was an increase of 2.71% in yield compared to hand plucking. However, continuous use of machine throughout the season brought about a significant decrease in yield to the tune of 6.28 percent over manual plucking (TBI, 2014-15).

4.3 Introduction to shear plucking and its outcome

It was reported that the yield of tea declines under continuous shear plucking from the start of the season towards the end of the season. Intermittent shearing i.e. hand plucking in the early season and shear plucking in peak cropping season followed again by hand plucking towards the end of the season produced significantly higher yield. Shear plucking produced an average of 42 percent fine leaf while this was 58 per cent under intermittent shearing. Continuous shearing produced the highest damage of shoot at 41 per cent as compared to 21 percent in intermittent shear plucking. In continuous shearing, the Theaflavin (TF) and Thearubigin (TR) contents in CTC tea were 1.27 per cent, 23.91 per cent in continuous shearing and 1.38 per cent and 19.36 per cent in intermittent shear plucking. Shear plucking is recommended for peak cropping season i.e. July to September with hand plucking during the remaining period (Saikia & Sharma, 2011).

As a substitution to the conventional method, Mechanical plucking is spreading quickly and should be investigated further for proper adoption. A crucial factor in this approach is height harvesting. A study was carried out in a research station of Fashalem, in Gilan province of Iran where the aim of the study was to find out the most appropriate height for the mechanised plucking.

The mechanical effect of plucking at height levels of 5, 10 and 15 cm has been investigated. Control (plucking with secateurs) and subsequent effects on bushes of hybrid tea were considered. The total green leaf revenue and standard of leaf were the quality parameters considered. The robust material contains green leaf, and tannin content was determined. A randomised complete block design with three replications was used to perform the study.

Results indicated that at plucking height of 5 cm, the aggregate of green leaves and the standard leaf was apparently higher. The 5 cm plucking height also showed the maximum amount of solid material and tannin compared to the other treatments. For

different parameters of quality, the effect of time was found to be significant (Babak et al., 1993).

4.4 Motorised plucking machines

Motorised plucking machines can be classified as spiral hob type, reciprocating cutting type, spiral roll-fold type, horizontal circle blade type and so forth (Han et al., 2014) based on operating principle of the cutting mechanism.

Plucking machines can be further divided into the following types

- a) Depending on power supply
 - i. Gasoline powered
 - ii. Battery operated
- b) Depending upon nature of cutting mechanism
 - i. Reciprocating Type
 - ii. Rotary Type
- c) Based on the number of operators
 - i. Single operator
 - ii. Two- operator
 - iii. Three- operator
 - iv. Self-Propelled

4.5 Some common handheld tea harvesting machines

4.5.1 Battery operated tea harvester- single operator

A non-metallic sheet is twisted and used as a blade. Leaves are chopped off by the rotating blade and pushed into the bag attached at the back end of the machine (Fig. 4.1). This machine is advantageous due to its Eco-friendly characteristics, light weight, easy operation and maintenance (Han et al., 2014). Also, less damage was caused to the bushes, as it could be directly carried to the focused bushes.

However, the disadvantage was a poor cutting process. Three blades, placed equidistant from each other were used. Less production rate compared to other machines because of less cutting span.



Fig. 4.1: A Single operator battery powered tea harvester. Source: Raju Limbu

4.5.2 Single operator, gasoline powered tea harvester

This machine (Fig. 4.2) operates on a two stroke or four stroke engines, with a series of reciprocating blades that are lightweight and noiseless. It is equipped with a flexible shaft for power transmission and has sturdy steel blades to cut leaves. A large bag is provided with this machine where the cut leaves are pushed through high speed air blower built integral with the machine. This machine is cost effective, labour and time-saving and increases productivity almost five times compared to manual plucking (Shankar et al., 2016).



Fig. 4.2: Single operator gasoline engine tea leaf harvester. Source: A. Chang

4.5.3 Two operator, gasoline powered tea harvester

Two-person operated tea leaf harvesting machines (Fig. 4.3) are larger in size. This machine's harvesting capacity is much higher though fuel consumption is also more. Besides the two operators, two additional people are necessary to handle the harvested leaves.



Fig. 4.3: Two persons, gasoline powered tea harvester, Source: R. Yadav

4.5.4 Two-operator gasoline powered selective tea harvester

Williams Tea Pty Ltd has developed a two operator gasoline powered selective tea harvester; with model number UL-750 & UL-1000. It is a two operator selective leaf harvesting machine. This machine selectively plucks 92000 times per hour at every four kilometres, with high quality leaves. Only two operators can harvest the same amount of tea leaves with the help of this machine compared to fifteen manual pluckers (Williames Tea, 2014).



Fig. 4.4: Two persons, gasoline powered selective harvester. Source: Williame Tea

4.6 Status of existing machines

The harvesting machines currently in use in Assam's tea estates require human resource and can only be operated with fuel like petrol (Gasoline). While this increases the production rate by increasing harvesting speed with reduced workforce, the machines fail to achieve the requirement of selective plucking of tea leaves, maintaining the quality and health of the plant. Moreover, the machines also failed to prevent the crop from pest attack (Shankar et al., 2016).

To increase productivity, mechanised harvesting seems to be the most viable option as evident from experimental findings at Tocklai and elsewhere. It was observed that plucking productivity/man day could be extended to the tune of 85 and 125 percent using 1-man operated and 2-men operated machines, respectively (Barbora et al., 1994). Studies conducted in South India also indicated that increase in productivity (kg green leaf/plucker/day) using the mechanical harvesters compared to shear and hand plucking was 170 and 626 per cent respectively (Baisya et al., 2014).

A single operator machine and double operator machine could cover 0.226 ha-0.236 ha and 0.730 ha-0.771 ha/day respectively (Ilango et al., 2001). It was reported from Kenya that single operator machine and double operator machine could harvest 350 kg and 900- 1500 kg green leaf/day respectively with double operator machine covering 0.7 ha of area/day (Bore, 2009).

Both these machines require one more person to hold the leaf collection bag.

In a study carried out by TRA, Tocklai at Nagrijuli TE, 400 kg green leaf/ha (average of a season) was harvested after a round of mechanised operation, total three "Two-operator" gasoline powered machines and one single operator machine were used and thirteen numbers manpower deployed for mechanised harvesting. The cost worked out to be Rs. 3.22/kg which is about 21 percent cheaper than (Rs. 4.07/kg green leaf) manual plucking. The share of wage and fuel is 44 per cent and 56 per cent respectively. This can be further reduced if battery operated machines were used (Baisya et al., 2014).

4.7 Some common problems associated with motorised tea harvesters

Some basic problems of motorised plucking machines are like quality compromise due to the high percentage of coarse leaves. Requirement of extra worker for sorting out

coarse leaves/ mature foliage/ stalks, cut pieces and broken or damaged shoots (applicable for selected machines only); land productivity is lowered due to the non-selective harvesting; poor manoeuvrability in the presence of shade trees, drains, steep terrains and high plucking table with dense canopy, high operating (fuel) cost; frequent break-downs, high wear and tear and lack of skilled workers for machine operation (Wijeratne M. A., 2012).

During this study, it was learned that the industry has reservations about using gasoline powered machines because of the followings

- a. High noise.
- b. High vibration.

From the point of operator's comfort during operation, 2- strokes gasoline powered machines are noisy and, vibration is high. This causes irritation and can cause loss of operator's productivity.

- c. Pollution from exhaust gases.
- d. Operating complication for starting, handling, collection and transfer of harvested leaves etc.
- e. Possible pilferage of fuel for using in personal vehicles of the employees etc.
- f. The engines used are two stroke engines where engine lubricating oil is directly added with the fuel to the extent of 20 – 40 ml/litre. These lubricants do not burn and come out with exhaust and can deposit on the tea leaves and this can deteriorate the quality of made tea.
- g. All those machines require more than one operator (Fig. 1.6). Two operators to carry the machine and another one helper is necessary to handle the plucked tea collection bag.

4.8 Performance comparison of various mechanised harvesting processes

The following important observation was recorded during experimental studies carried out TRA Tocklai (Barbora et al., 1994):

- i. During July-September at 9-11 days' round, the growth in the height of shear 'Step-up' yield increased and was maximum at 2 cm. Quality continued to improve up to the maximum 'step-up' (2.5 cm) under shear plucking.

- ii. Wheel mounted machines recorded a 233-297 % increase in plucking average, producing superior yield, quality, and plucker productivity.
- iii. Using wheel mounted machine plucking at 11-13 days' interval during July-September allowing a creep of 1 cm in each round, could see a further improvement of yield and quality of tea.

A study carried out at National College, Tiruchirappalli, Tamil Nadu, India, has recommended that integrated harvesting schedule may be applied in fields when they are over three or six months from pruning. Both one and two men operated machines should be used. A new schedule of integrated harvesting system may help achieve optimal production, quality, and profitability in Indian tea industries. Thus, it can be said that mechanical harvesting is capable of harvesting tender shoots, which could be achieved by raising plucking heights at regular intervals.

Mechanical harvesting over several years might change plucking table, allowing only three leaf and buds to emerge out of the plucking table. It may also result in keeping the mother leaf uniformly in a plain, horizontal level, allowing the harvest of tender shoot alone.

Data obtained from the experiments with machine harvesting carried out for years, highlight changes observed in quality parameters of both green and black tea. Some results for one man and two men harvesting machines are provided below in tabular form; all quality parameters were found to have improved and lie very close to the integrated shear harvesting rate. The data also shows that quality deterioration with time normalises continuous machine harvesting and has an adverse impact on bush physiology and production (Nandagopalan et al., 2014).

Table 4.2: Effect of mechanical harvesting on annual yield of tea. Source: Barbora et al., (1994).

Plucking mode	Yield (KMTH)		
	Deep Skiff	Light Skiff	Mean
Wheel mounted machine	2146	2473	2310
Single operator machine	1974	2196	2072
Double operator machine	2440	2432	2436
Flat shear	2147	2242	2195
Raised shear	2074	2173	2124
Hand plucking	2036	2323	2180

Table 4.3: Effect of mechanical harvesting on quality of the harvested leaf during July to September. Source: Barbora et al., (1994).

Plucking mode	Shoot (%) Standard	Damaged	Coarse
Wheel mounted machine	58.9	28.5	12.6
Single operator machine	54.4	32.7	12.9
Double operator machine	54.2	32.2	13.6
Flat shear	60.9	16.4	22.7
Raised shear	62.7	11.5	25.8
Hand	65.5	10.4	24.1

Table 4.4: Effect of mechanical harvesting on quality of tea during July to September; Taster's score on CTC tea. Source: Barbora et al., (1994).

Plucking mode	DS	LS	Mean
Wheel mounted Machine	6.667	6.333	6.5
One man carrying Machine	6.5	5.667	6.084
Two men carrying Machine	5.833	5.167	5.5
Flat shear	6.333	6.333	6.333
Raised shear	7	6.667	6.834
Hand	7.5	7	7.25

The annual yield of mechanised harvesting can be increased by maintaining creep, which is a small gap between the top of the tea table and bottom of the cutters. The highest yield was obtained when the creep was maintained at 1 cm during plucking round carried out during July to September Barbora et al., (1994).

Experiments on mechanical plucking at TRA, Tocklai revealed that optimum plucking round for shear plucking was 9-11 days and 11-13 days for machine plucking (TRA, Tocklai, 2013).

4.9 Conclusion on mechanised harvesting of tea

From studies carried out by various researchers, it can be concluded that enhanced plucker productivity is the prime benefit of shear and machine plucking. As per method for calculating plucking cost (Awasthi and Sarkar, 1983), increased plucker productivity from 25 to 40 kg green leaf/man day would result in 31% reduction in the

cost of plucking. With quantification of plucker productivity, this research will be directed to minimise adverse effects of mechanised harvesting on yield and quality.

Further, the following points are recommended for consideration during the research for mechanised harvesting (Baisya et al., 2014):

- i. Yield at 11-13 days' interval under machine harvesting, 9-11 days' interval under shear plucking was similar to hand plucking at 7 days' interval.
- ii. Machines should preferably be used after 15th July in a plucking season.
- iii. For mechanised harvesting, sections having hardy planting materials and minimum vacancy which facilitates easy movement of machines are to be selected.
- iv. The height of plucking table should be 75 cm (+/- 5 cm). Higher height would lead to less coverage.
- v. Position of the drains in a section. Drain along the hedges is preferable.
- vi. A tarpaulin sheet to be placed below the leaf collection bag for easy gliding and to prevent leaf from getting bruised
- vii. Machine should go on one row (*Pahi*) and return through another row
- viii. A row should be harvested in the same direction on every round
- ix. Men deployed should be tall and strong enough to carry the machine
- x. Proper incentive scheme must be in place for making mechanised plucking attractive for the workers

During field study for this research work, it was learned that in the tea gardens of Assam, wheel mounted machines are not suitable due to uneven terrain. Machines will not be able to move freely due to the presence of shade trees and drains. Drains are essential to flow out rain water from the gardens. Handheld machines are the only suitable solution.



Fig. 4.5: Provision for drains at tea gardens of Assam

Dr. Amrit Chandra Barbora, Chief Scientist at Citrus Research Station, Tinsukia, in an interview with the author on 4th August 2015, mentioned that reciprocating type of machines is suitable for tea gardens on hilly terrain and rotary type suitable for tea gardens situated on plain areas like Assam.



Fig. 4.6: Shade trees in tea gardens of Assam.

Almost all end users suggest that battery operated machines are more comfortable to use than petrol operated ones. Moreover, female workers do not feel comfortable with petrol operated machines. However, battery operated machines are less productive than petrol operated machines due to its smaller cutting span.

On the basis of the information gathered related to mechanical harvesting of tea, it is evident that while designing the machine, emphasis should be given on the development of machine which can be operated comfortably by both male and female workers. During interviews carried out for this research, the female pluckers suggested that a battery operated the machine with higher production rate is a prime necessity of the pluckers. They further informed that currently available petrol operated machines are cumbersome and uncomfortable to operate. Even though the single operator battery operated machines are convenient, their productivity is less and hence solely due to this, they are looking for a battery operated the machine with high productivity.

Keeping in view the above information, it has been decided to design a single operator handheld battery operated rotary type tea harvesting machine with high productivity in comparison to presently available machines with a similar mode of operation.

Higher productivity can be achieved by increasing the cutting span of the machine to cover larger area during operation of the machine in a single row.

Design and prototyping of a battery operated tea harvesting machine considering various factors derived from study carried out was initiated and mentioned in the next chapter.

Chapter 5 Concept Generation, Design and Prototyping

A pilot study of the possible areas of design intervention in the field of mechanised tea plucking as per the need of the tea industry was explored, which was mentioned in Chapter 1, section 1.5 and Chapter 4, section 4.9. The information from this survey validated that there is a high demand for an efficient battery operated hand held tea harvesting machine which can be operated by a single worker because of its various advantages.

5.1 Working principle of single operator battery powered tea leaf harvesting machine

The graphical representation of basic working principle and interaction of a shoot and the blades of the proposed machine is provided in Figures 5.1, 5.2, 5.3 & 5.4.

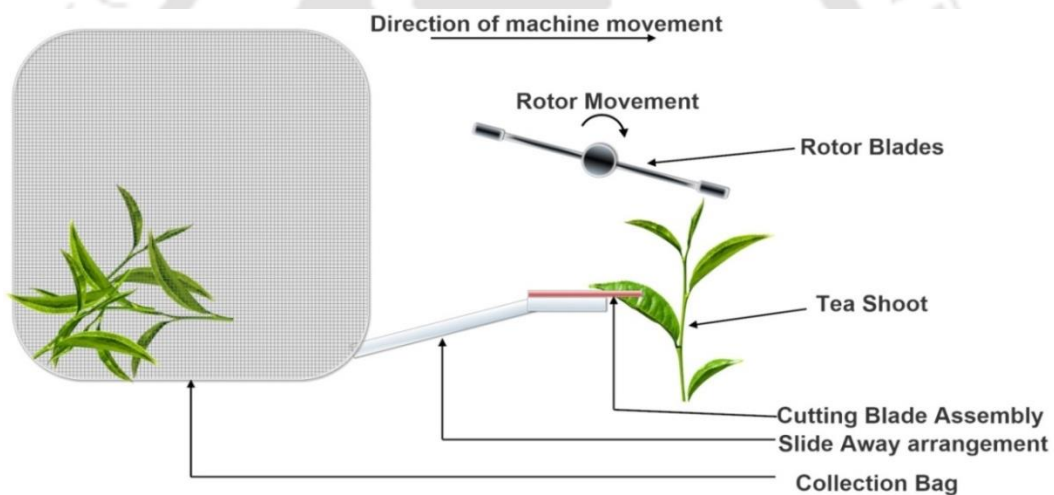


Fig. 5.1: Approach phase

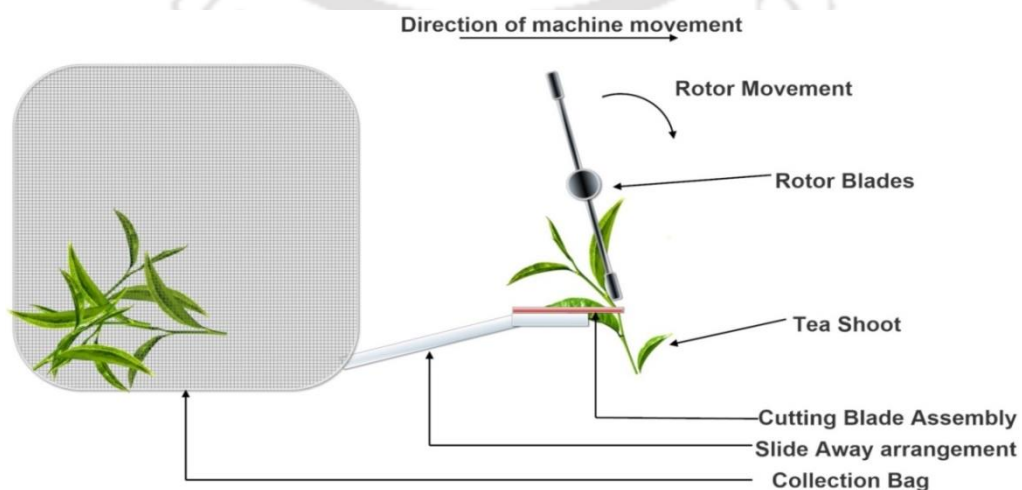


Fig. 5.2: Contact phase

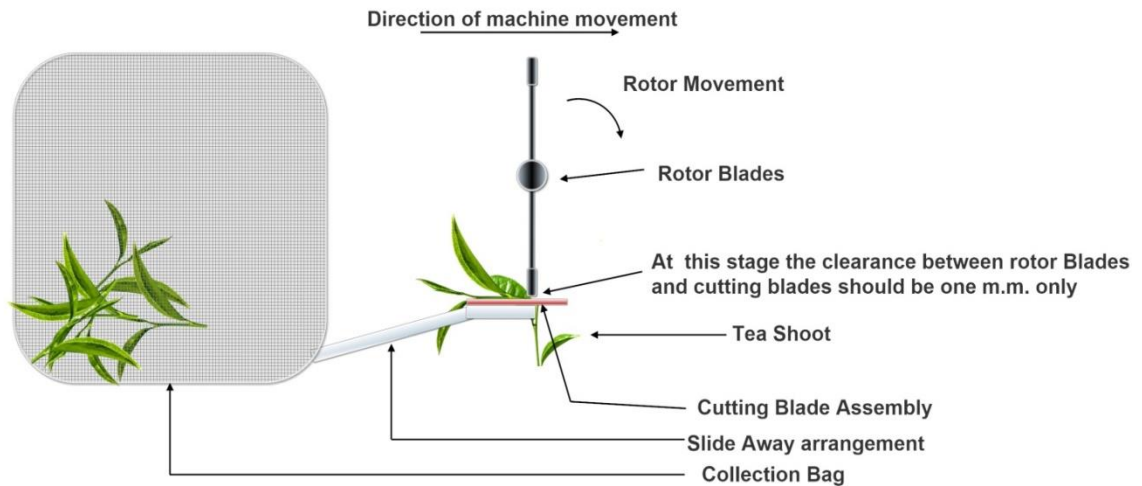


Fig. 5.3: Cutting phase

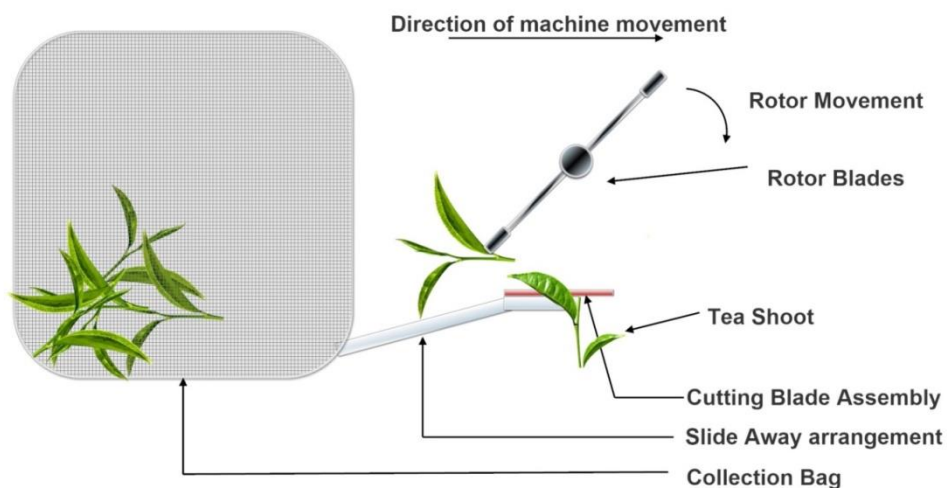


Fig. 5.4: Disengagement phase

Based on the study, the following requirement was formulated related to the end users' requirement for mechanical harvesting device:

- i. The machine will be used by both male and female pluckers; 80% of tea leaf pluckers in tea garden of Assam are women (Devi, 2014).
- ii. Female pluckers are not comfortable with the currently available engine powered machines since these machines are bulky.
- iii. Most of the pluckers are satisfied with single operator battery operated rotating type plucking machines because of less noise, less vibrations, fume free and light weight.

- iv. The only limitation of this single operator battery operated rotating type plucking machines is less productivity in comparison to engine powered machines due to less cutting span and hence to make it feasible, needs extending its cutting span.

The main need of the end users can be summarised as a machine which will be single operator battery powered rotating type with high productivity.

Based on the suggestions and feedback from the pilot study, it has been decided to develop a machine on the basis of presently available single operator battery powered ones similar to Zhejiang Kawasaki BY-608 machine. This model is available with some of the tea gardens of Assam, but due to less productivity tea gardens are not using this machine in regular manner. For the design of cutting head, reverse engineering has been partially adopted.

The specification of the Zhejiang Kawasaki BY-608 machine is provided in Table 5.1.

Table 5.1: Product specification of Zhejiang Kawasaki single tea harvester, model no BY-608.

Source: Zhejiang Kawasaki

Product Specifications	
Number of operators	One
Source of power	12v, 10 Ah, DC Battery
Charging voltage	220 ~ 240 volt
Power consumption	< 0.2 kWh
The motor speed	1400 rev/min
Weight of the battery	3.0 kg
Net weight of machine	1.6 kg (excluding battery)
Cutting Span	196 mm
Charging time	7 to 8 hours
Machine Dimensions	L 317 x H 317 x B 265 mm
Number of Rotors	6 numbers
Operational time	7-9 hours

An in-depth study was carried on the Zhejiang Kawasaki, Model no BY-608 single operator tea harvesting machine to understand the working mechanism and shortcomings of the machine and decision was taken to design the similar kind of machine with high productivity by increasing the cutting span and simultaneously increasing the number of rotors & cutting blades to compensate the increased cutting span. The rotors are out of phase at a fixed angle of 10 degrees.

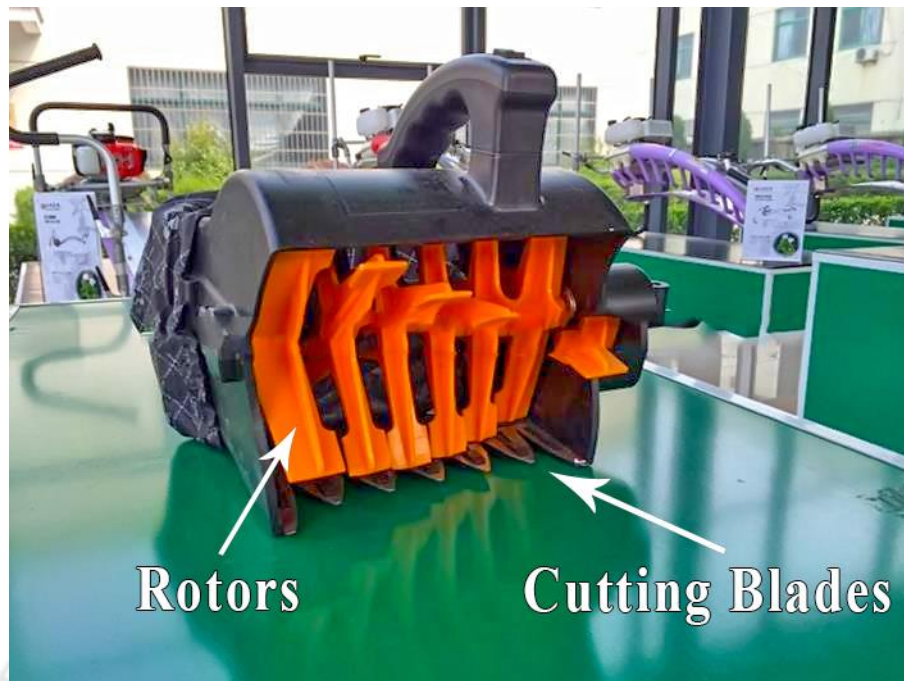


Fig. 5.5: Zhejiang Kawasaki battery powered single operator tea harvester machine showing Cutter and Rotor arrangements. Source: Zhejiang Kawasaki

Due to this modification, the weight of the machine will increase. To compensate this additional weight, it has been decided to move out the integrated motor assembly from the machine and to place it in a backpack along with the battery. However, to reduce the overall weight, NiMH rechargeable battery has been considered. The motion transmission from the motor to the machine will be carried out with the help of a Bowden cable.

5.2 Expansion of cutting span

In the presently available machine, the length of the cutting span is 196 mm. By justifiably increasing the cutting span of the machine production can be increased.

As per the data collected for this research, the average diameter of the tea table for plants which are between 5 to 10 years are in between 700 to 800 mm and plants whose age is above ten years their average canopy diameter is 1000 mm.

The plantation patterns adopted in the tea gardens of Assam are mainly single row and double rows.

The cutting span is primarily dependent on the diameter of the tea table and the spacing between the rows.

During field study, it was observed that majority of the gardens in Assam at present has adopted the single hedge plantation pattern of 105 cm x 75 cm (Fig: 5.6) and in some garden double hedge plantation pattern with a spacing of 105 cm x 75 cm x 75 cm (Fig: 5.7) is still prevalent.

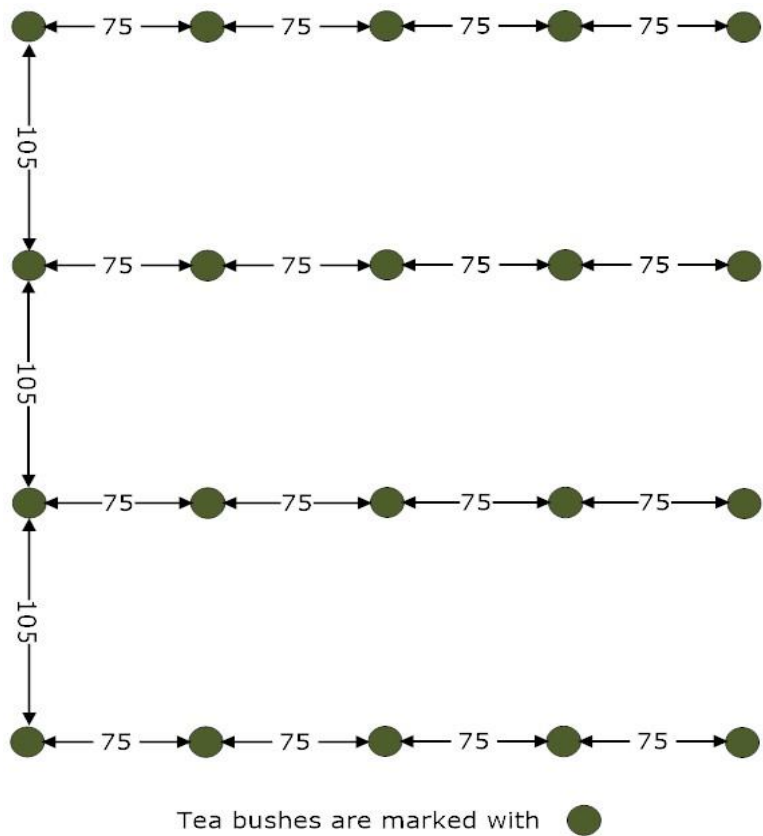


Fig. 5.6: Schematic diagram of single hedge plantation (Spacing unit in cm.)

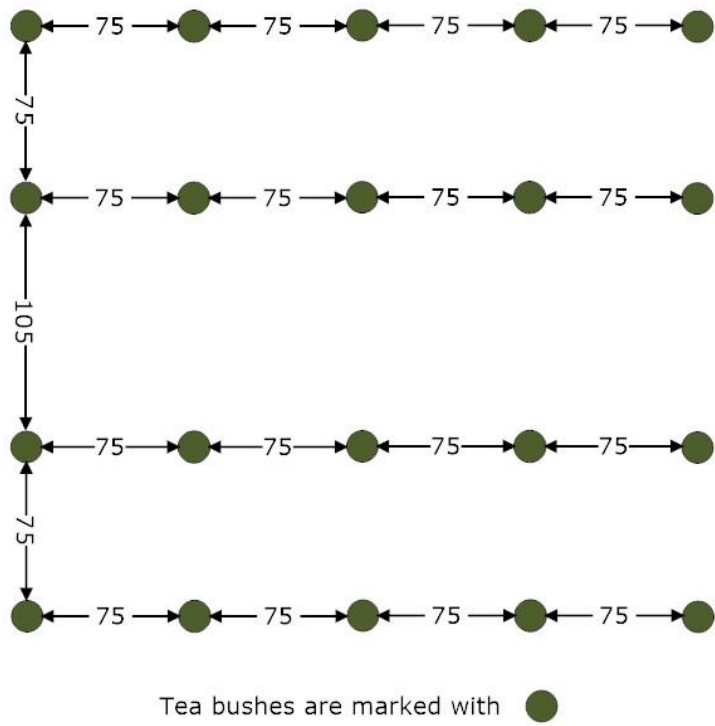


Fig 5.7: Schematic diagram of double hedge plantation. (Spacing unit in cm)

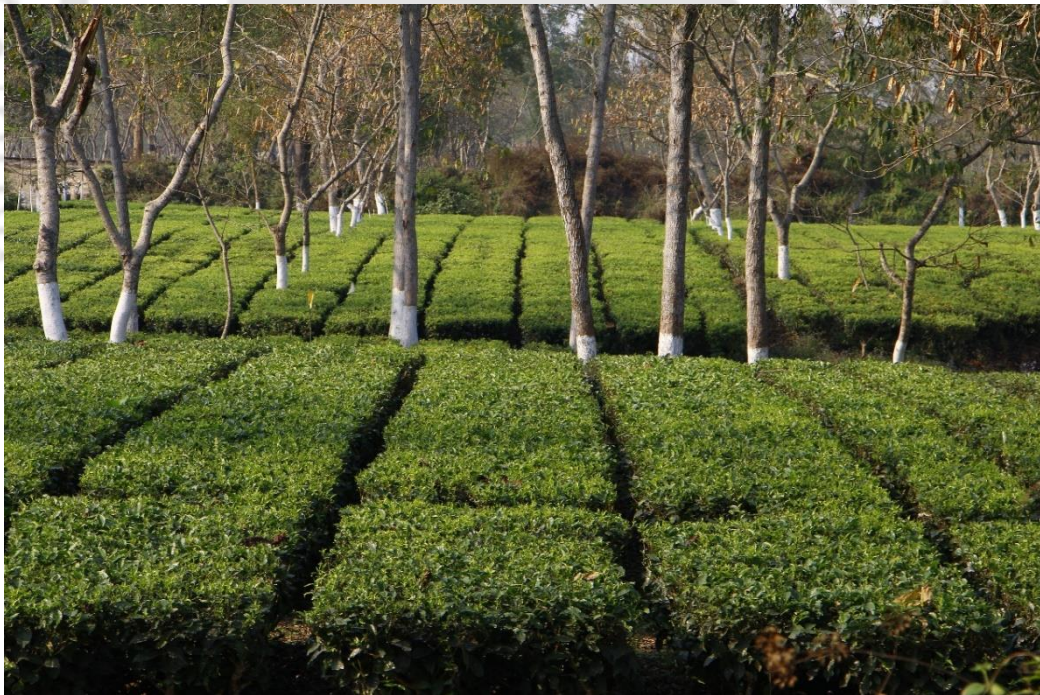


Fig. 5.8: Double hedge plantations



Fig. 5.9: Single hedge plantation, Source: Ben Discoe

Given the above references and after discussion with the end users it has been decided to increase the cutting points of the machine to approximately 2.5 times of the current cutting points of the battery operated machine to have approximately 520 mm span.

In the currently available machines, the numbers of cutting points are six numbers and in the machine to be developed the cutting points are decided to keep as sixteen numbers.

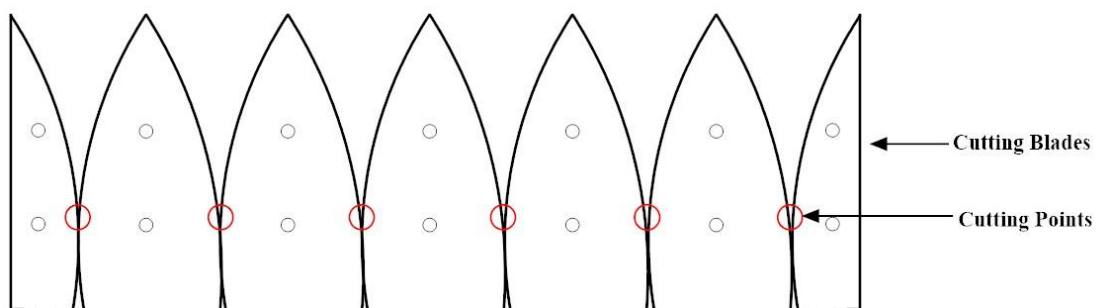


Fig. 5.10: Semantic diagram of cutting points

Although as per the data provided by the manufacturer productivity of BY-608 type machines are minimum 30 kg of green leaf per hour. So by increasing the cutting points 2.5 times, the minimum productivity of the proposed machines can be achieved 75 kg per hour irrespective production losses.

5.3 Design conceptualisation

Based on the requirement of the industry and information obtained from the stakeholders, a concept was generated for a handheld single operator battery powered plucking machine and 3D model of the same using Catia software was prepared the with increased cutting span.

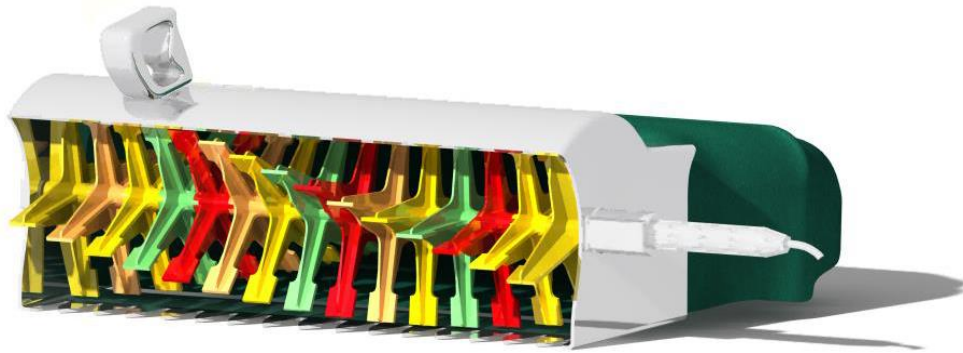


Fig. 5.11: 3D rendered image of the proposed machine

The conceptualised machine will consist of following main components: -

- i. Rotor assembly & drive shaft
- ii. Cutters
- iii. Spacers
- iv. Casing assembly
- v. Handling mechanism
- vi. Prime mover
- vii. Motion transmission system
- viii. Leaf collection bag

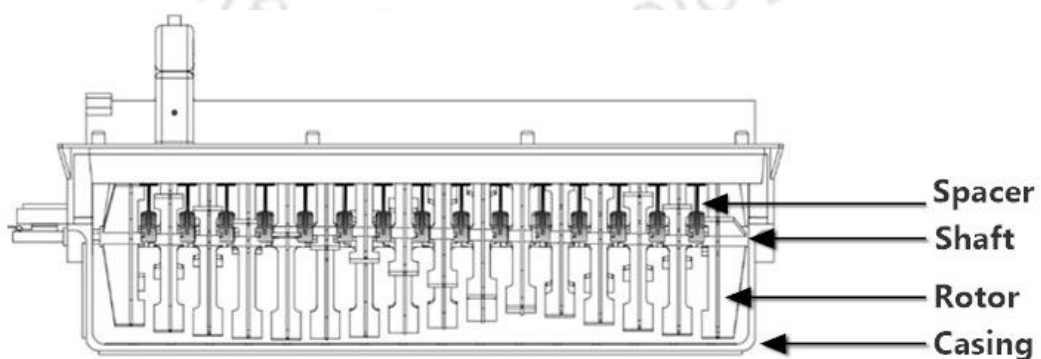


Fig. 5.12: Schematic diagram to represent arrangement of spacers, rotor assembly, cutting blades inside casing.

5.4 Rotors

The rotor assembly's main objective is to pull in the tea leaves towards cutters; rotors are made up of High-density polyethylene (HDPE). A 3D model of the proposed machine was prepared using Catia software adopting the same design parameters of the existing rotors of Zhejiang Kawasaki tea harvester model no BY-608. Individual rotor components were fabricated by injection moulding. In this machine, there will be 16 such rotor components compared to six rotors in the existing machines. The rotors will be mounted on an SS hexagonal shaft. The average space between two rotors is 30 mm. The detail drawing is provided at Appendix B (Fig. B.-5, B-6 & B-7)

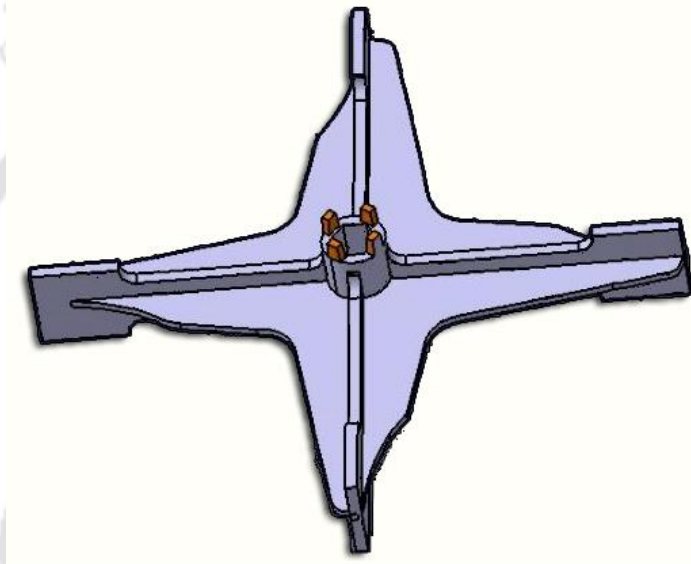


Fig. 5.13: 3D rendered image of individual rotors



Fig. 5.14: Individual rotor after fabrication

5.5 Drive shaft

Main Drive shaft has been designed and fabricated, and rotors were fitted on the drive shaft. The hexagonal shaft is of 510 mm in length and 10 mm in diameter. The drawing of the drive shaft is provided at Appendix B. (Fig. B.-8)

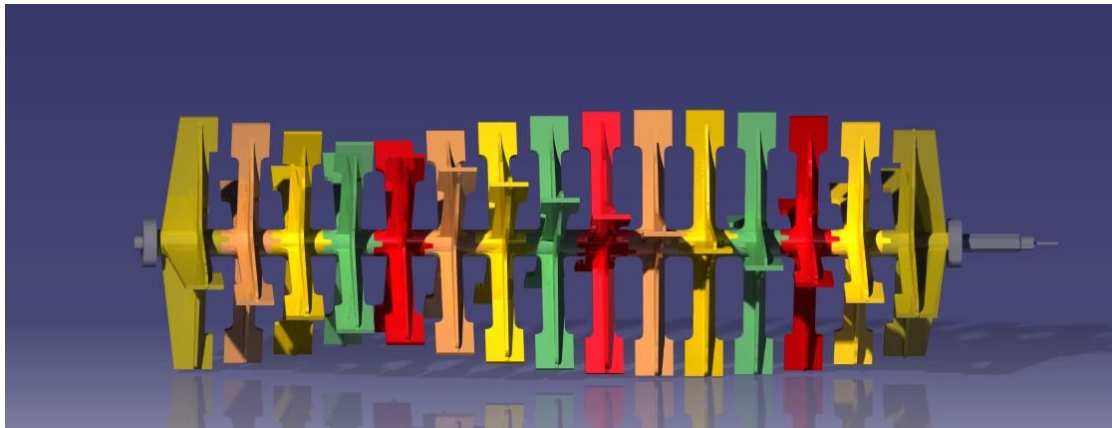


Fig. 5.15: 3D rendered image of Drive shaft fitted with rotor and bearing.



Fig. 5.16: Rotor & Driveshaft assembly after fabrication.

5.6 Cutting blades

For cutting of tea leaves, stainless steel blades have been designed which will be mounted on a base plate. There will be 17 numbers of cutting blades in the machine. The stainless steel cutting blades were fabricated with the help of Laser cutting. The detailed drawing of cutting blades and base plate are provided at Appendix B (Fig. B.-9 & B-10).

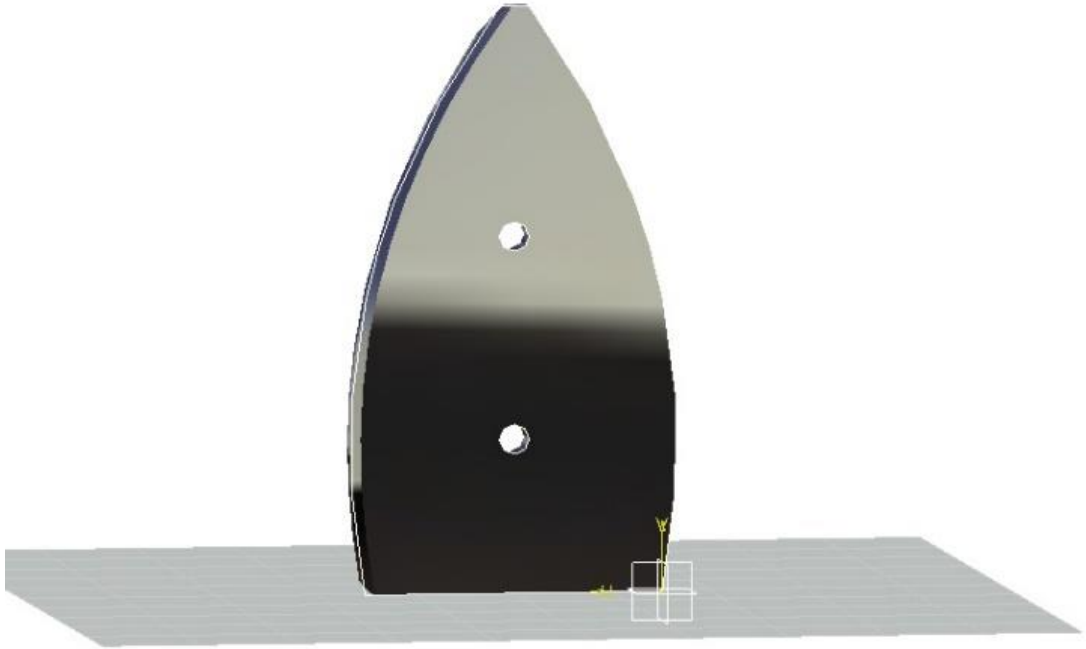


Fig. 5.17: 3D rendered model of cutting blades.



Fig. 5.18: Fabrication of stainless steel cutting blades with the help of Laser cutting machine.



Fig. 5.19: Cutting blades after fabrication



Fig. 5.20: Base plate of the machine.



Fig. 5.21: Cutting blades attached on the base plate of the machine.

5.7 Spacers

To accommodate a free and unidirectional flow of the harvested leaves to collection bag fifteen numbers of spacers has been provided in between the rotors. Those spacers were fabricated using fibreglass. The average distance from one spacer to another spacer is 18 mm. All the spacers are fixed to a common rail with an equal interval, as shown in Fig 1.6. The detailed drawing of the spacer is provided at Appendix B (Fig. B.-13).

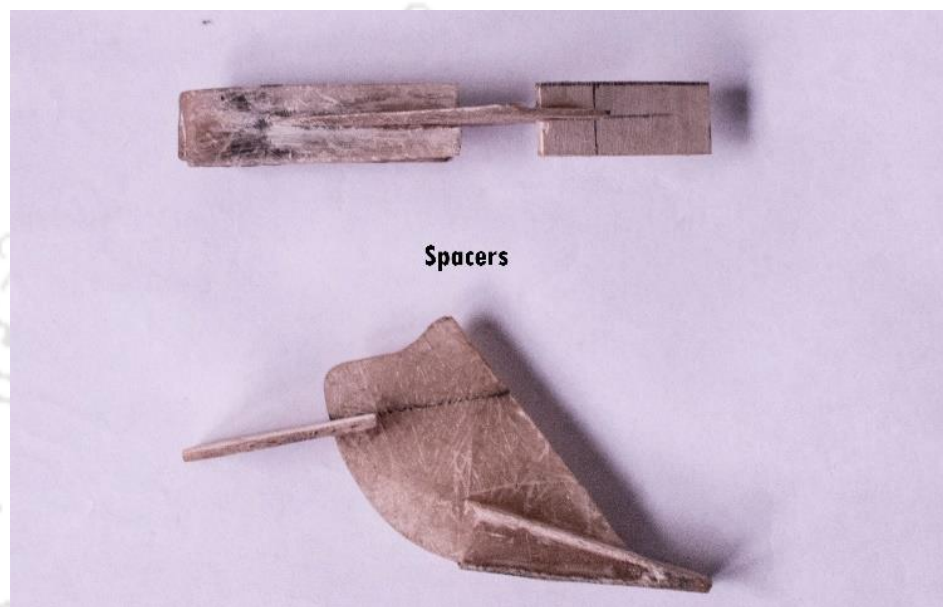


Fig. 5.22: Spacers after fabrication

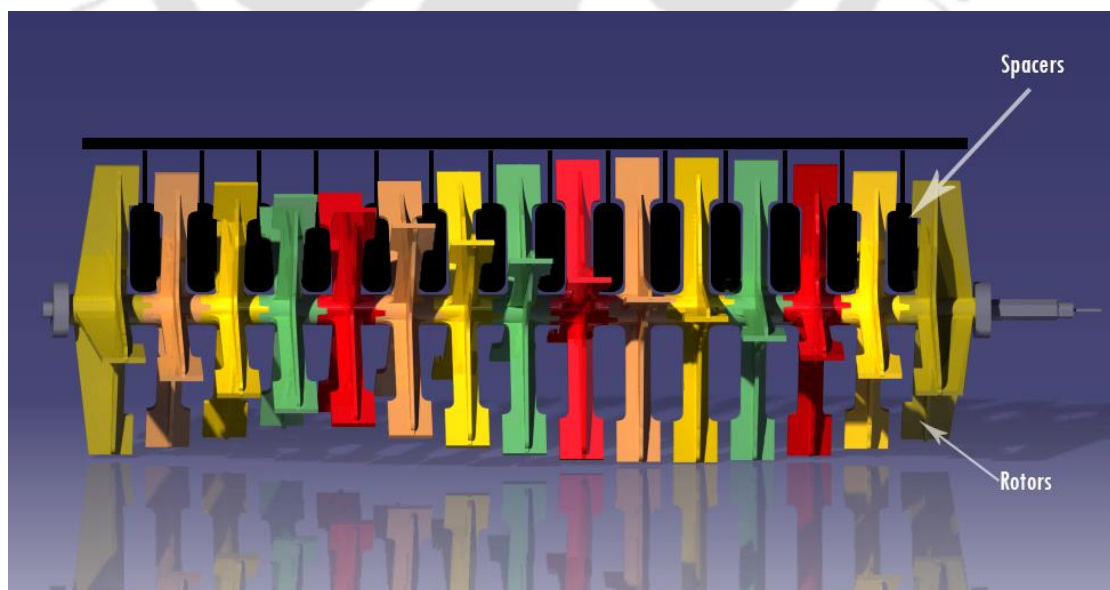


Fig. 5.23: 3D rendered image of the spacer position' in between rotors.

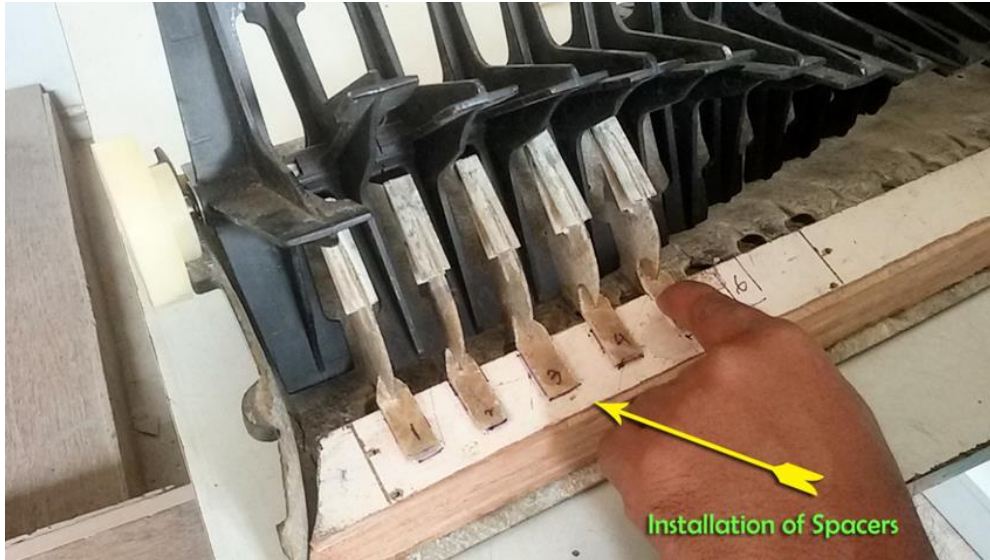


Fig. 5.24: Attachment of spacers with the casing.

5.8 Casing

The rotor assembly, cutters & spacers are placed inside a fibreglass casing. The casing assembly has two parts, upper and lower part. The 3D model of the casing assembly has been prepared and top and bottom parts were fabricated from fibreglass. The detailed drawing is provided at Appendix B (Fig. B.-11 & B-12).

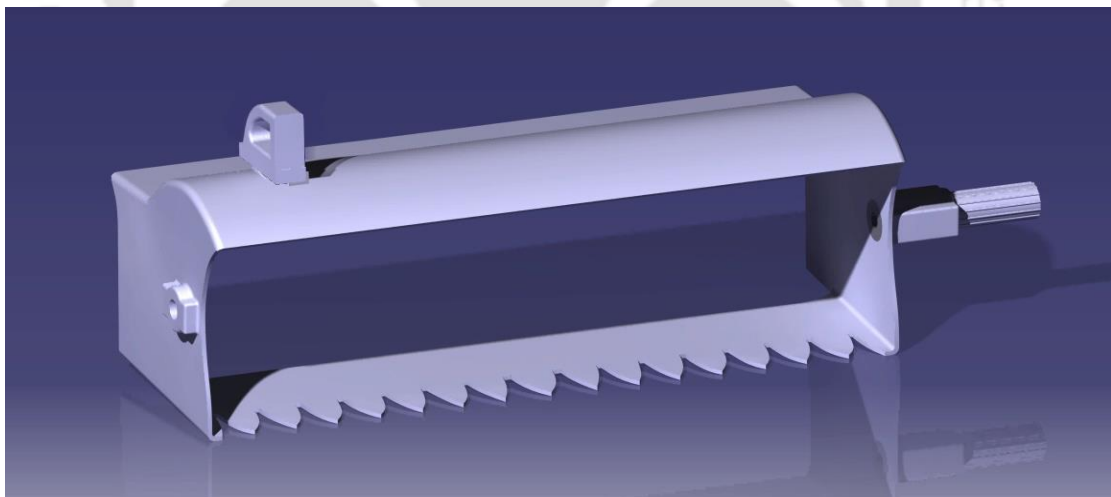


Fig. 5.25: 3D rendered image of casing assembly.

5.9 Assembly of different components of the cutting head

After fabrication of the different components, they were assembled together to construct the prototype. Various activities like the attachment of the rotor mechanism

with the machine, fixing up the carrying hands are done in this step (Fig 5.26). After assembling the machine, the trial run of the machine was satisfactorily carried out.



Fig. 5.26: Initial assembly of the machine showing rotor, cutting blades and spacers in casing

During this, it has been learned that a fixed clearance of 1 mm is necessary between the rotors and the cutting blade to achieve optimum cutting performance. If clearance is increased, then the machine fails to shear the tea leaves properly, and if the clearance is reduced, then soaking of leaves takes place.

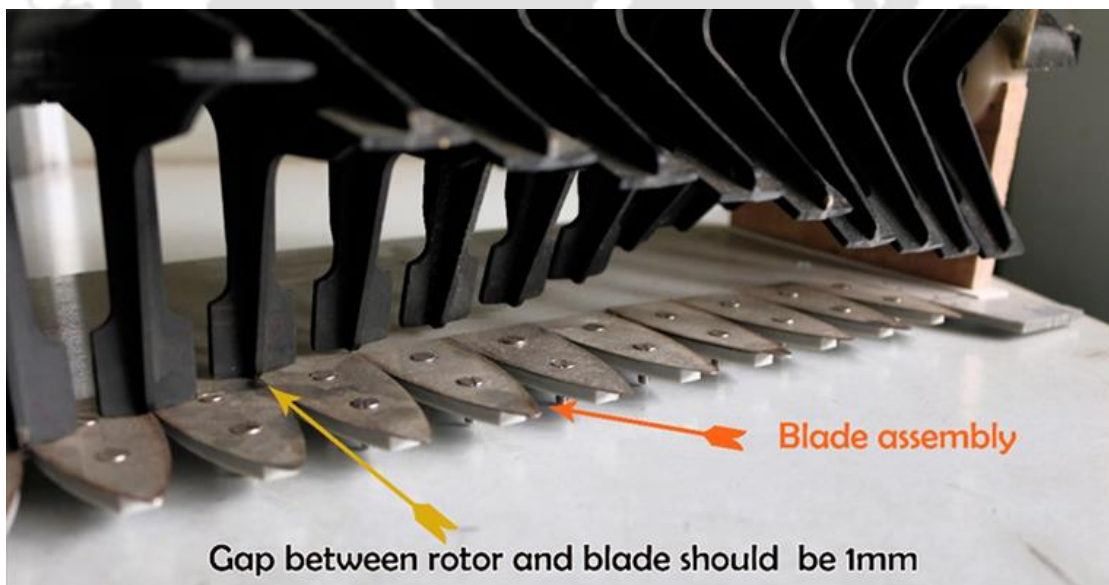


Fig. 5.27: Clarence between cutting blades and rotors.

5.10 Selection of prime mover

In the machine which is under development, a DC battery driven motor will be used as the prime mover. To determine the minimum power necessary to operate the machine with the help of a 12 V d.c. motor for four hours, following calculations were carried out.

Weight of the drive shaft assembly = 0.430 kg

Required speed = 400 r/min (Reference Table 5.3)

Shaft radius = 7.5 mm = 0.0075 m

5.10.1 Mechanical Power (Work done per second)

$$= \text{Mass} * \text{Radius} * 2 \frac{\pi n}{60} * 1.5 \quad \text{Eq 5.1}$$

Where, n = r/min, standard mechanical allowance = 1.5

$$= 0.43 \times 0.0075 \times 3.14 \times 2 \times 400 \times 1/60 \times 1.5$$
$$= 0.2025 \text{ kg-m}$$

5.10.2 Calculation for equivalent electrical power

Since, 1 kg-m = 9.81 watt

Therefore, electrical power = 9.81 x .2025 x 1.5

Where Standard electrical allowance is 1.5

$$= 2.98 \text{ watt}$$

5.10.3 Calculation for the rated current of the motor

Rated current for the motor will be electrical power / voltage

Therefore the current rating of the motor will be 2.98 / 12 = 0.248 amps

5.10.4 Calculation for battery specification

To run the machine for four hours the capacity of the battery will be

$$\text{Ampere rating} \times 10 \text{ hr} = 0.248 \times 10 = 2.48 \text{ Ah}$$

From the above findings to operate the machine for four hours by a 12 V dc motor, performance ratings of various available dc motors were compared and the motor manufactured by Chuang Li, China, model no RD-550 KFA with attached speed controller mechanism was decided to use in the machine as prime mover. Basic

specification of the motor has been provided in Table 5.2. This motor was selected after comparing the performance ratings from commonly available DC motors.

Table 5.2: Motor Specification

Motor Specification	
Maximum Speed	1500 r/min
Size	90 x 38 mm; (length x dia)
Net Weight	0.25 kg;
Current rating	1.3 A
Working Voltage	12 V dc

5.11 Details of battery and battery pack

To operate the machine up to minimum four hours, 12V, 10 Ah NiMH rechargeable battery manufactured by AA Portable power corporation, USA has been used and the casing of the battery pack was fabricated with the help of vacuum casting.



Fig. 5.28: Mock up for motor and battery module



Fig. 5.29: Fabrication of battery cabinet



Fig. 5.30: Assembly of battery & prime mover module

5.12 Motion transmission

To make the machine lighter in weight the prime mover will be placed in a backpack along with the battery, and with the help of Bowden cable, the motion will be transmitted to the rotor shaft.



Fig. 5.31: Final assembly of battery module, prime mover module and attached with Bowden cable with waist belt

5.13 Collection chamber

Tea leaves harvested from the tea plants are required to be collected in a leaf assortment bag (collection bag) made up of nylon. The collection bag made of nylon is attached to the machine as is shown in Fig. 5.28.



Fig. 5.32: 3D rendered image of leaf collection chamber

The mouth of the bag is broad enough and bigger than the cutting plane (Minimum 520 mm). The minimum depth of the collection bag should be the minimum depth of the

bamboo baskets carried by the manual pluckers in traditional process which is shown in Fig. 5.29 and has a depth of around 430 mm. Thus dimensions of the collection bag integrated with the machine is: 550 mm x 170 mm x 500 mm (Width x Height x Depth).



Fig. 5.33: A plucker with conventional bamboo basket



Fig. 5.34: Dimensional measurements of the conventional bamboo basket are recorded.



Fig. 5.35: Detachable type collection bag attached to the machine.



Fig. 5.36: Plastic flute board sheet placed below the leaf assortment bag

One plastic flute board sheet placed below the leaf assortment bag (Fig. 5.32) for straight forward sailplaning and to prevent damage to tea table. This can also facilitate maintaining the required creep.

5.14 Integrated motor assembly and motion transmission system

As mentioned in section 5.1, the integrated motor assembly with the nickel–metal hydride (NiMH) battery has been attached to the leather waist belt (Reference section 5.15.2). With the help of a Bowden cable motion transmission from the motor to rotor shaft of the machine has been transmitted. The diagram of motor and battery assembly is provided at Appendix B (Fig. B.-14).



Fig. 5.37: Integrated motor assembly

One end of the Bowden cable has been attached to the motor, and the other end of the cable has been connected to the rotor shaft with the help of push-pull type coupling arrangement. The diagram of coupling assembly is provided at Appendix B (Fig. B.-15).

5.15 Handling

The span of the existing battery operated tea harvesting machine is 196 mm, since there are six rotors and cutting blades. In the newly designed machine the number of rotors will be 16 numbers and there will be 17 numbers of cutting blades. To accommodate these additional rotors and cutting blades the length of the machine has been increased by 2.5 times than the existing machine. Considering this factor additional load sharing & handling mechanism are considered. Two concepts were generated to design the handling arrangement.

5.15.1 Alternative-1

There will be two handles to hold the machine one will be placed on the top of the casing, and another handle will be placed at the side of the machine as shown in the Fig. 5.34. Here the handle provided on the top of the machine will have the sliding mechanism, and the handle which will be provided on the side will be of fixed length. The length of the fixed handle is 280 mm.



Fig. 5.38: Handling arrangement as per Alternative-1.

5.15.2 Alternative-2

In this alternative too, there will be two handles to hold the machine. One will be placed on the top of the casing, and another one will be placed at the side of the machine as shown in the Fig. 5.35. In this alternative, the handle provided on the top of the machine will be fixed. The handle provided at the side of the machine will be a telescopic type handle, and the length of the handle can be adjustable. Telescopic type adjusting mechanism has been implemented to facilitate effortless horizontal movement during operation as well as counterweight.



Fig. 5.39: Handling arrangement as per Alternative-2.

Handling mechanism based on Alternative-1 and Alternative-2 were fabricated, and their performance was tested. During testing, it was found that the handling mechanism described in the Alternative-2 is more convenient for the operator than the Alternative-1. The diagram of telescopic handle mechanism as per Alternative-2 is provided at Appendix B (Fig. B.-16 & B.17).

5.16 Design for ease of operation of machine while carrying and operation at field

After assembling the various components of the machine's cutting head excluding motor, transmission and battery, the weight was measured, this was found to be 2.5 kg.



Fig. 5.40: Weighing of the machine

It was found that the weight of the existing Zhejiang Kawasaki single tea harvester, model no BY-608 is only 1.6 kg. This is because the cutting span of the BY-608 machine is approximately three times smaller than the newly designed machine.

A digital Manikin was constructed with the help of Catia software to study the maximum load that can be carried comfortably by one hand. Manikin is a model of the human body for study various studies related to ergonomics, anatomy and so on. From this study, it was found that one hand can lift maximum 1 kg load comfortably without any stress on the human body for a maximum working duration of 30 minutes in the position shown in Fig. 5.37. The weight of the prototyped machine was 2.5 kg. Because of this; it will not be possible to carry the machine comfortably for the long duration during field operation.



Fig. 5.41: 3D rendered image of Manikin.

To overcome this problem, it was essential to design an additional arrangement which will help to facilitate even distribution of load of the machine on various body parts. This system will help operators to work with the machine comfortably for longer duration.

Two alternatives were generated to carry the machine and are described in the sections 5.15.1, 5.15.2 respectively.

5.16.1 Alternative 1: Single lever mechanism with support from backpack

In this concept, a metal back support was fabricated which will carry the load of the machine with the help of metallic lever mechanism. This metal structure was enveloped with back straps to distribute the load to shoulder and back.



Fig. 5.42: Single lever mechanism with support from back strap



Fig. 5.43: Machine carried with single lever mechanism supported from metal structure

From this study, it has been found that the operators experienced hip pain when they have to carry the machine continuously for more than 20 minutes. The system was tested with different operators with the help of Nordic body parts discomfort mapping method.

5.16.2 Alternative 2: Carrying mechanism with adjustable hinge

In the second alternative, an adjustable hinge was fabricated and fixed on a cushioned leather waist belt. The telescopic handle, as mentioned in section 5.14.2 was attached to the machine. This handle will work as a counterweight. Comfortable cushioned arm straps were provided around the arm which will share a part of the load of the machine.

In this system, the primary weight of the machine will be compensated by the counterweight provided at the telescopic handle. The remaining load will be transmitted to the waist belt with the help of the hinge mechanism, and a part load will be transmitted to operator's arm with the aid of the arm strap. The system was evaluated in human subjects with the help of Nordic body parts discomfort mapping method, the format of the same has been provided at Appendix C. From this evaluation, it was learned that the operators could operate the machine without discomfort for longer duration and hence it has been decided to adopt Alternative-2 for the purpose. The diagram of this assembly is provided at Appendix B (Fig. B.-18).



Fig. 5.44: Construction of adjustable hinge

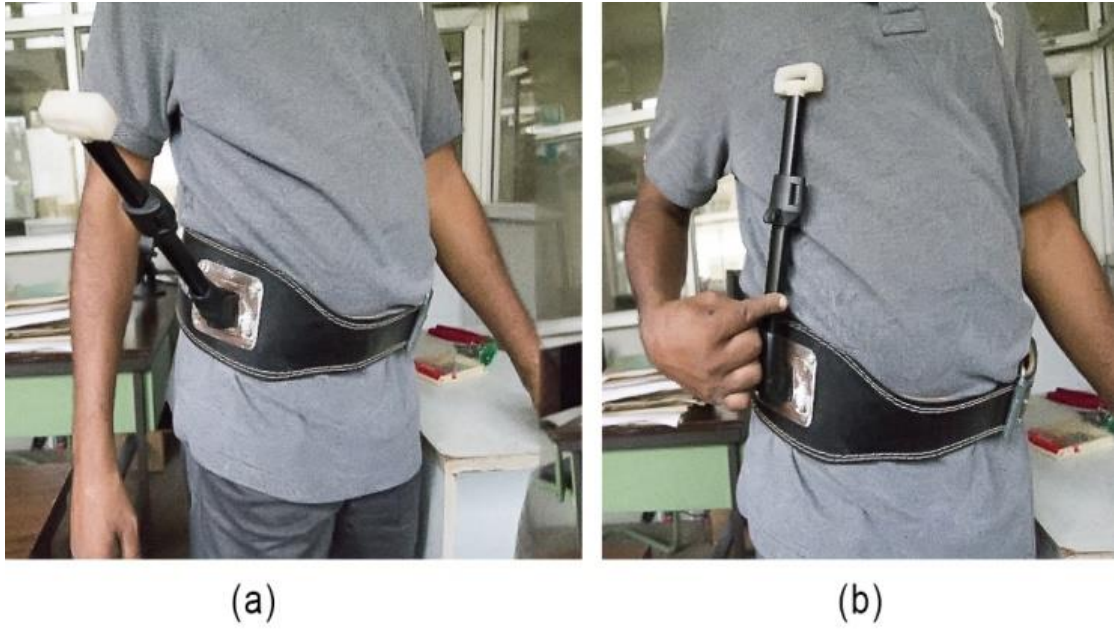


Fig. 5.45 (a) & (b): Adjustable hinge fixed on a leather waist belt



Fig. 5.46: Adjustable hinge fixed on a leather waist belt and connected with nylon arm strap

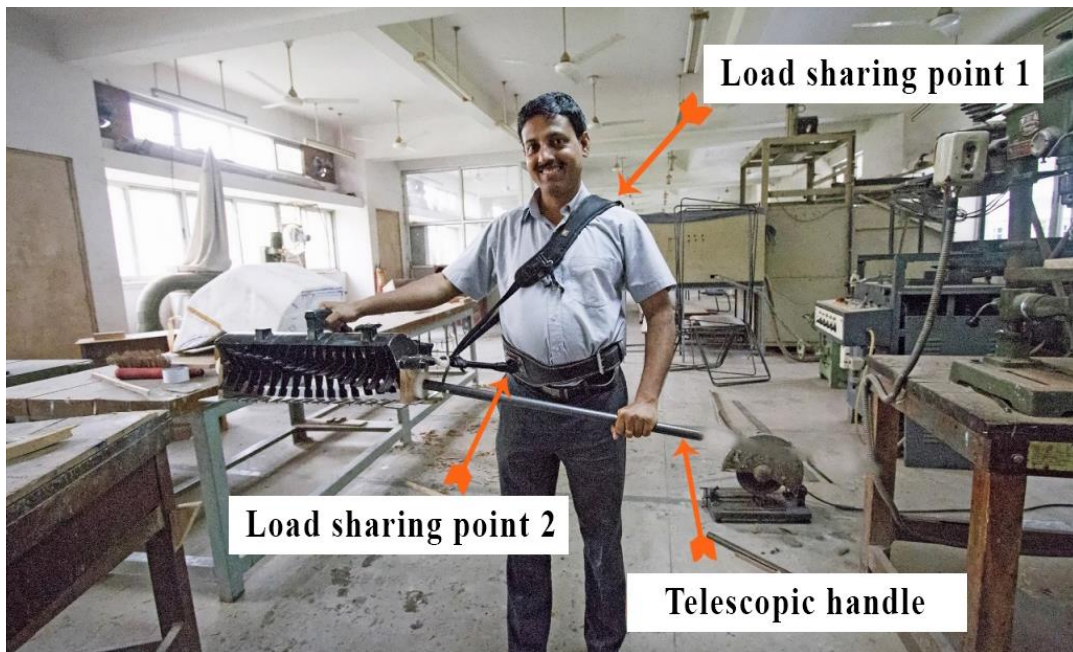


Fig. 5.47: Load sharing points

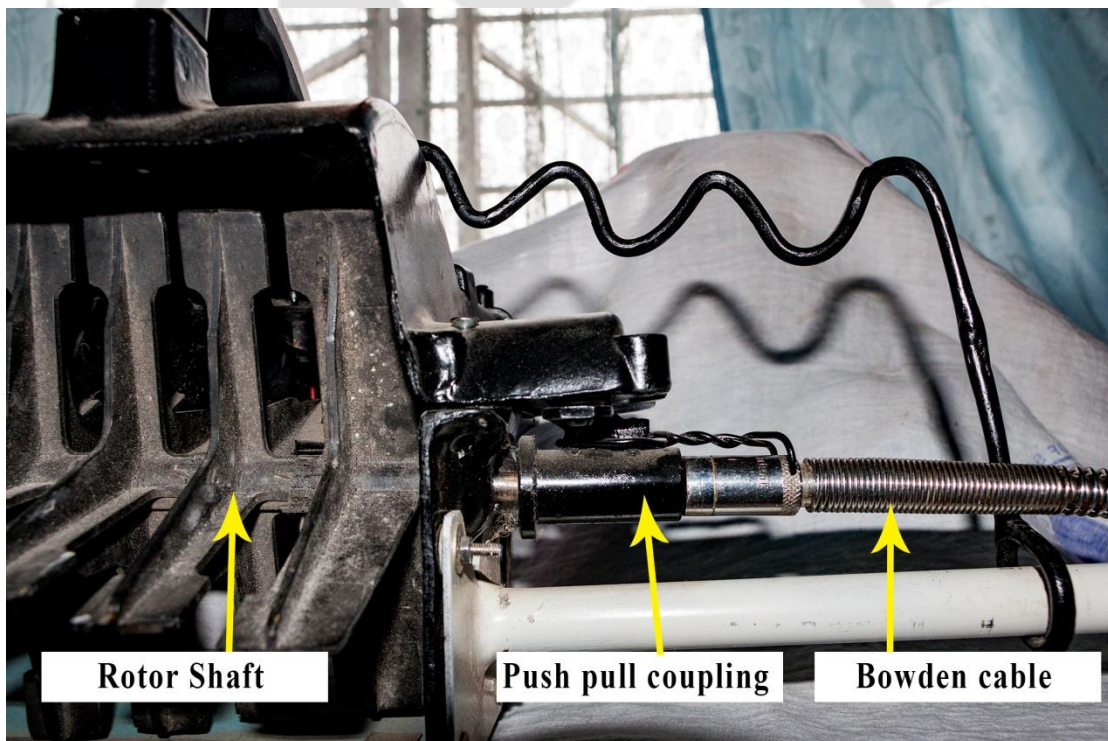


Fig. 5.48: Attachment of Bowden cable with the machine.



Fig. 5.49: Final assembled machine

5.17 Calculation of optimum revolution of the rotor assembly through functional test

Once the prototype machine was assembled, a trial run of the machine was done. This was to determine the revolution per minute (r/min) at which optimum harvesting of tea leaves can be achieved. The result of this trial is presented in a tabular manner in Table 5.3.



Fig. 5.50: Field experiment to find out the optimum revolution of the rotor shaft.

Table 5.3: Observation recorded during r/min optimisation of rotor shaft.

Observation Number	r/min of Shaft	Observations
1	100	Failed to rotate while applied on tea table.
2	150	Failed to rotate while applied on tea table.
3	200	Rotated around five times and then stopped because of tea leaves with more than 1 mm diameter stems were stuck-up in between rotor and cutting blades.
4	250	Rotated about fifteen revolutions and then stopped because of tea leaves with more than 1 mm diameter stems were stuck-up in between the rotor and cutting blades.
5	300	Rotated smoothly but cutting quality was not as per requirement. The machine failed to cut some shoots. As a result, uniform cutting was not obtained.
6	350	Rotated smoothly cutting quality improved than earlier speed but still some shoots was plucked not as per the standard of one bud and two leaves.
7	400	Comfortable Speed for the operator, quality of cutting of tea leaf was proper; tea leaves were properly collected in the collection bag. Tea table levelling was proper.
8	450	Comfortable speed and Comfortable Speed for the operator, quality of cutting of tea leaf was proper; tea leaves were properly collected in the collection bag. However, difficulties observed to maintain the uniformity of tea table.
9	500	High speed and rate of cutting was somewhat high due to which free flow of tea leaves to collection bag was obstructed. Uniformity of maintaining tea table was not possible.
10	550	Very high speed and high rate of cutting due to which free flow of tea leaves to collection bag was hampered because leaves were stuck-up at the entry passage of the collection bag. The vibration was high and difficult to maintain the even tea table. Also, the operator was not comfortable with the operation.

Graphically it is represented in Figure 5.51.

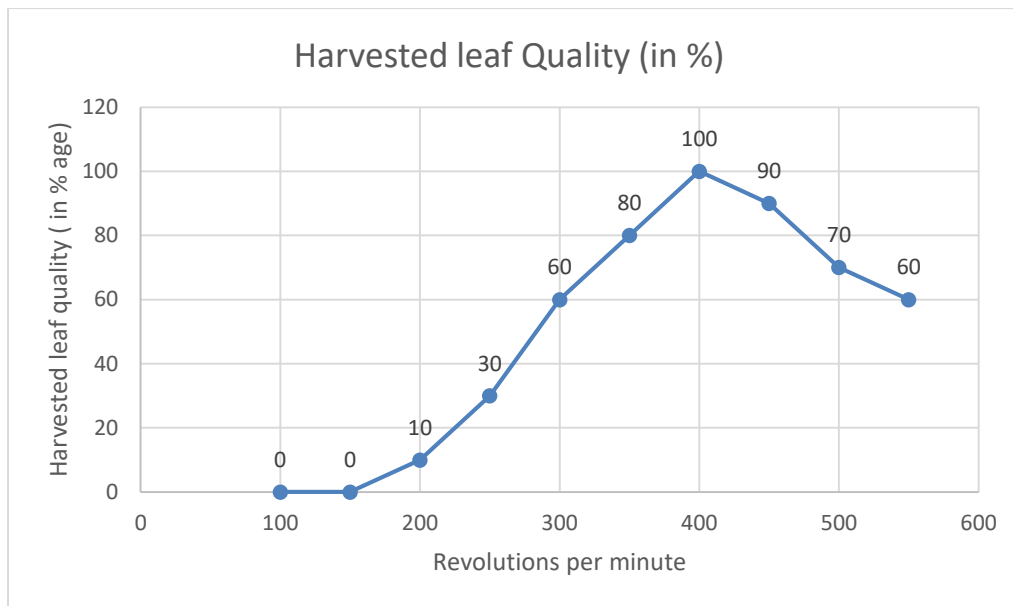


Fig. 5.51: Graphical representation of optimum revolution of the rotor shaft.

From this study, it has been found that to achieve optimum harvesting performance the r/min of the rotor should be 400 (Measured by tachometer). This test was done with the help of a variable speed DC motor. This test was carried out to know the cutting behaviour of the machine at different r/mins and hence to find out the optimum operating r/min of the machine. Exact shaft r/min was tested with the help of Laser guided digital tachometer.

Once the machine has been found functionally satisfactory, actual operational trial in a selected tea garden was carried out. Results of the field trials are analysed and inferences drawn. These are covered in the next chapter.

Details of materials with their contribution to develop the prototype is provided in Table 5.4 & 5.5 respectively. Since the skill already available at IITG so it has been decided to fabricate some components at IITG's workshop.

Table 5.4: Standard items procured from various sources (Price as on 22-11-2015 in Guwahati)

Sl No.	Part Name	Material	Rate per unit (Rs.)	Quantity	Unit	Amount (Rs.)
1	Grip	Rubber	50	1	Numbers	50.00
2	2 mm Bolt & Nut	Stainless Steel	1	34	Numbers	34.00
3	4 mm Bolt & Nut	Stainless Steel	2	38	Numbers	76.00
4	Battery (Make: AA Portable power corporation)	NiMH	150	10	Numbers	1500.00
5	Belt	Leather	500	1	Numbers	500.00
6	Bowden Cable (Make: Unident Dental)	Steel	2500	1	Numbers	2500.00
7	Hanging Strip (Make Focus)	Nylon	500	1	Numbers	500.00
8	Hook	Steel	20	1	Numbers	20.00
9	4 mm Rivet	Aluminium	8	4	Numbers	32.00
10	Height adjustment sliding Bar (Make Digitek)	Aluminium	700	2	Numbers	1400.00
11	3 mm screw	Stainless Steel	1.5	8	Numbers	12.00
12	Motor with speed controller (Make: Chuang Li, China)	Composite Material	2200	1	Numbers	2200.00
13	Male Female power jack	Composite Material	20	4	Numbers	80.00
14	Power Cable (Make Qorx Energy)	Insulated copper wire	27	5	Meters	135.00
Total A Rs.						9039.00

Table 5.5: List of items fabricated at IITG Workshop (Price as on 22-11-2015 in Guwahati)

Sl No.	Part Name	Material	Rate per unit in Rupees (With material & fabrication charges)	Quantity	Amount (Rs.)
1	Battery Casing	ABS Plastic	200	1	200.00
2	Battery Casing Cap	ABS Plastic	100	1	100.00
3	Bowden Cable Holder Jaw	Mild Steel	150	1	150.00
4	Collection chamber	Plastic	400	1	400.00
5	End Blade	Stainless Steel	100	2	200.00
6	End Rotor Female	ABS Plastic	150	1	150.00
7	End Rotor Male	ABS Plastic	150	1	150.00
8	Handle 1	Mild Steel Tube	200	1	200.00
9	Handle 2	Mild Steel Tube	200	1	200.00
10	Intermediate Blade	Stainless Steel	100	15	1500.00
11	Intermediate Rotor	ABS Plastic	100	14	1400.00
12	Locking Nut	Mild Steel	80	1	80.00
13	Locking Pin	Mild Steel	20	1	20.00
14	Locking Pin Support	Mild Steel	150	1	150.00
15	Lower Casing	ABS Plastic	600	1	600.00
16	Motor Casing	ABS Plastic	200	1	200.00
17	Motor Holder	ABS Plastic	300	1	300.00
18	Motor Holder Cap	Aluminium	200	1	200.00
19	Common rail for spacers	ABS Plastic	300	1	300.00
20	Shaft	Mild Steel	200	1	200.00
21	Spacer	ABS Plastic	75	15	1125.00
22	Support Handle	Mild Steel Tube	400	1	400.00
23	Upper Casing	ABS Plastic	600	1	600.00
24	Leaf collection bag	Nylon	300		300.00
Total in B Rs.					9125.00
Total A+B (In INR)					18164.00
An overhead of 10% is required to cover indirect costs like supervision etc. and profit is not considered in this calculation. C					1816.40
Grand Total (A+B+C) in Rs.					19980.40
Rounding off (Rs.)					19980.00

Chapter 6 Design Validation of the Newly Designed Machine

Once the design development was completed, it was prototyped, the newly designed machine was found to be functionally satisfactory while testing it through a dry run. However its performance and efficiency was required to be evaluated through actual field trials. For this and design validation of the newly designed tea harvesting machine, five numbers of tests were carried out.

Objectives of these tests are:

- vi. To compare the area harvested using the newly designed tea harvesting machine in unit time with area harvested by hand plucking by the same worker in the same time.
- vii. To study the time required to harvest a unit area of 100 m² by a worker using the machine and by hand plucking.
- viii. To compare quantity of tea leaves plucked in unit time using the machine and by hand plucking.
- ix. Hand grip strength testing to understand the effect of using the tea plucking machine on the workers.
- x. Documentation of feedback from workers, who were exposed to the machine to understand their experiences while operating the machine using a questionnaire and then to carry out Nordic body parts discomfort mapping. A questionnaire was provided to each worker for this purpose and the sample questionnaire is provided at Appendix C.

6.1 Materials & methods

The design validation experiment was conducted during the month of November 2015 on Clone TV-23 tea plants at Section 18 of Dolaguri Tea Estate in Golaghat District of Assam. The plantation type was double hedge with a spacing of 75 cm x 75 cm x 105 cm. In these experiments, newly developed single operator battery powered hand harvester was used. The cutting span of the newly developed machine is 520 mm. During the field experiments, a participatory approach was adopted.

In Dolaguri Tea Estate, Section 18 consists of 8.4 hectares (84000 m²) of plantation area. It consists of 13,333 numbers of tea bushes per hectare. There were approximate 1, 11,997 tea bushes in section 18. The shade tree available at this section is Albizzia Odoratissima. As per the garden record in this section annual average of nine Man-days per hectare (10000 m²) is allotted.

6.2 The pruning cycles adopted in this section

In section 18, following pruning cycle were adopted

- i. Year 2016 -- Deep Skiff (Planned)
- ii. Year 2015 – Medium Skiff
- iii. Year 2014 – Unpruned
- iv. Year 2013 – Light Pruned

6.3 Experiment design

The layout was in a randomised block design, and each experiment carried out in 100 m² areas per plucker which consist of average 134 numbers of plants. During the experiment, a total area of 4000 m² (2000 m² each for hand plucking and machine plucking) was covered and where 2,666 plants were plucked by machine and 2,666 number plants was hand plucked.

A total number ten pluckers were randomly selected for the experiment; the team consists of both male and female pluckers. The selected workers were briefed on the details of the experiment and informed that the new device would help to increase their plucking productivity and hence this will enhance their financial incomes.



Fig. 6.1: Field Experiment is in progress



Fig. 6.2: A woman tea garden worker harvesting tea leaves with the newly developed machine.

After collecting the data from the various field experiments, the result of data analysis was interpreted with the help of t-test.

6.4 Experiment details

In experiment number one, each plucker was allotted to harvest an area of 100 m² each with the machine; the quantity plucked and time required were recorded accordingly. Similarly, the same sets of worker were allotted to another 100 m² area each for the

hand plucking. This time also the quantity plucked and time required were recorded accordingly. Here area was kept as constant and time required is variable.

In the experiment number two, the same procedure was adopted. In this experiment, the time was kept as constant and area covered was kept as a variable. Each worker was allotted 60 minutes to carry out the harvesting work with the help of the machine, and similarly, they were allotted another 60 minutes for hand plucking of tea leaves. The quantity of tea leaves plucked and the areas covered in 60 minutes were recorded accordingly for both machine harvesting and hand plucking.

In the experiment number three, quantities of the tea leaf plucked with the help of the machine and by hand in an hour were compared.

The experiment number four the hand grip strength was studied; it was to find out whether there is any adverse effect on grip strength of the workers after using the machine. This study was carried out with the help of Grip Dynamometer before and after machine harvesting and hand plucking (Fig. 6.3); results were recorded accordingly.



Fig. 6.3: Testing of hand grip strength with the help of Grip Dynamometer.

In the experiment number five, the comfort factor of the workers while working with the machine was studied. A questionnaire was provided (Appendix C) to each worker to understand their experiences while using the machine. In this experiment, a sample of fifty workers was studied, and they were allowed to operate the machine for 30

minutes, and after the operation, their feedback was recorded with the help of a questionnaire.

One performance certificate has been issued after successful completion of the field experiments by the authority of Dolaguri Tea Estate, a copy of which is provided at Appendix D.

6.5 Findings of experiments

Findings and interpretations of the above experiments are provided in sections 6.5.1 to 6.5.10.

6.5.1 Experiment no.1

Findings and interpretation of independent sample test for experiment one (Comparison of time to cover an area of 100 m². using machine and hand plucking).

Table 6.1: Group statistics for Experiment No.1

Group Statistics					
	Method	N	Mean	Std. Deviation	Std. Error Mean
Time to cover 100 m ² Area	Manual	10	38.3	2.31181	0.73106
	Machine	10	13.75	0.78865	0.24939

Table 6.2: Independent samples test for Experiment No.1

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Time to cover 100 m ² Area	Equal variances assumed	10.52	0.01	31.77	18	0	24.542	0.77243	22.9192	26.1648
	Equal variances not assumed			31.77	11.07	0	24.542	0.77243	22.8432	26.2409

6.5.2 Interpretation of Experiment No 1

H₀₁ - Null Hypothesis: There is no significant difference of time in minutes to cover an area of 100 m². by machine plucking and manual plucking.

An independent sample t-test was conducted for a significance level of 0.05. The null hypothesis was rejected (Two-tailed Sig: 0.000) and concluded that there is a significant difference of time in minutes to cover an area of 100 m² by machine plucking and manual plucking. The mean time required to harvest an area of 100 m² by machine plucking in minutes is 13.75 minutes, and with manual plucking, the value is 38.3 Minutes.

6.5.3 Experiment no.2

Findings and Interpretation of independent sample test (Comparison of the area covered in an hour using machine and hand plucking).

Table 6.3: Group statistics for Experiment No.2

Group Statistics					
	Method	N	Mean	Std. Deviation	Std. Error Mean
Area covered in an hour by machine & manual plucking (In m ²)	Machine	10	439.4	24.27	7.675
	Manual	10	156.5	2.799	0.885

Table 6.4: Independent samples test for Experiment No.2

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the	
									Lower	Upper
Area covered in an hour by machine & manual plucking (In m ²)	Equal variances assumed	20.01	0	36.62	18	0	282.91	7.73	266.68	299.14
	Equal variances not assumed			36.62	9.24	0	282.91	7.73	265.50	300.32

6.5.4 Interpretation of Experiment No 2

H₀ - Null Hypothesis: There is no significant difference of area covered in m². in an hour by machine plucking and manual plucking.

An independent sample t-test was conducted for a significance level of 0.05. The null hypothesis was rejected (Two-tailed Sig: 0.000) and concluded that there is a significant

difference of area covered in m². in an hour by machine plucking and manual plucking. The mean area covered in an hour by machine plucking in m² is 439 m², and with manual plucking, the value is 156.5 m².

6.5.5 Experiment no.3

Findings and Interpretation of independent sample tests (Comparison of the quantity of leaves plucked in an hour using machine and hand plucking).

Table 6.5: Group statistics for Experiment No.3, (Mean in kg).

Group Statistics					
	Method of Plucking	N	Mean (kg)	Std. Deviation	Std. Error Mean
Quantity of tea leaves plucked per hour (In kg)	Machine	10	6.59	0.363	0.1148
	Hand	10	2.35	0.041	0.0131

Table 6.6: Independent samples test for Experiment No.3

Independent Samples Test										
		Levene's Test for Equality of		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Quantity of tea leaves plucked per hour (In kg)	Equal variances assumed	20.3	0	36.707	18	0	4.242	0.116	3.999	4.485
	Equal variances not assumed			36.707	9.234	0	4.242	0.116	3.982	4.502

6.5.6 Interpretation of Experiment No 3

H₀₃ - Null Hypothesis: There is no significant difference of quantity of tea leaf plucked per hour using machine and hand plucking.

An independent sample t-test was conducted for a significance level of 0.05. The null hypothesis was rejected (Two-tailed Sig: 0.000) and concluded that there is a significant difference between the quantity of tea leaves plucked per hour using machine and hand

plucking. The mean amount of tea leaves plucked in an hour using the machine is 6.592 kg, and with hand plucking, the value is 2.350 kg.

6.5.7 Experiment no.4

Findings and Interpretation of independent sample test. (Comparison of hand grip strength before and after hand plucking & before and after using the machine). The unit for grip strength is kg/cm²).

6.5.7.1 Test for left hand

Table 6.7: Group Statistics for left hand, Experiment No.4

Group Statistics					
	Manual or Machine	N	Mean	Std. Deviation	Std. Error Mean
Left Hand Grip Strength	Manual	10	27.26	2.88991	0.91387
	Machine	10	26.7	3.12872	0.98939

Table 6.8: Independent sample test for left hand, Experiment No.4

Independent Samples Test										
		Levene's Test		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Left Hand Grip Strength	Equal variances assumed	0.072	0.791	0.416	18	0.682	0.56	1.34686	-2.26966	3.38966
	Equal variances not assumed			0.416	17.888	0.683	0.56	1.34686	-2.27093	3.39093

6.5.7.2 Test for right hand

Table 6.9: Group Statistics for right hand, Experiment No.4

Group Statistics					
	Manual or Machine	N	Mean	Std. Deviation	Std. Error Mean
Right Hand Grip Strength	Manual	10	30.49	3.25455	1.02918
	Machine	10	30.43	3.48076	1.10071

Table 6.10: Independent sample test for right hand, Experiment No.4

Independent Samples Test										
		Levene's Test		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Differenc	Std. Error Difference	95% Confidence	
									Lower	Upper
Right Hand Grip Strength	Equal variances assumed	0.041	0.842	0.04	18	0.969	0.06	1.50691	-3.1059	3.2259
	Equal variances not assumed			0.04	17.919	0.969	0.06	1.50691	-3.10692	3.22692

6.5.8 Interpretation of Experiment No 4

H₀₄ - Null Hypothesis: There is no significant difference of grip strength while working with or without plucking machine. Independent Sample t-Test was conducted to see the variance of the grip strength with or without using the machine. It has been found that there is no significant difference in grip strength with or without using the machine. Hence this experiment accepts the null hypothesis.

6.5.9 Experiment no.5: Body part discomfort study

To explore the discomfort of the machine operator Nordic body parts discomfort mapping (NBPDM) was conducted during the field trial. The summarised findings with analysis are provided herewith.

Table 6.11: Case processing summary for body pain analysis, Experiment No.5

Case Processing Summary							
	Body Pain Experienced	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
Worker height	No Pain	30	100.00%	0	0.00%	30	100.00%
	Arm Pain	8	100.00%	0	0.00%	8	100.00%
	Hip Pain	12	100.00%	0	0.00%	12	100.00%
Height of the tea table : 850 mm							

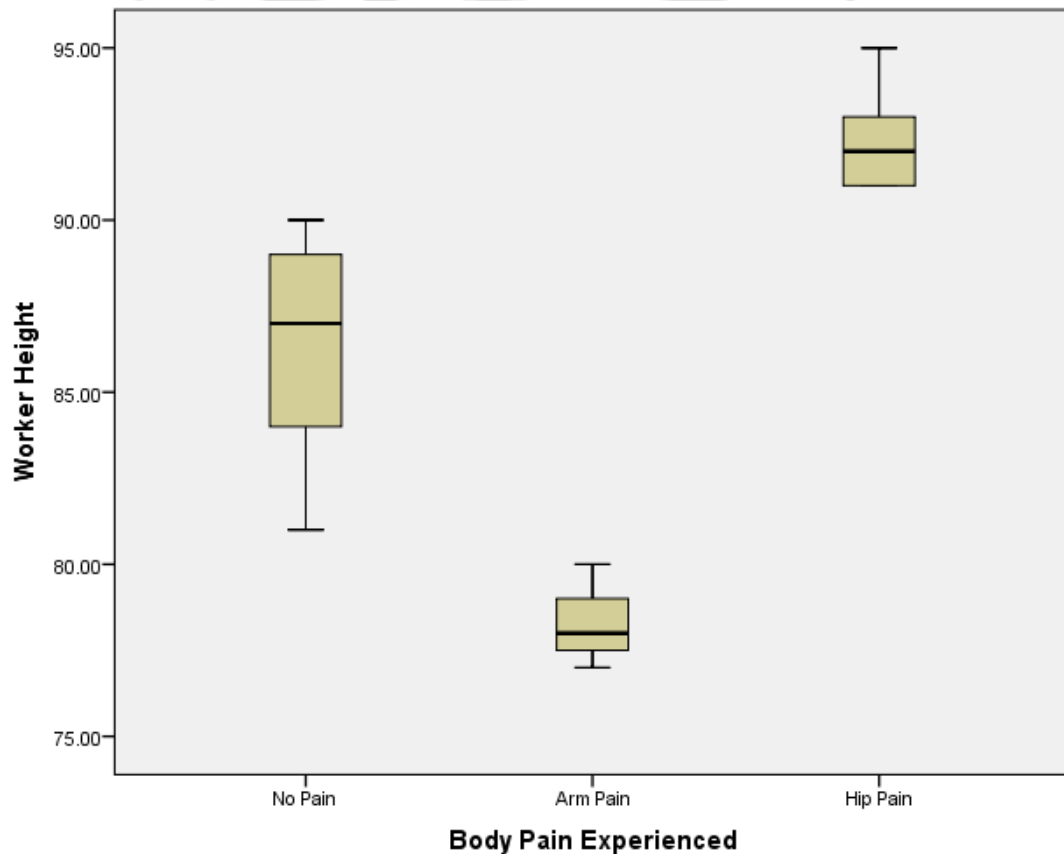


Fig. 6.4: Body pain analysis through comparative Boxplot (Workers height in mm)

6.5.10 Interpretation of Experiment No 5

From the experiment number 5, it has been observed that when there is a significance difference between the tea table and the height of the worker, and then the machine operator experiences body pain. In this experiment, the tea table's height was 85 cm.

Workers whose heights of the waist were within the range of 80 cm to 90 cm they have operated the machine without any body pain. Those workers whose height of the waist was below 80 cm they have experienced pain on right arm (All workers were right-handed). The workers whose height of the waist were more than 90 cm they have experienced the hip pain.

From this experiment, we can come to the following conclusion that to operate the machine comfortably without any body pain, the height of the waist of the worker from the ground and the height of the tea table should be proportional. This proportionality can be related as follows:

Let the height of the tea table = x cm

The height of the waist of the worker = y cm

For a comfortable machine harvesting operation, $x = y \pm 5$ cm Eq. (6.1)

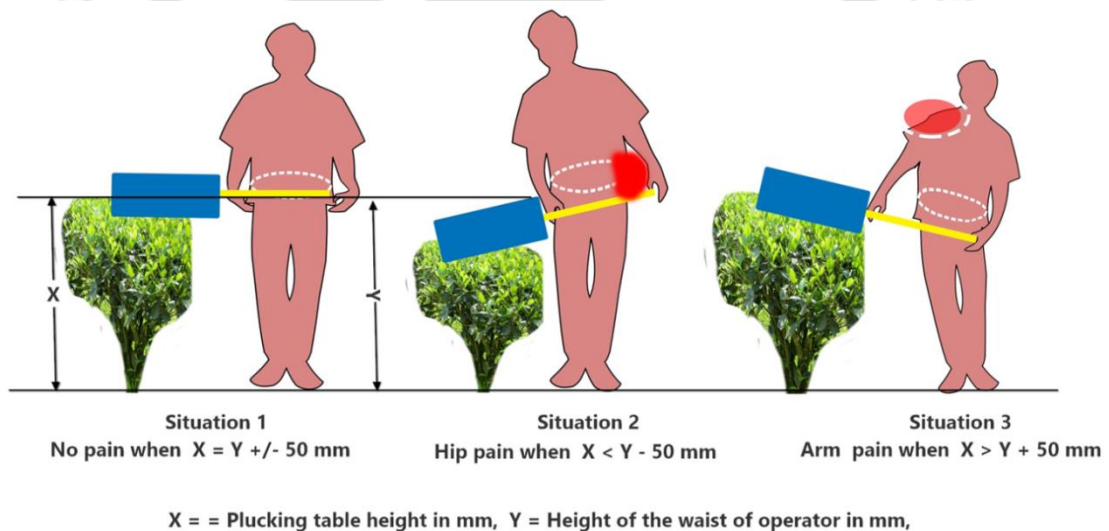


Fig. 6.5: Graphical Representation of findings of NBPDM, (Experiment No.5)

6.6 Validation of hypothesis

The hypothesis formulated in Chapter 1, section 1.9 that “Design intervention through the introduction of an efficient mechanised tea harvesting device will lead to enhanced productivity in harvesting of tea leaves to meet the challenges of shortage of tea garden workers engaged in plucking.” has been established after conducting numbers of exhaustive experiments in five phases, as described in Experiment No.1 (Chapter: 6.5.1), Experiment No.2 (Chapter: 6.5.3), Experiment No.3 (Chapter: 6.5.5), Experiment No.4 (Chapter: 6.5.7) and Experiment No.5 (Chapter: 6.5.9). The

interpretations of various experiments as mentioned above are also given. Findings from the above interpretation clearly indicates that the productivity of the operator using the machine was higher and thus to cover more area in peak reason will be possible with less nos. of workers than currently engaged and hence will compensate for the shortage of pluckers in the tea plantations. It was also found that there was no adverse effect on the worker while operating the machine. All users expressed their eagerness to use the machine. Hence, the proposed hypothesis has been established.

Next chapter contains the discussion about the results, conclusions that can be drawn from the research, recommendations and scope for future work.



Chapter 7 Discussions, Conclusion and Recommendations

7.1. Brief summery

Tea harvesting involves a significant expenditure on the seasonal worker. To produce 1kg Made Tea 4.5 kg of green tea leaves are necessary under normal condition (TRA, 2014).

Worker shortages in Indian tea industry mean that mechanical plucking must replace traditional manual plucking of tea leaves whenever possible.

The mechanical harvesting of tea leaves is quite common in Japan, Argentina, Sri Lanka, China (Han et al., 2014).

In the tea industries of Assam, the mechanised harvesting is very limited due to the various problems like the presence of shade trees, Storm water drains, unfavourable plantation patterns, etc. but countries like Japan, China, and Sri Lanka have currently encouraging mechanised harvesting of tea leaves. From the studies, it is clear that mechanised harvesting of tea leaves is more efficient and economic than the conventional manual harvesting (Han et al., 2014).

7.2. Precautions to be taken for mechanised harvesting

From the experiments conducted during the research, it has been established that the mechanical harvesting also leads to time-saving and ensures more productivity. However, it should be noted that hand plucking causes less tea leaves losses during plucking and hence improves tea quality and that mechanical plucking requires a pre-classification of tea leaves to get a superior quality tea. Since shoots with two leaves and a bud produce the best quality of tea (Okal et al., 2012) so while harvesting with the machine, it should be ensured that the device should collect the highest percent of such type of shoots. This can be achieved by adopting a creep of 10 mm and maintaining a uniform cutting table (Barbora et al., 1994).

To reduce the production costs and to address the labour shortage in Assam, the implementation of the mechanical plucking of tea leaves is preordained. However, machine plucking over a long time, causes the tea buds to germinate and the density excessively increases. As a result, the tea buds will develop facing-leaves, the leaves become weak, and tea quality will be deteriorated (Han et al., 2014).

Therefore, before introducing mechanised harvesting; the pruning operations are to be carried out properly. There must be an appropriate control of the cutting blades.

7.3. Guidelines to implement the mechanised harvesting process

In the coming years, the tea plantations of Assam where mechanical harvesting will be introduced, will not only require a good harvesting machine but also have to adopt some guidelines to implement the mechanisation process successfully. These are as follows (Baisya et al., 2014):

- i. Proper planning to be done while selecting correct tea varieties during plantation suitable for mechanical harvesting.
- ii. The plantation pattern should be favourable for machine harvesting; from this study it was found that single row plantation would be the best for mechanised harvesting.
- iii. The tea bud germination density must be correct, and there must be tidy growth, to allow mechanical harvesting and to maintain tea leaf quality.

7.4. Suggestions for successful implementation of mechanized harvesting

Automation & mechanisation of tea plucking in Assam will require coordination between tea plantations and automation so that production costs are reduced and competitiveness is improved. To popularise machinised harvesting, the appropriate authority including tea associations should encourage the tea growers by creating proper awareness in this regard about benefits that can accrue financially and socio-economically. Government may intervene through their policy to benefit the small tea growers by adopting mechanised tea harvesting in their plantations to ensure that the century old tea industry of Assam remains internationally competitive and to facilitate sustainable development. The workers should be encouraged to use tea harvesting machine and trade unions should be taken into confidence in this regard. To achieve the use of machines for tea harvesting, appropriate incentive schemes may be introduced.

7.5 Findings of present study

After contextual inquiry and conducting exhaustive experiments related to scope of design intervention in pre-processing of tea the salient findings are as follows:

After analysing various mechanised tea harvesting process across the world, it is evident that according to working principle, the tea harvesting machines could be classified as rotary type, reciprocating type, horizontal-circular blade type, spiral hob type, spiral roll folding type, battery operated type, engine operated types. Among these, rotary type machines are found to be suitable for tea gardens located in plains and reciprocating type is found to be suitable for hilly terrains. For the tea gardens of Assam, Single operator battery powered rotary type machines will be suitable.

7.5.1 Battery charging and replacement system

Present battery attached to the machine can continuously supply power up to four hours. After four hours the battery has to be recharged. However, to facilitate continuous working with the machine battery pack is designed such way that it can be replaced with another set of recharged battery pack. Thus to operate the machine continuously for seven to eight hours two sets of batteries will be necessary. The alteration of the batteries can be done during the lunch hours. In the tea gardens of Assam; harvested leaves are collected two times in a day. A vehicle collects harvested leaves after weighing during lunch time and at the end of daily working hours. After collection of the plucked leaves this vehicle goes to tea factory for unloading the same.

There should be provision of battery charging rooms at the factories. The vehicle which leaves the factory to collect the leaves from the garden during lunch hours, that same vehicle can carry the second set of batteries for workers and while returning from the field to factory then it can collect discharged batteries from the field for recharging at factories. Hence no additional system is necessary for alteration of battery during field operation.

7.5.2 Optimum clearance between rotor assembly and cutting plane

The machine will harvest quality tea shoots if a fixed gap of 1 mm is maintained between rotor assembly and the cutting plane and this has been fixed based on optimisation. A creep of 1 cm to be maintained between the tea table and the cutting blades (Barbora et al., 1994)

7.5.3 Optimum revolution per minute of the rotor shaft

During this study it has been found that the optimum revolution per minute of the rotor shaft is 400.

7.6 Contribution of present research

This research provides a solution to overcome the current shortage of work force in tea industry of Assam. As mentioned earlier proper mechanisation of tea manufacturing process is the best possible way to solve this problem. In tea industry of Assam, full process mechanisation is only present in the factory. To carry out majority of field operations, tea industry is still adopting century old manual processes. Tea plucking is one of the most important field operations and a considerable number of manpower is necessary to carry out plucking. As cited earlier, in the tea gardens of Assam, due to certain hindrances mechanisation in the plucking operation is still not popular. Through this research work a mechanical tea harvesting device has been designed and developed considering the working environment of tea estates of Assam and tested successfully. In near future, by proper utilisation of this new machine will help not only to increase the productivity of tea industries of Assam but also to improve the socio-economic conditions of the associated workforce.

7.6.1 Benefits for Small tea growers

Small tea growers will be most benefitted by adopting this newly developed harvesting machine, since they will not be any more dependent on manpower engaged in organised tea estates to harvest tea leaves at higher wage rate since owners can either be able to harvest tea of their own or can only engage few manpower for harvesting. This will not only reduce their cost of production for the small tea growers but also big tea estates will be able to retain their workforce intact during tea plucking season leading to harmonious relations between the STGs and organised tea estates.

7.6.2 Cost benefits

Cost of labour is one of the major factor in tea industry. From the results of Experiment 1, it is found that to harvest 100 m² area by this machine time necessary is around 14 minutes in comparison to 38.3 minutes by manual plucking. Hence per day more area can be covered for harvesting. This will help to reduce labour cost.

7.6.3 Increase in productivity

This machine will help to increase the productivity. From the experiment number 3. It has been learned that the machine plucking helps to increase productivity by 2.8 times in comparison to hand plucking.

Hence low production cost and high productivity will boost the tea industry of Assam in near future by using the machine under consideration.

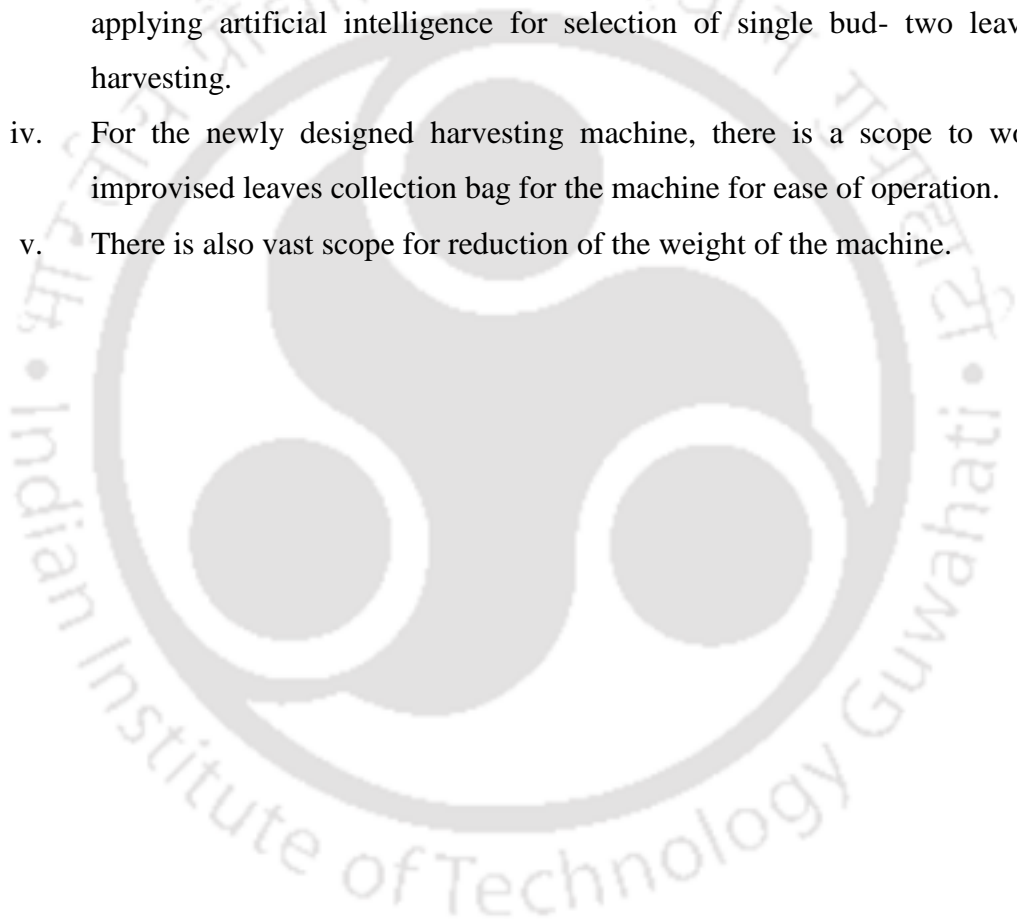
7.7 Suggestions and recommendations

The followings are the suggestions for consideration to enhance the operational efficiency while adopting mechanical harvesting by using the newly developed tea harvester:

- a. Machines ought to rather be used after second week of July during a season when yield of tea are more and there is shortage of plucking workforce.
- b. Choice of the section ought to be such that sections having hardy planting materials and minimum vacancy that facilitates simple movement of machines are solely selected.
- c. The height of plucking table ought to be $X = Y \pm 5$ cm, wherever X is that the plucking table height & Y is that the height of the waist of the machine operator. Additional height would result in less coverage. Thus man-machine and plant table height matching may be considered.
- d. For the smooth movement of the man with machine, drains should be along the rows rather than across as far as possible. This should be kept in mind for any future plantations.
- e. One plastic flute board sheet should be placed below the leaf assortment bag for straightforward sailplaning and to prevent damage to tea table. This can also facilitate maintaining the required creep.
- f. Machine ought to persist one row (Pahi) and come back through another.
- g. A row should be harvested in the same direction on each round.

7.8 Limitation of the current research and future scope

- i. Though less in numbers, there are some tea gardens in Assam which are located in the hilly terrains. This research was limited to tea gardens located in the plain area of Assam. However, the machine may be reworked to facilitate harvesting in these areas too in future considering context of use.
- ii. The newly developed machine does not take into account single bud- two leaves preference for making Orthodox variety of tea and more suitable for CTC variety. In this research, this scope was not considered exclusively.
- iii. There is a scope in future to concentrate more on selective plucking possibly applying artificial intelligence for selection of single bud- two leaves for harvesting.
- iv. For the newly designed harvesting machine, there is a scope to work on improvised leaves collection bag for the machine for ease of operation.
- v. There is also vast scope for reduction of the weight of the machine.



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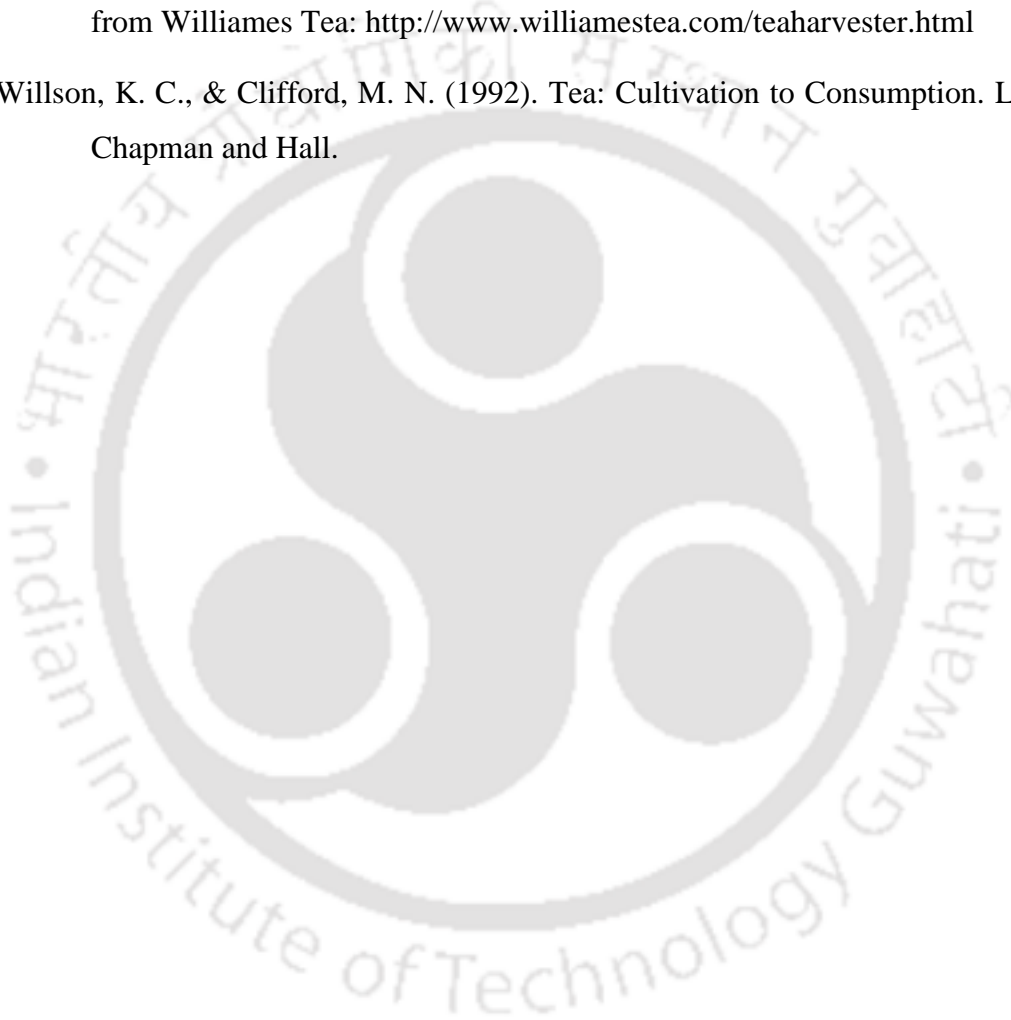
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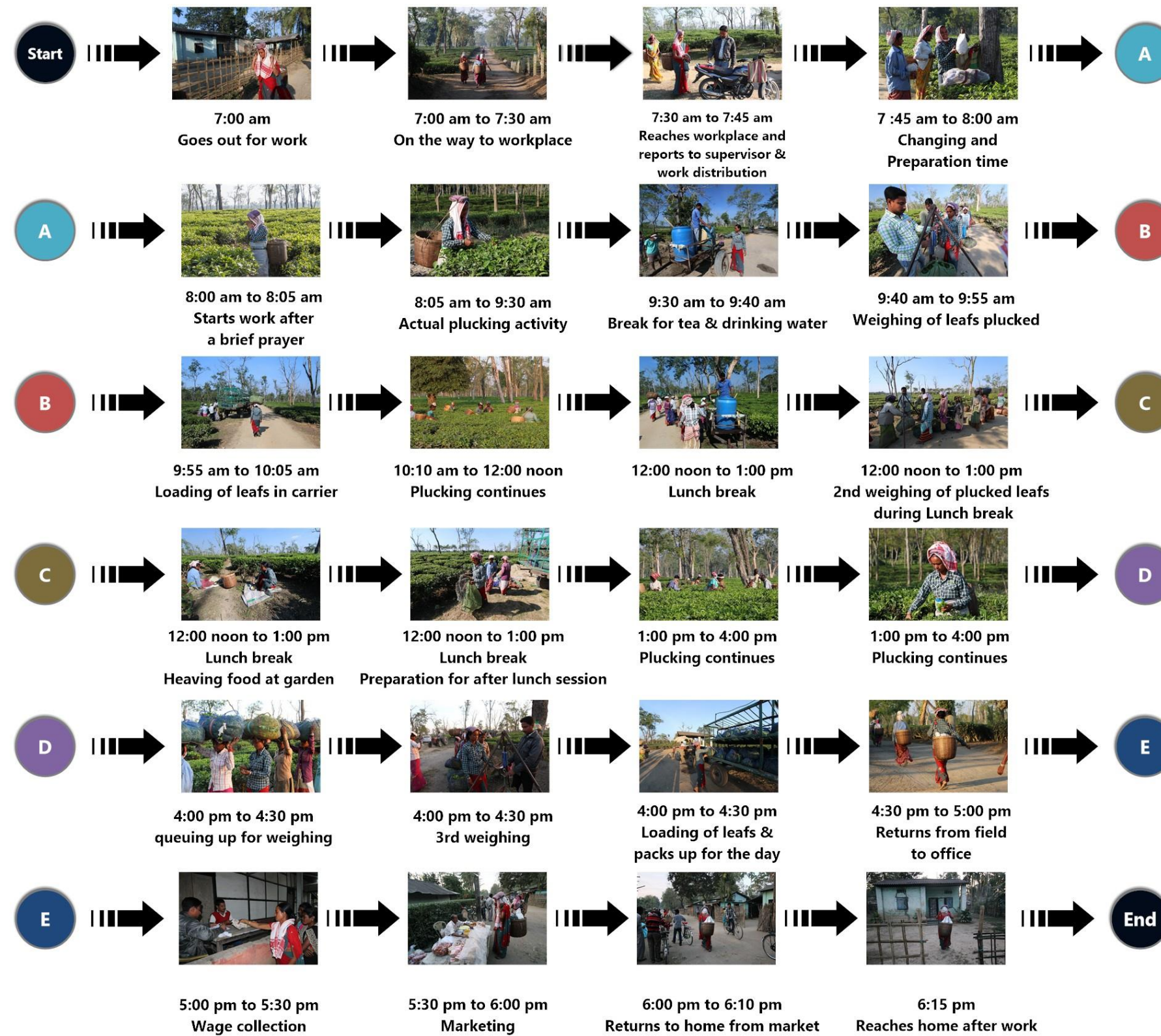
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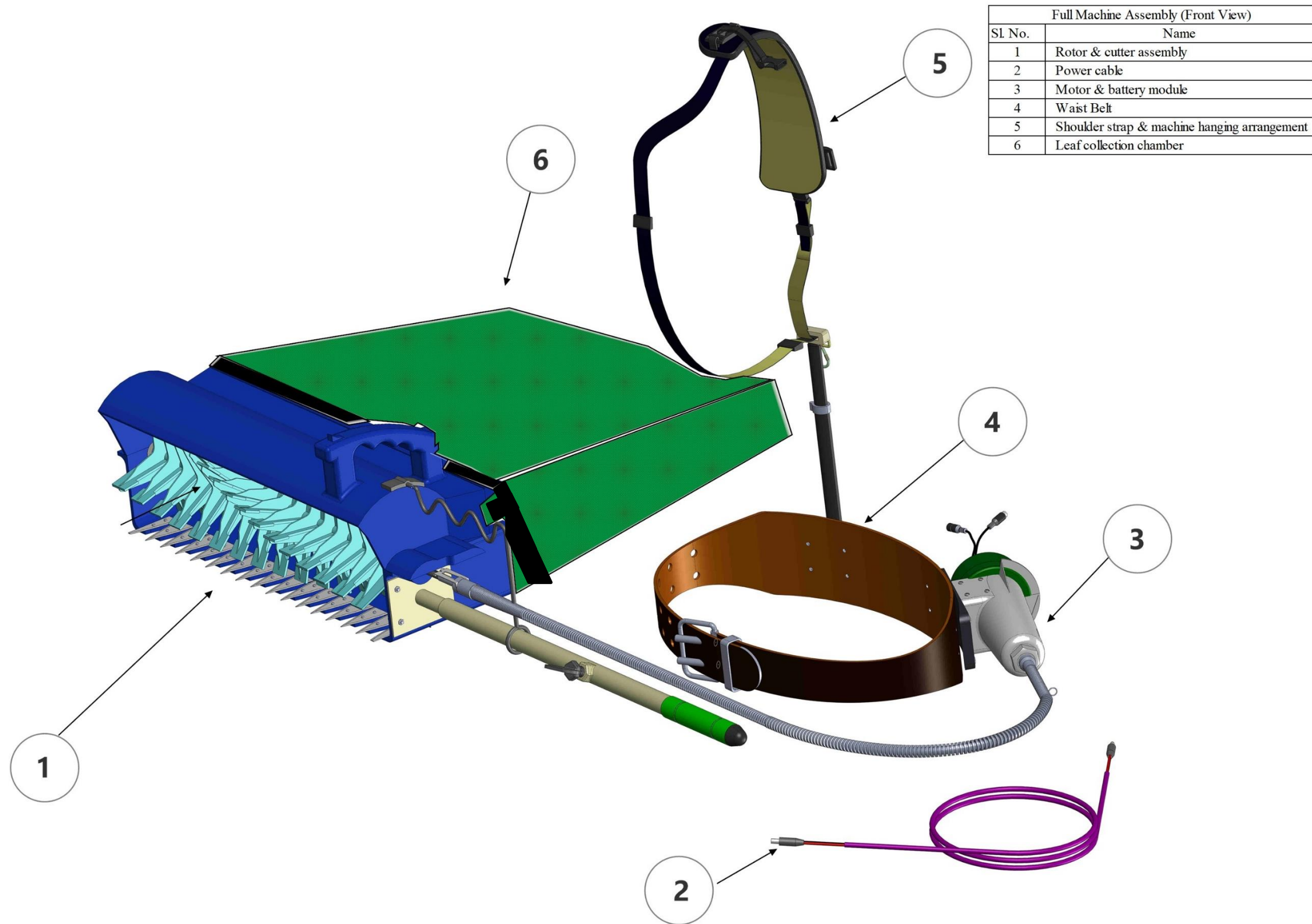
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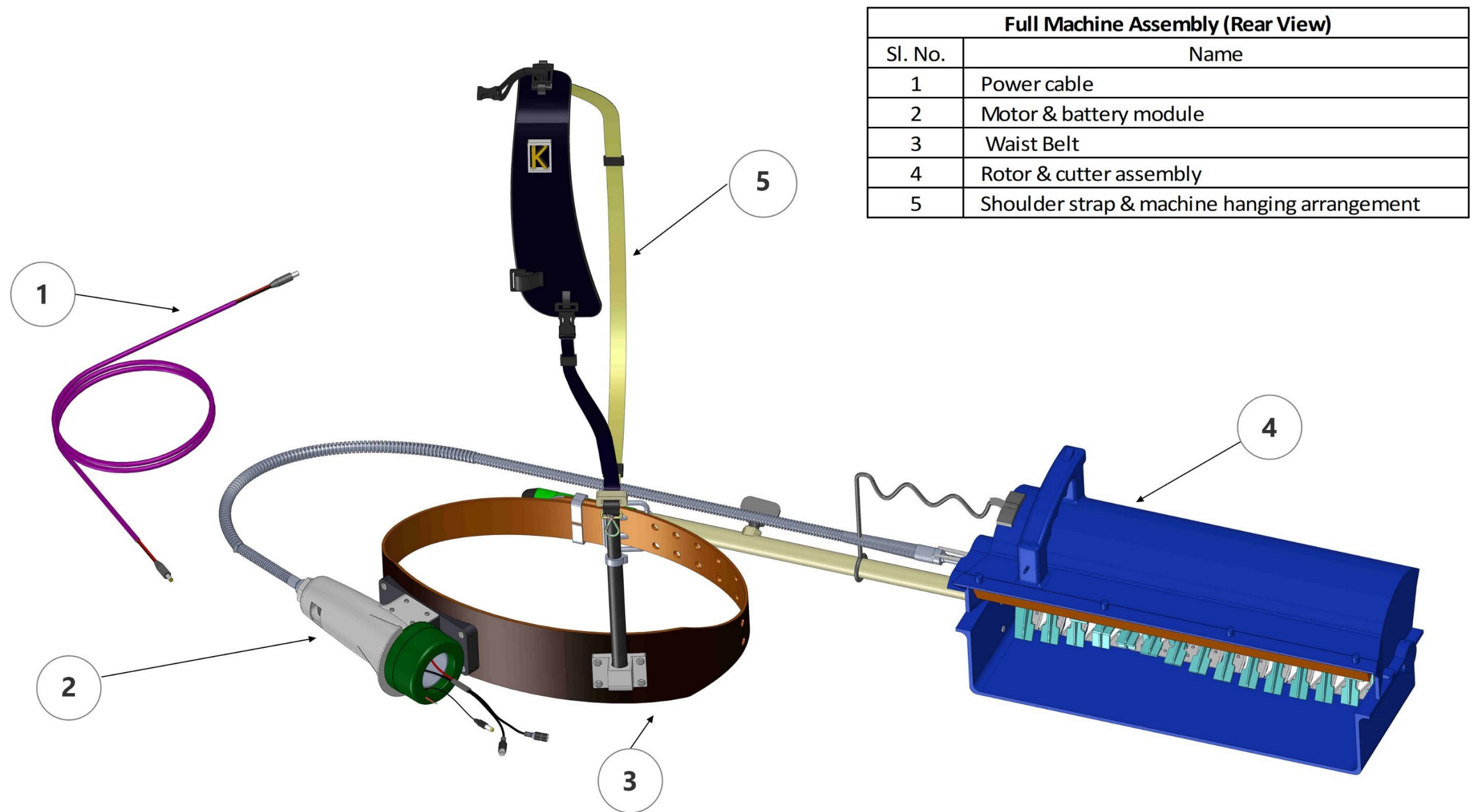
Appendix – A - A pictorial activity diagram on the female field worker in a tea garden of Assam



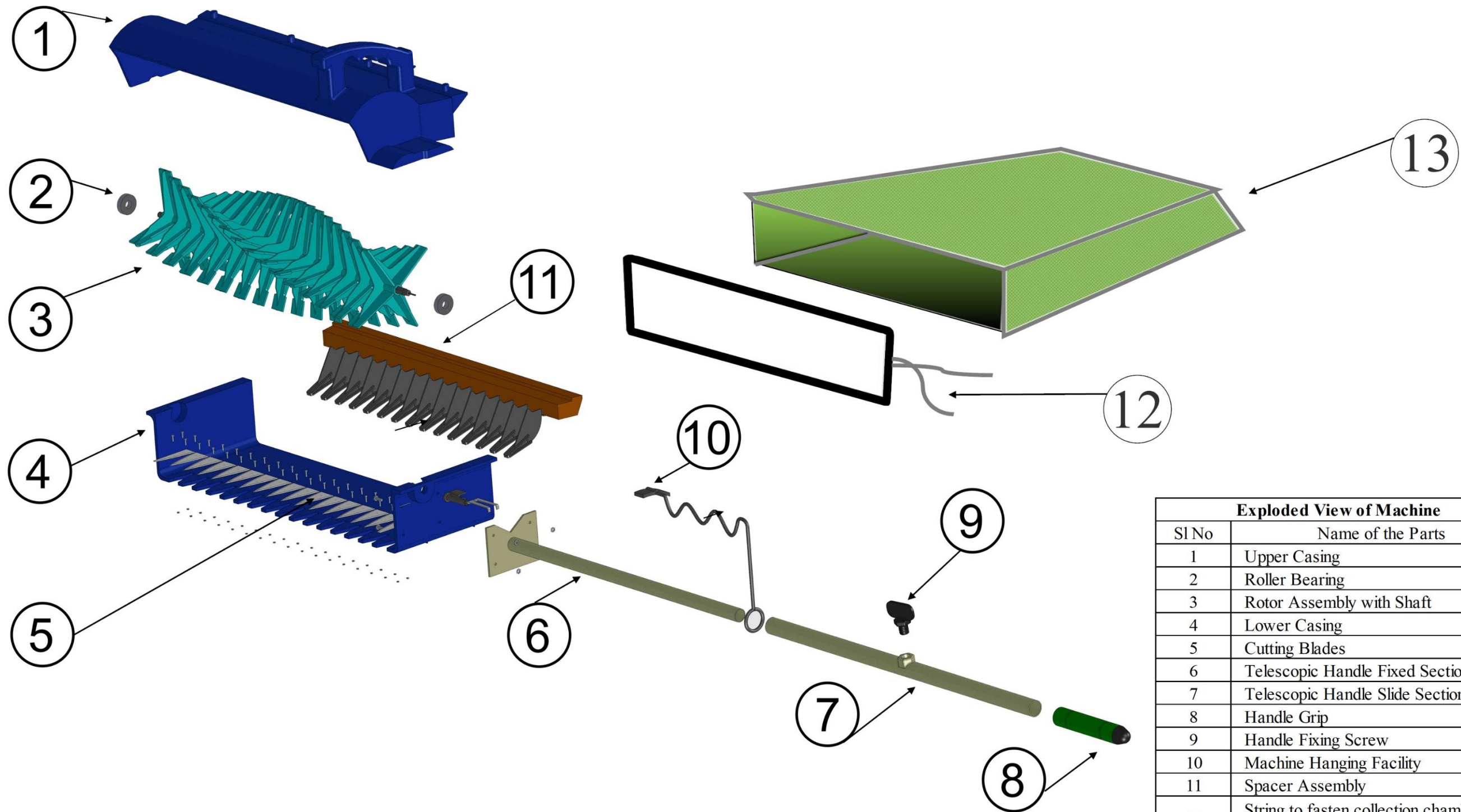
Appendix B - Fig. B -1- Complete machine assembly front view



Appendix B - Fig. B -2- Full machine assembly rear view

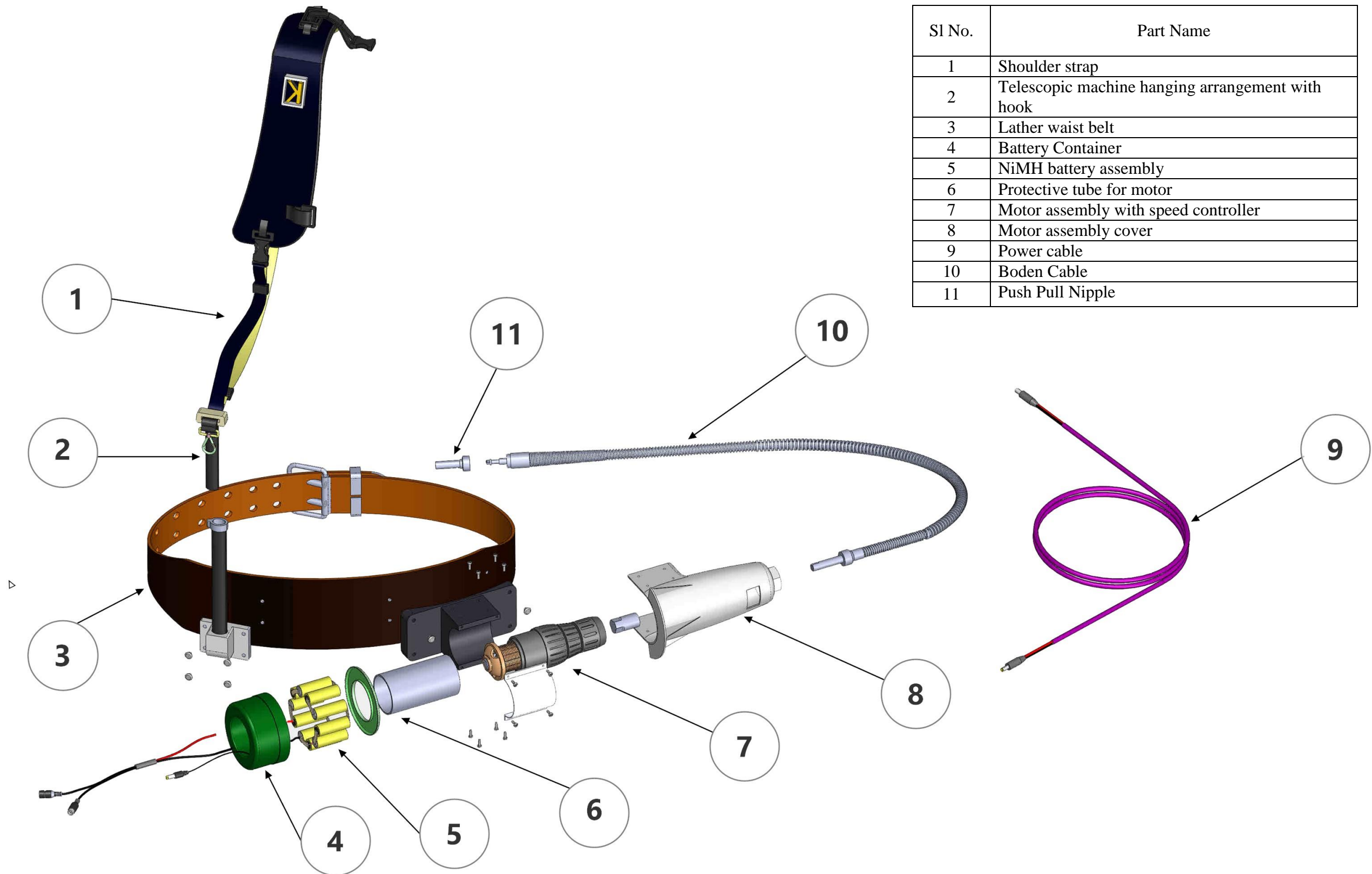


Appendix B - Fig. B -3- Exploded view of rotor, cutter assembly & collection chamber



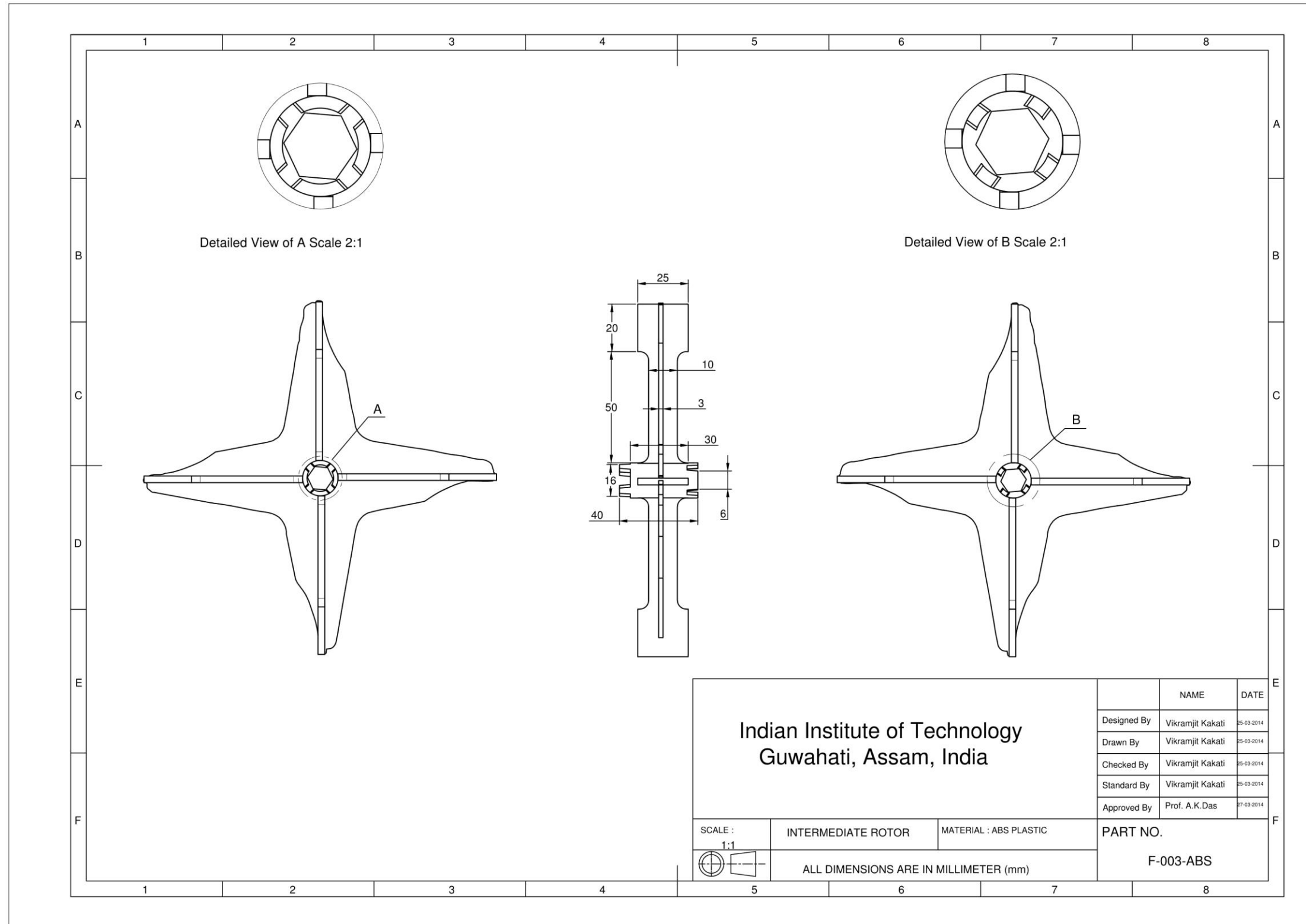
Exploded View of Machine	
Sl No	Name of the Parts
1	Upper Casing
2	Roller Bearing
3	Rotor Assembly with Shaft
4	Lower Casing
5	Cutting Blades
6	Telescopic Handle Fixed Section
7	Telescopic Handle Slide Section
8	Handle Grip
9	Handle Fixing Screw
10	Machine Hanging Facility
11	Spacer Assembly
12	String to fasten collection chamber with machine
13	Collection chamber

Appendix B - Fig. B -4- Exploded view of motor assembly, battery assembly and machine carrying mechanism

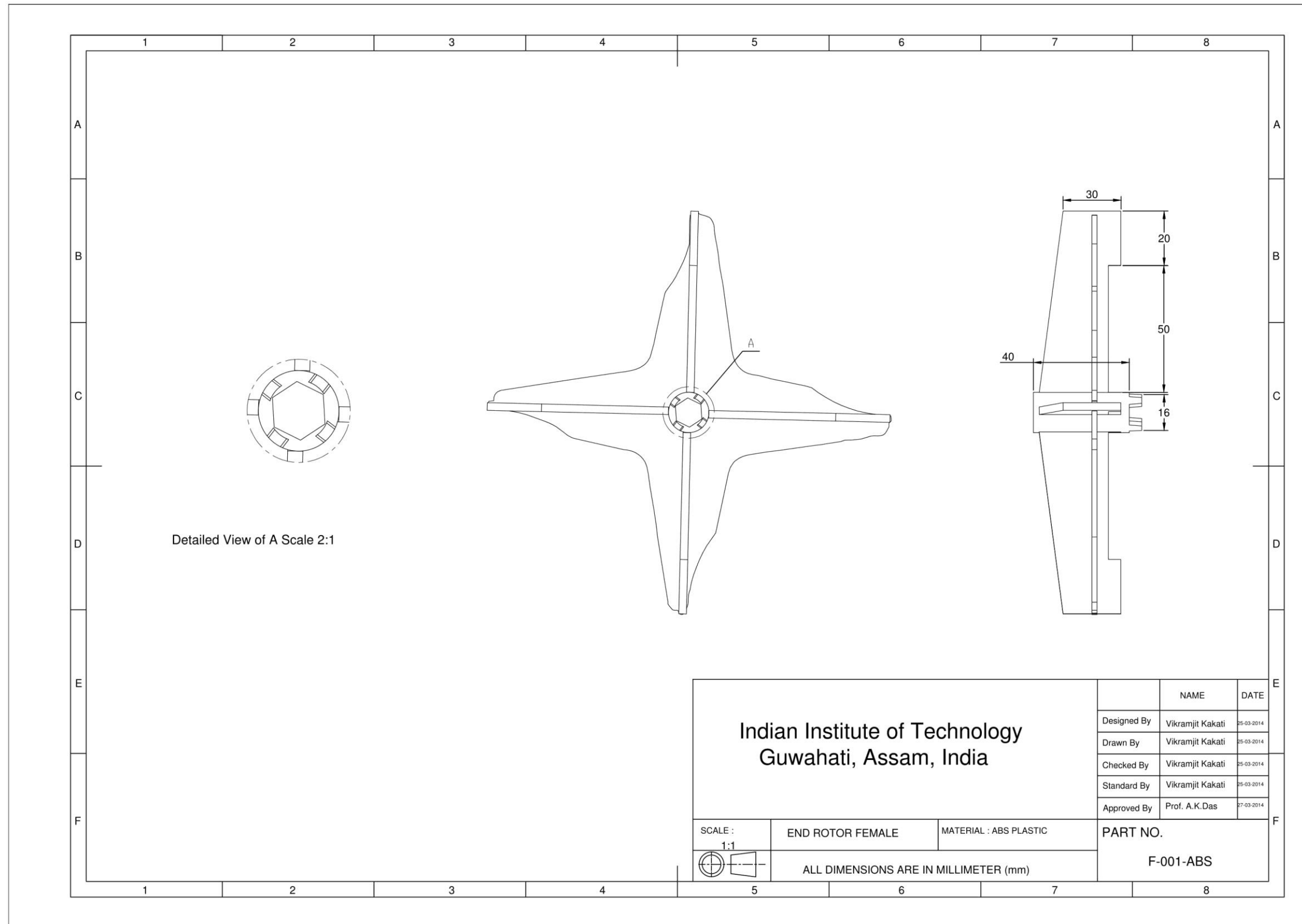


SI No.	Part Name
1	Shoulder strap
2	Telescopic machine hanging arrangement with hook
3	Lather waist belt
4	Battery Container
5	NiMH battery assembly
6	Protective tube for motor
7	Motor assembly with speed controller
8	Motor assembly cover
9	Power cable
10	Boden Cable
11	Push Pull Nipple

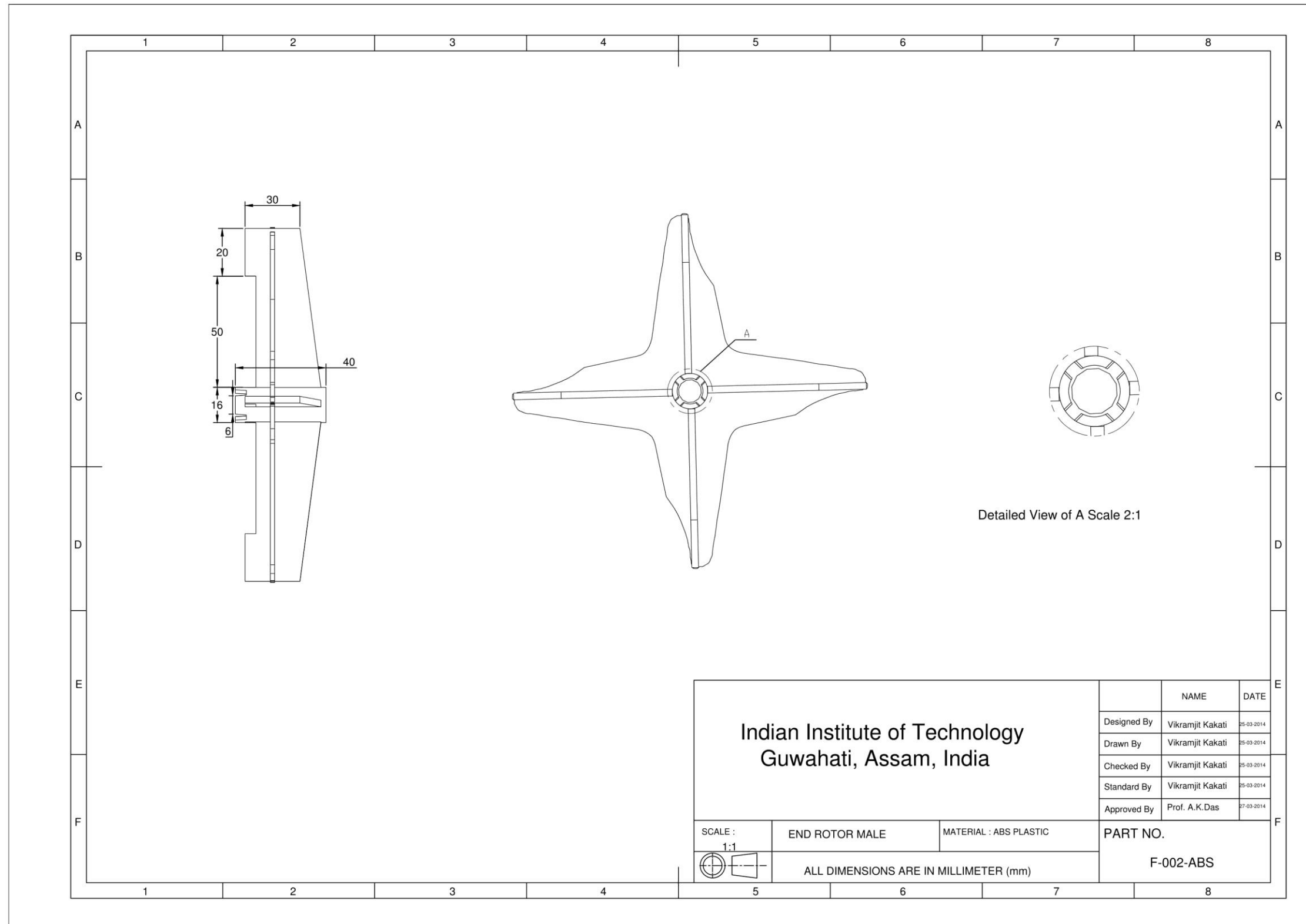
Appendix B - Fig. B-5: Detail drawing of intermediate rotor



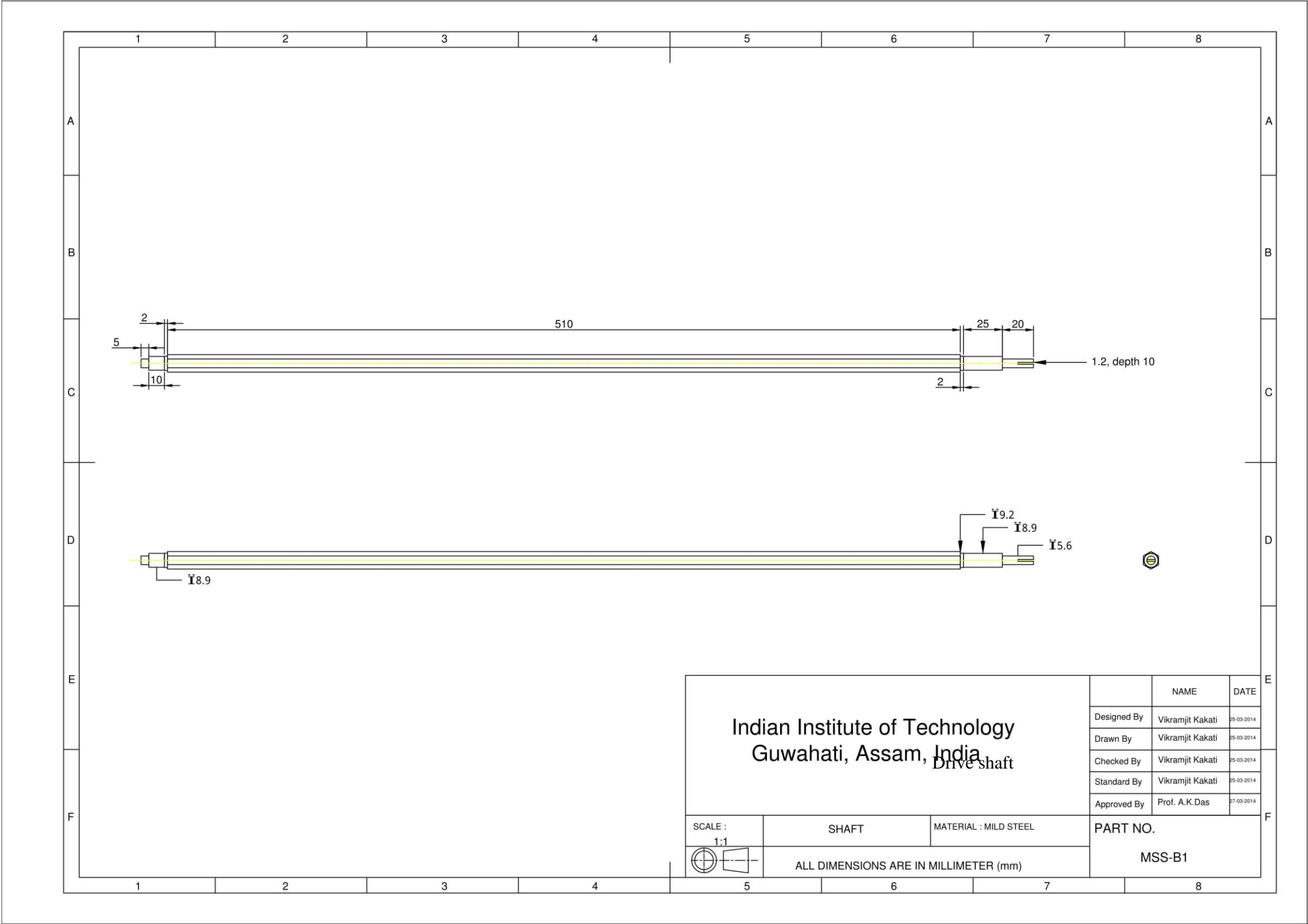
Appendix B - Fig. B-6: Detail drawing of end rotor (Female)



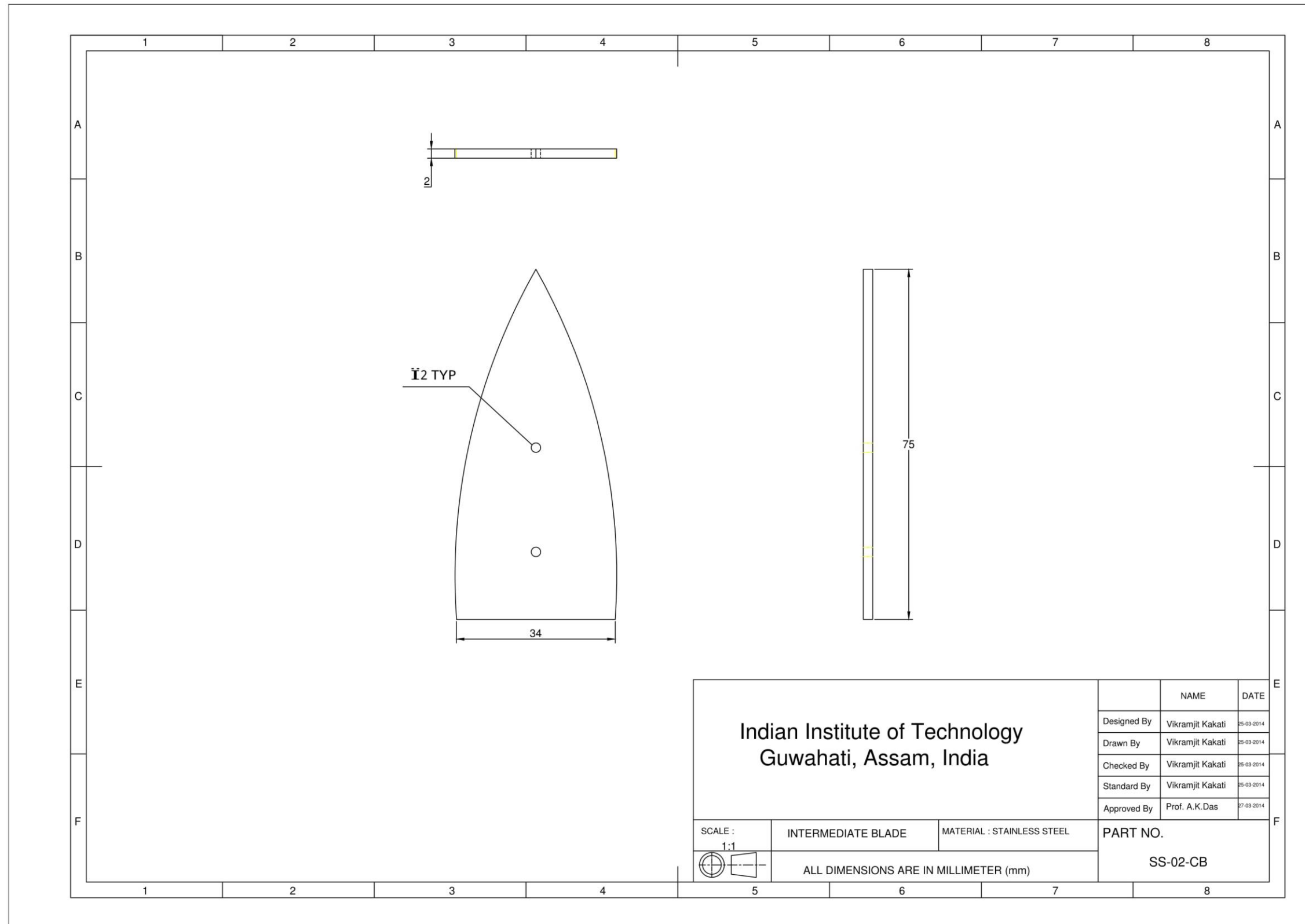
Appendix B - Fig. B-7: Detail drawing of end rotor (Male)



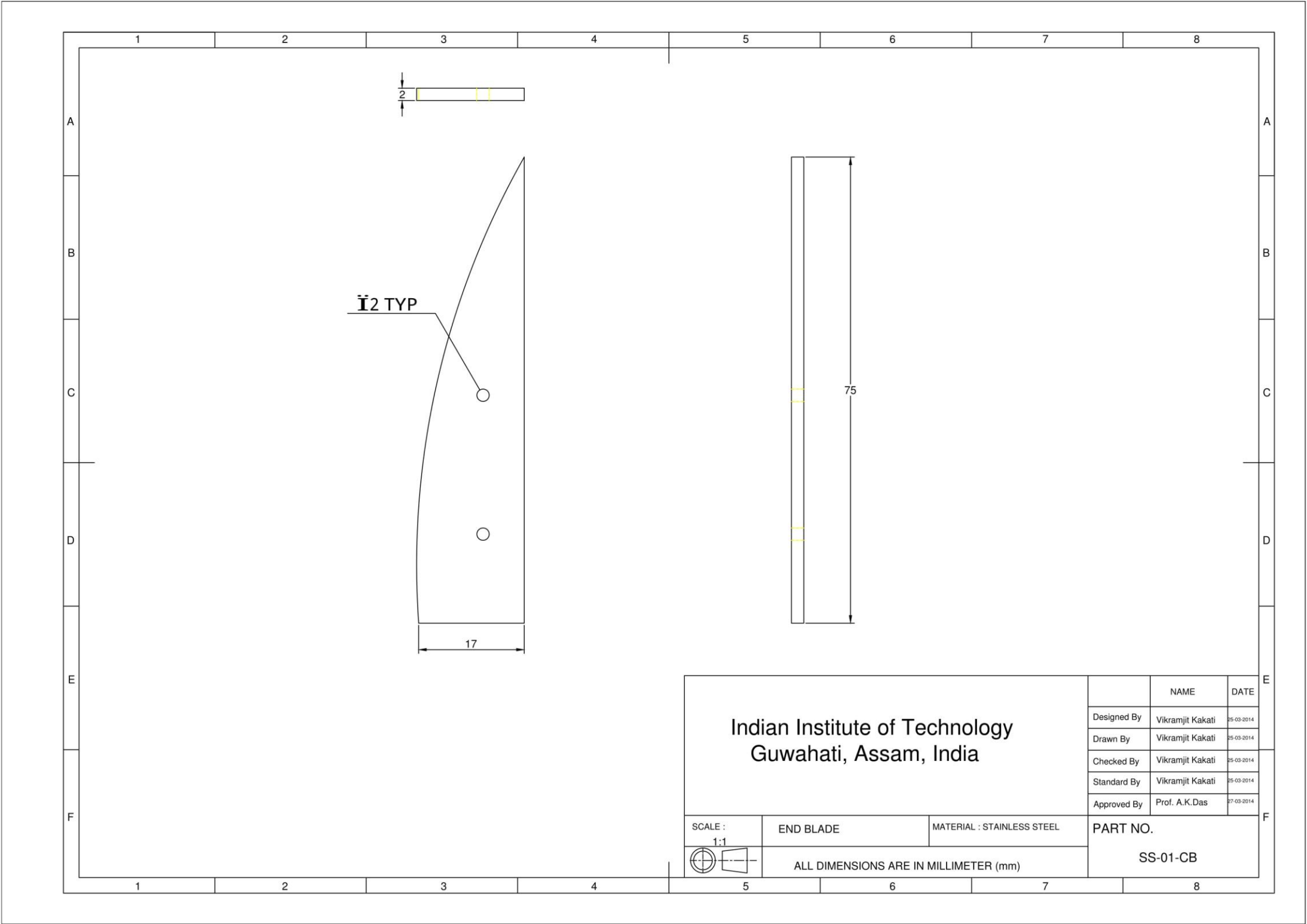
Appendix B - Fig. B-8- Detail drawing of drive shaft



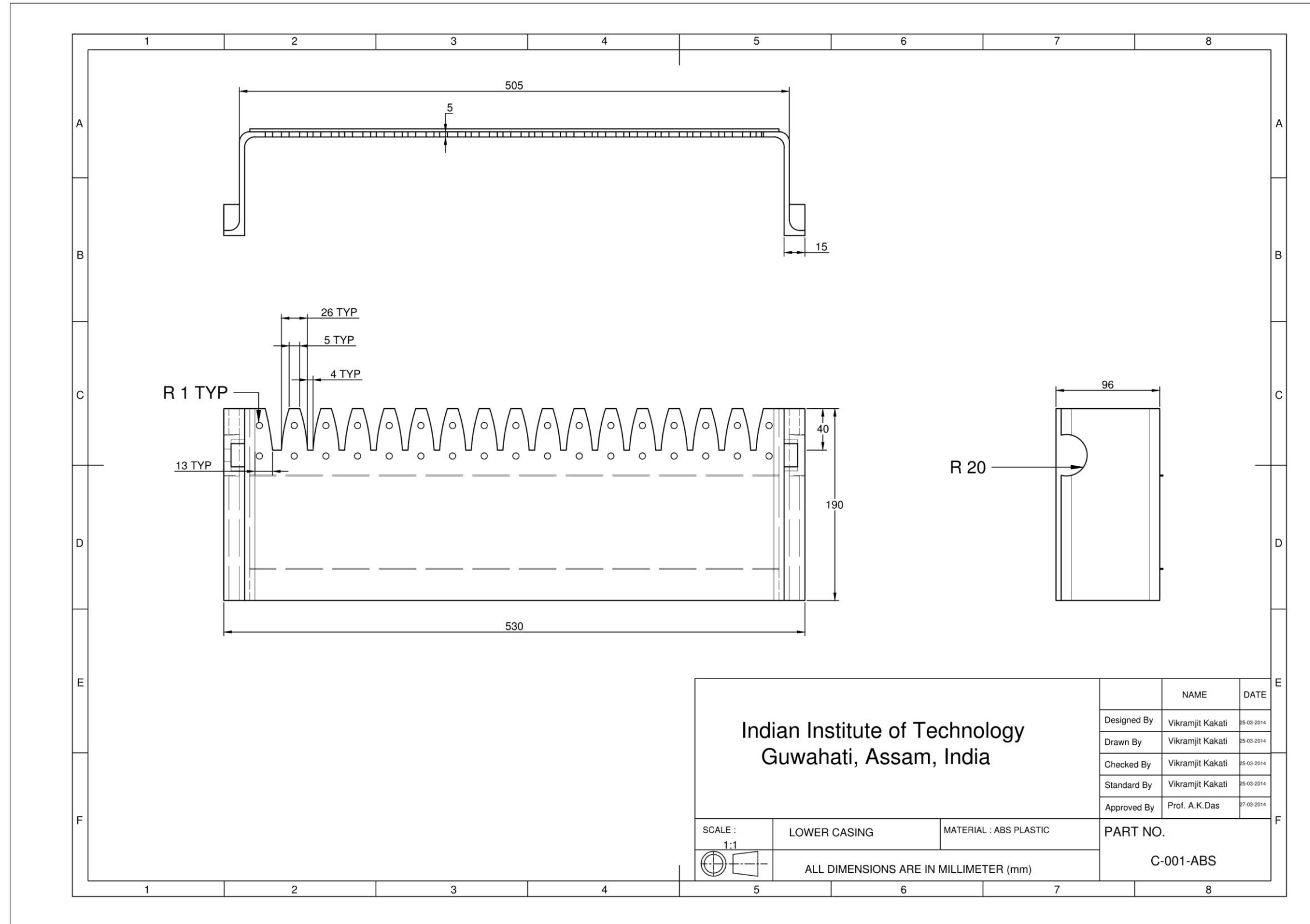
Appendix B - Fig. B-9- Detail drawing of intermediate cutting blades



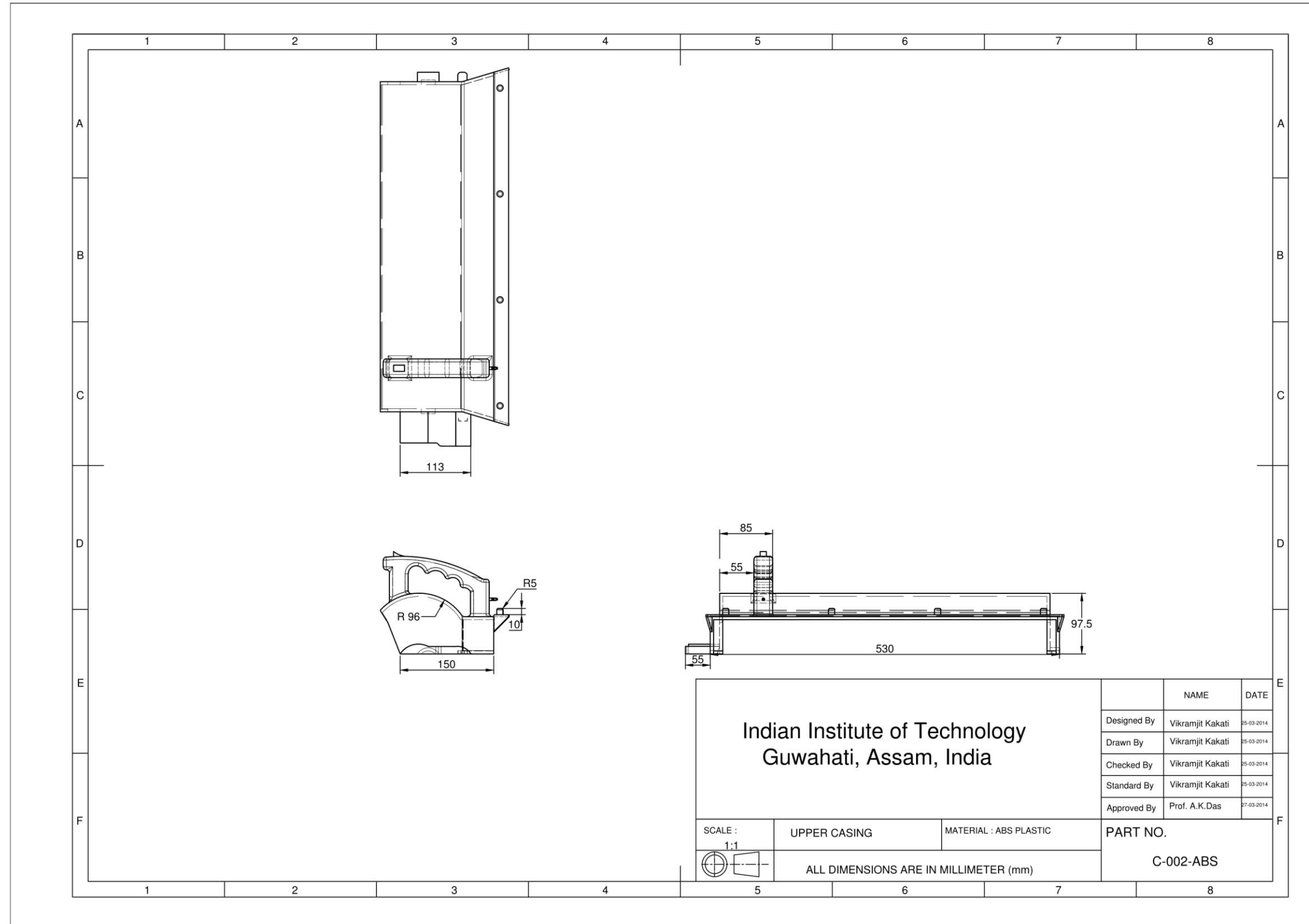
Appendix B - Fig. B-10- Detail drawing of end cutting blades



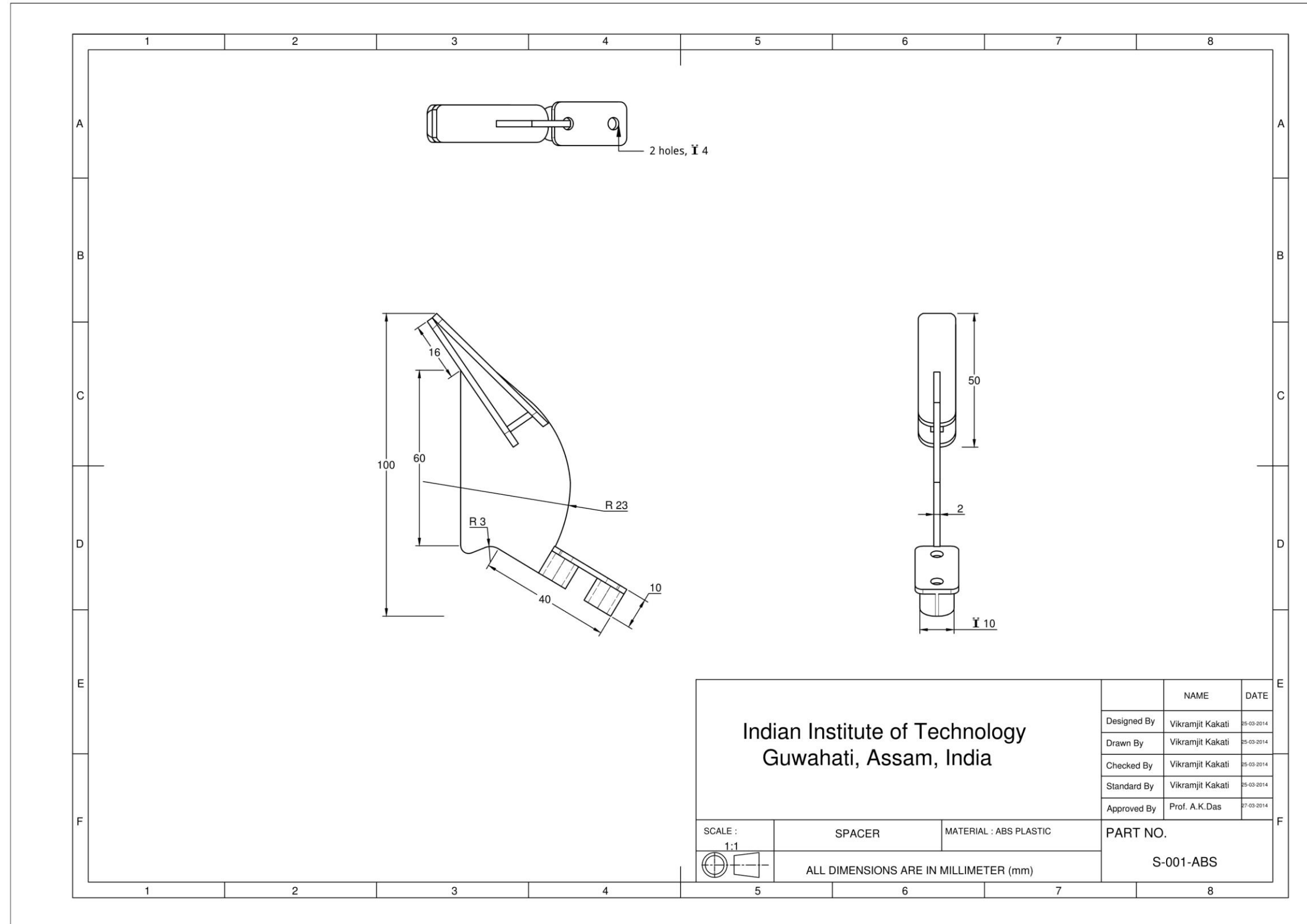
Appendix B - Fig. B-11- Detail drawing of lower casing



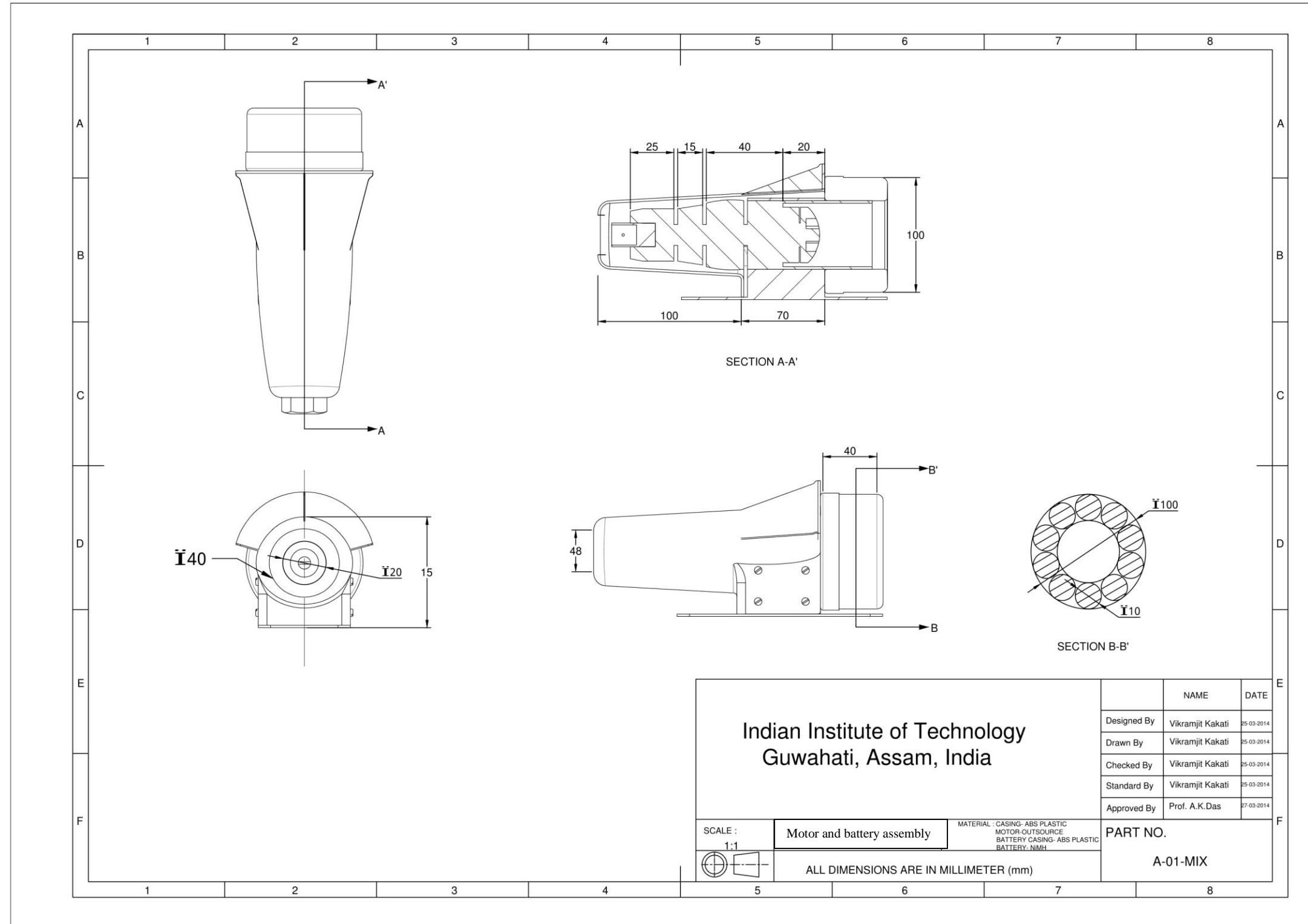
Appendix B - Fig. B-12- Detail drawing of upper casing



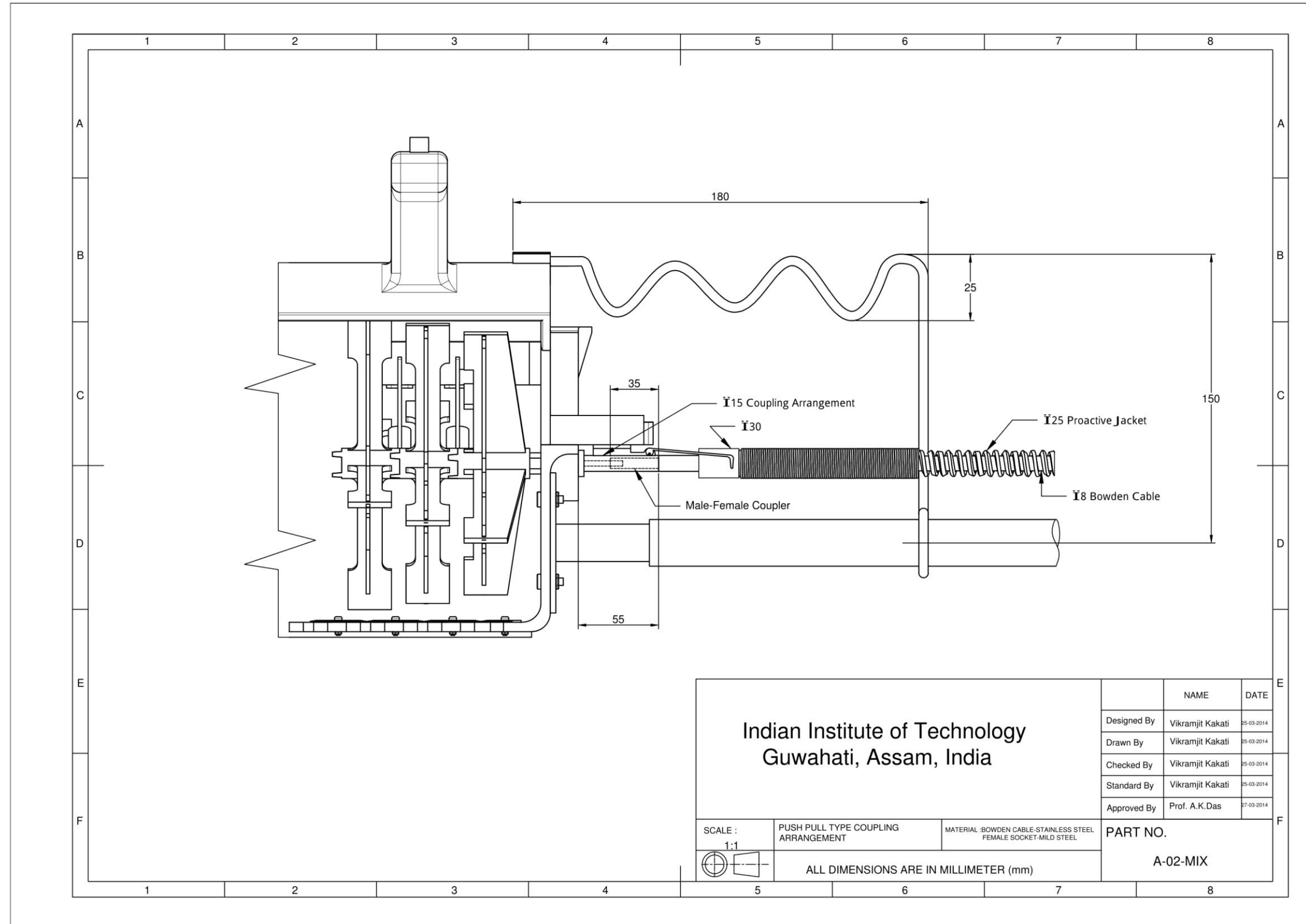
Appendix B - Fig. B-13- Detail drawing of spacer



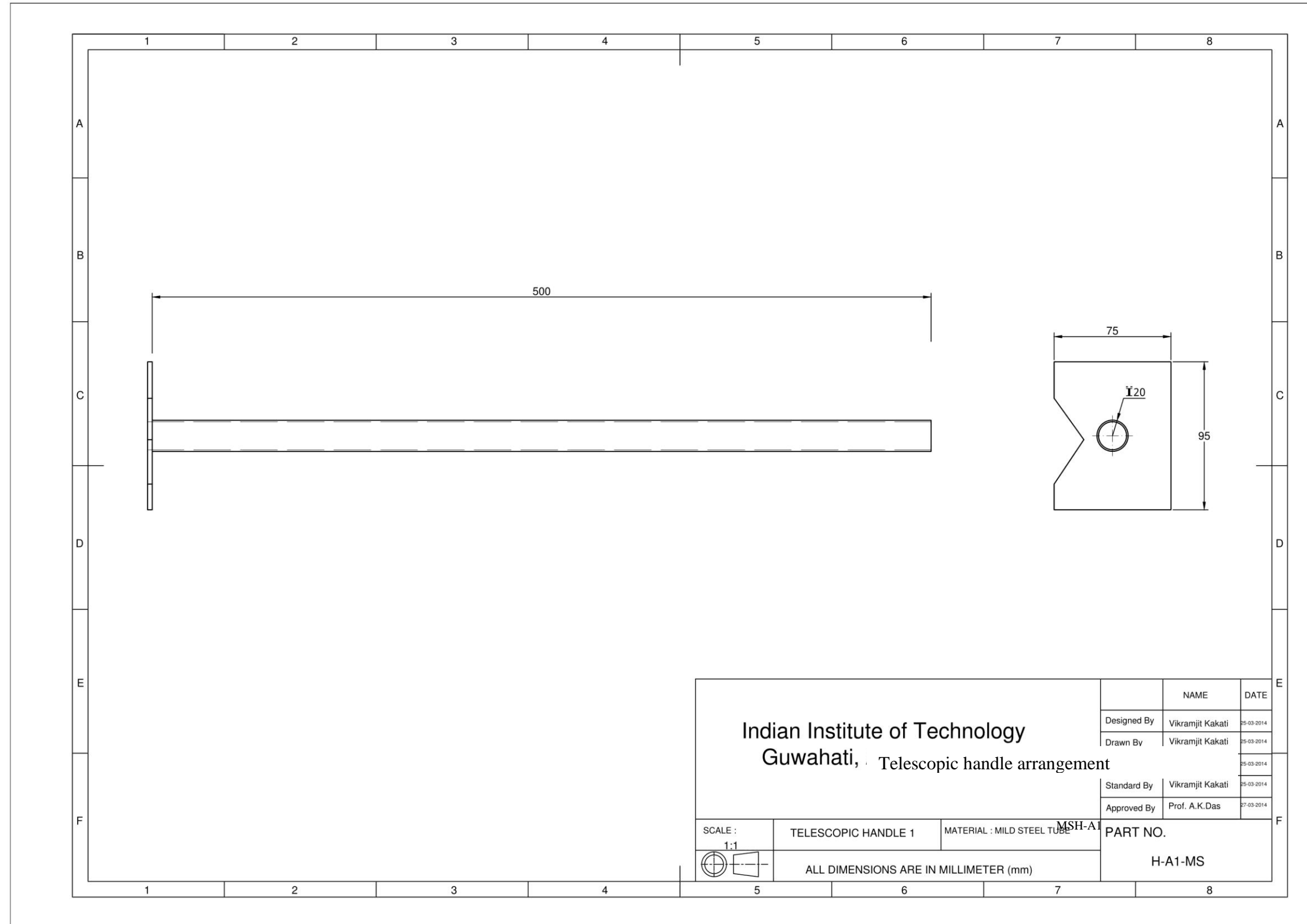
Appendix B - Fig. B -14- Detail drawing of motor and battery assembly



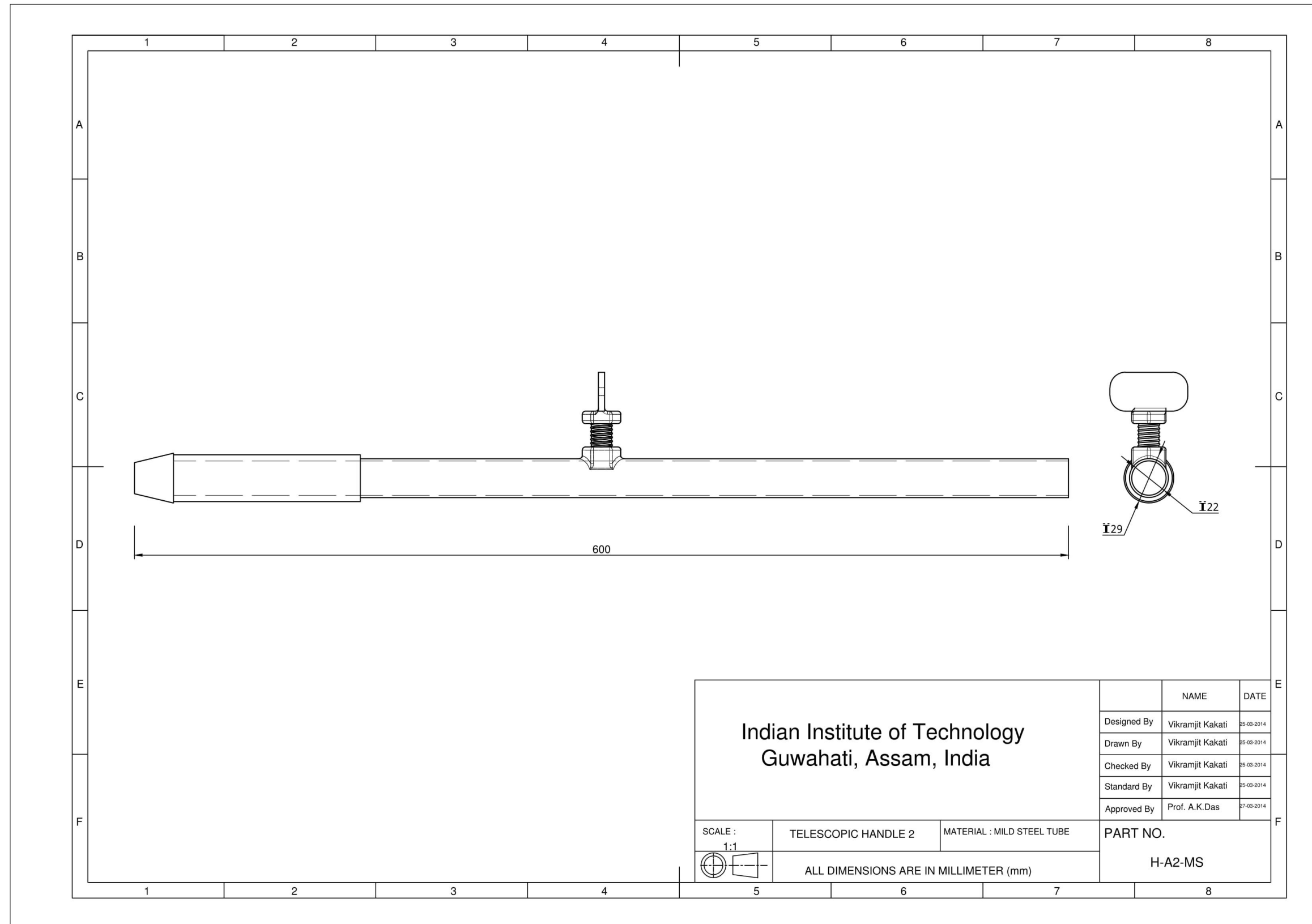
Appendix B - Fig. B -15- Diagram of push-pull type coupling arrangement



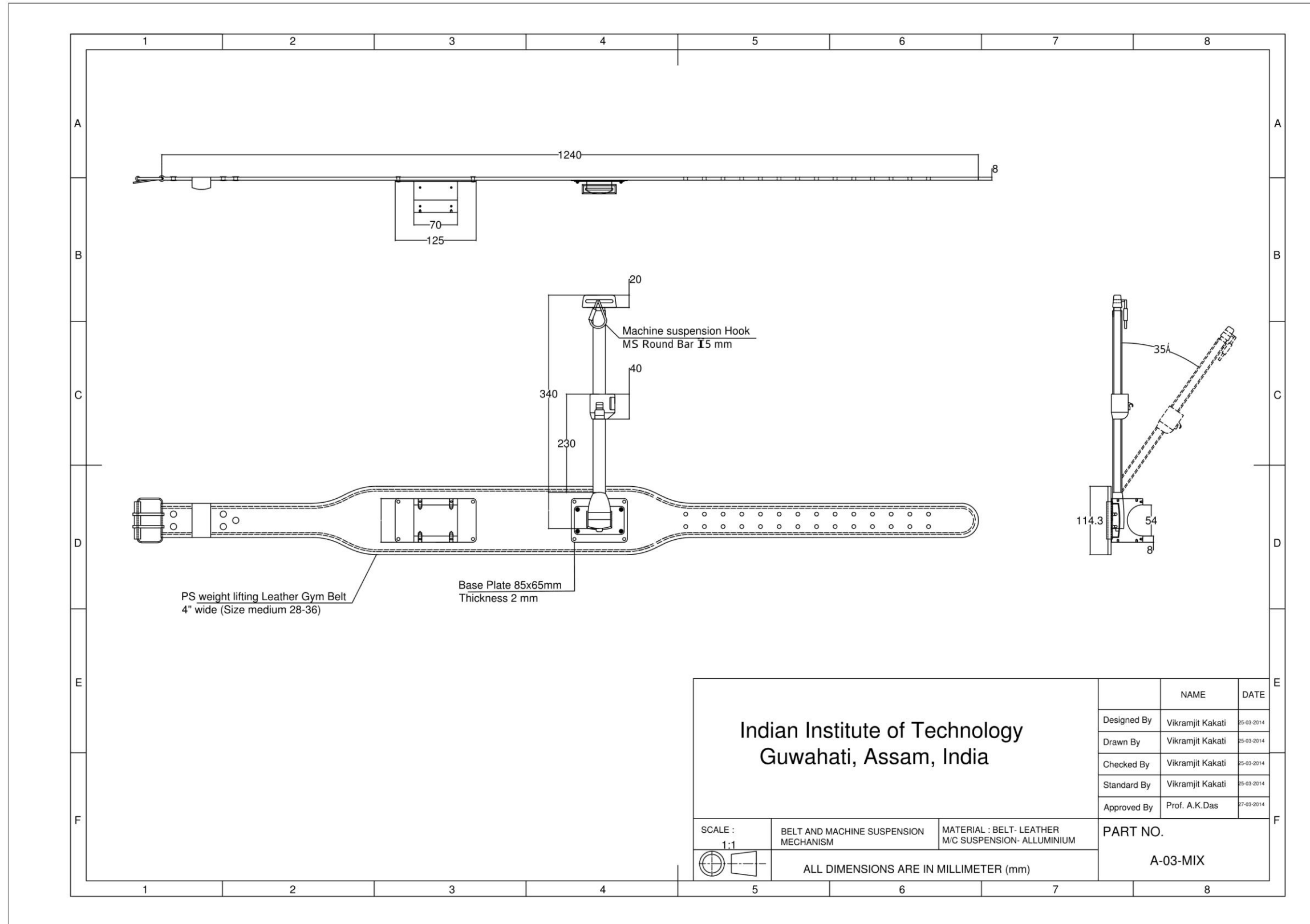
Appendix B - Fig. B -16– Diagram of telescopic handle arrangement as per Alternative-2



Appendix B - Fig. B -17– Diagram of telescopic handle sliding arrangement as per Alternative-2



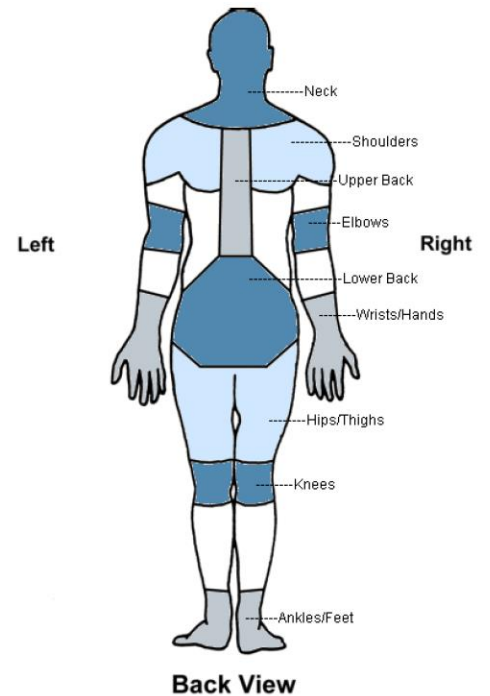
Appendix B - Fig. B -18- Diagram of machine suspension mechanism



Appendix – C - Sample of questionnaire for field study

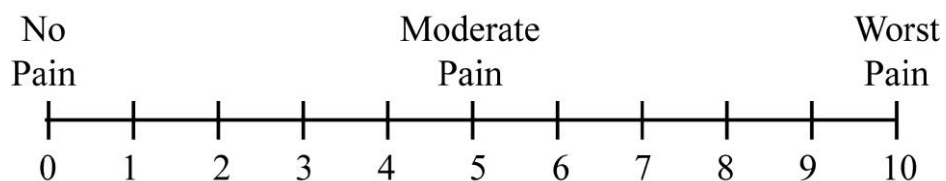
**Questionnaire on improved tea leaf harvesting device related to field operation
based on Nordic Musculoskeletal Questionnaire (NMQ)**

1. Serial No:
2. Name of the tea garden:
3. Employee ID:
4. Employee Name:
5. Job/ Position:
6. Date:
7. Gender:
8. Age:
9. Height (in mm):
10. Waist height (in mm):
11. Work experience in years:
12. Any known health issues:

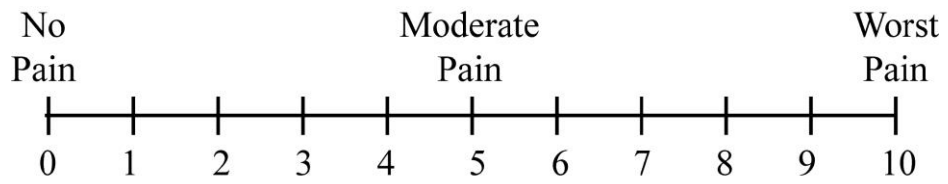


Pain Rating:

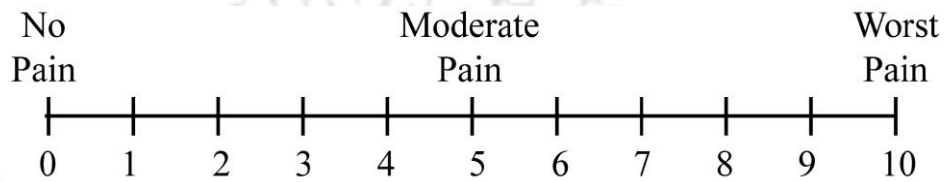
1. Neck Pain:



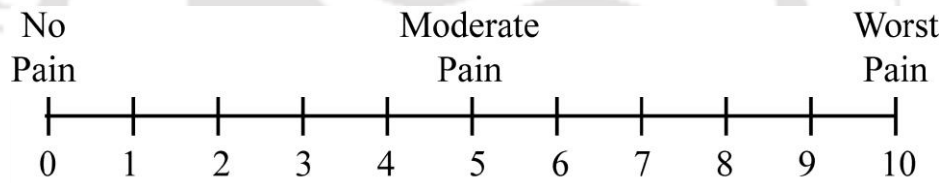
2. Lower Back Pain



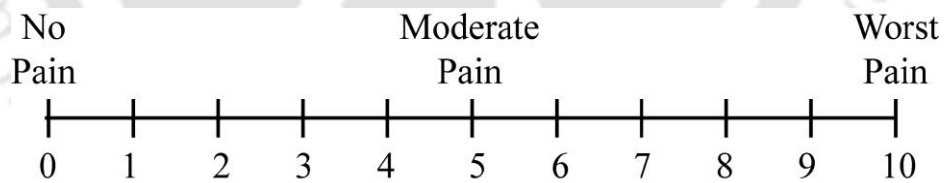
3. Thigh Pain



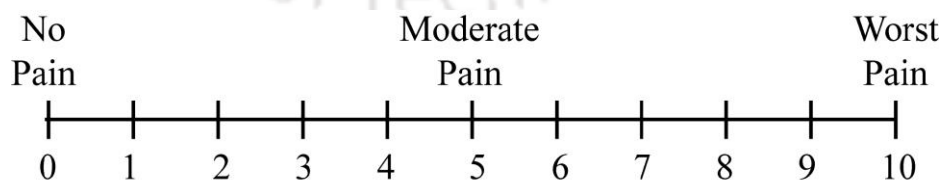
4. Right Leg Pain



5. Left Leg Pain



6. Right Ankle/ Feet Pain



2. Forced Experienced during harvesting

Very Unsatisfied	Unsatisfied	Neutral	Satisfied	Very Satisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1	2	3	4	5

3. Are you satisfied with comfortless of holding handle?

Very Unsatisfied	Unsatisfied	Neutral	Satisfied	Very Satisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1	2	3	4	5

4. Are you satisfied with the time taken to complete the task?

Very Unsatisfied	Unsatisfied	Neutral	Satisfied	Very Satisfied
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1	2	3	4	5

Appendix – D – Performance certificate

To whom it may concerned

This is to certified that Mr. Vikramjit Kakati , Research Scholar (Roll No : 11610502) , Department of Design , Indian Institute of Technology , Guwahati has carried out the field trial of Hand Held Battery Operated tea Harvesting Machine in Dolaguri Tea Estate, District Golaghat, Assam .

During the field trial we are very satisfied with the quality of tea leaves plucked with the help of the machine. The productivity of the machine is very satisfactory.

Dated: 30-Nov -2015


20/11/15

Manager,

Dolaguri Tea Estate

MANAGER
DOLAGURI T.E.



List of publications

Boruah, D., Kakati, V., & Das, A. K. (2013). Indigenous product development based on contextual innovation and link to market. *Proceedings of E&PDE 2013, the 15th International Conference on Engineering and Product Design Education* (pp. 252-257). Dublin: Dublin Institute of Technology.

Teklemariam, H. G., Kakati, V., & Das, A. K. (2014). Application of VR technology in design education. *Proceedings of the 16th International Conference on Engineering and Product Design Education (E&PDE14)* (pp. 117-122). Enschede: University of Twente.

Kakati, V., & Das, A. K. (2014). Evaluation Criteria of Battery Operated Handheld Tea Harvesting Machine. *International Ergonomics Conference HWWE 2014* (pp. 248-251). Guwahati: Indian Institute of Technology.

Kakati, V., & Das, A. K. (2016). Evaluation of single operator handheld battery powered tea harvesting machine in context to tea gardens of Assam. *14th International Conference on Humanizing Work and Work Environment HWWE-2016* (pp. 470-475). Jalandhar: NIT, Jalandhar.