Ab Initio Design and Prototyping of a Tea Plucking Machine: A Case Study

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Category: Rural Machines and Mechanisms

Abstract

The paper presents a case study of designing and prototyping of a tea-plucking machine to be used on uneven landscape for significant increase of yield. Ab initio designing requires one to understand the harvesting process, mechanics of plucking or shearing of tender shoots, gather data on strength and density of tea shoots and capabilities of the operator and use all these information in the design of the machine and mechanisms. A number of concepts for the plucking machine are explored. A simple device for measurement of strengths of tender shoots is also developed and used for obtaining the statistical variation of shoot-strength. This data is later used in the dimensional synthesis of the selected concept. The first prototype of the machine is fabricated and tested in field. The result indicated that the mechanism is working as expected but it required improvement of ergonomics and manufacturability aspects.

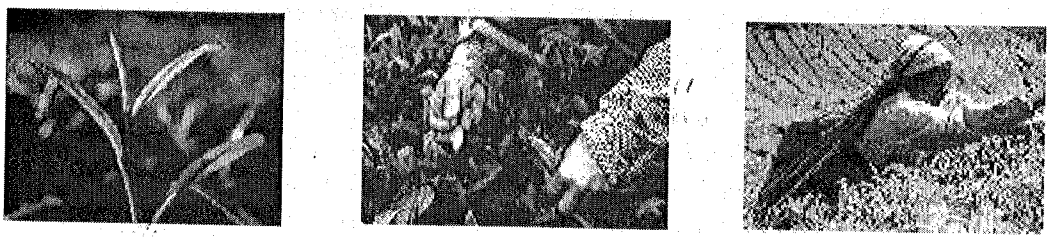
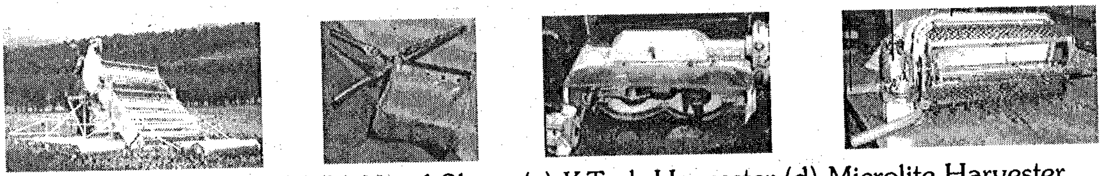


Fig. 1 Hand Plucking of tea

1. Introduction

India is one of the largest tea producing countries in the world. However, unlike many other agricultural sectors, tea growing has not got the benefits of mechanization. This contributes to stiff pricing of tea in global competition. Tea harvesting is a delicate process of hand plucking in most cases and other agricultural harvesting machines being designed mostly for level grounds: the Magic Carpet™ (Fig2. (a)) from Williames (Australia) [1] is a patented technology, expensive and not suitable the present industry culture and for the hilly terrains as in the present case. There are some hand-operated equipments in use in tea estates in south India, e.g. the hand shear (Fig2. (b)), K-Tech mechanised harvester (Fig2. (c)), of which hand shear is more common. The author could not trace any archival literature on this subject; business literature on tea harvesters [2] related artefacts available in Internet lacks technical/design details. [3] mentions about a very efficient machine in use but without any detail whatsoever. [4] reports use of a modified cane harvester being used in their own farm for tea harvesting and is not a commercially available. [5] reported the development of Selective Tea Harvester in Srilanka which is patented and now in production.

In India, by far, most operations are done manually and especially the operation of tea plucking is carried out without any tool. Large-scale mechanisation of this industry is not possible because the tea plantation topography posed great practical challenges with terrains being as steep as sixty degrees in many locations; and is also not that desirable because it would have direct impact on the livelihoods of a large number of people. Hence the aim of the present exercise is to provide the workers with tools that would improve their productivity as well as quality of life. This in turn is expected to provide the management with greater flexibility in operation in business as well as production under different environmental or climatic condition because tea production is highly sensitive to climatic conditions.



(a) Magic Carpet ™ (b) Hand Shear (c) K-Tech Harvester (d) Microlite Harvester

Fig. 2 Machine plucking of tea

Under favourable climate, growth of shoots can be sporadic and requiring more frequent and voluminous harvesting. On the other hand higher educational ambition among the workers for their progeny is a welcome trend but it implies a depletion in the workforce, as revealed by competent authorities in this area during the course of this study. Although there are several factors that affect productivity, plucking operation have been identified as the single largest contributor to the quality and quantity of the produce; hence an *ab initio design of a tea-plucking machine* is necessitated.

2. Problem Analysis

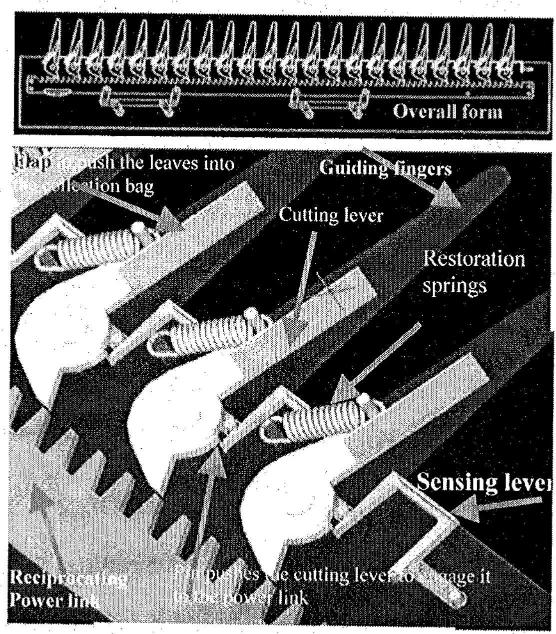
Tea is grown as rows of bushes. The bushes of a given estate are of same age maintained at the same height and define the ***bed***. The tea plucking operation can be divided into following steps: (a) **Identification** of the shoots on level of bed, (b) **Isolation** of the pluckable shoots from the rest, (c) **Harvesting** by plucking or shearing, (d) **Collection** of the harvested shoots and (e) **Transfer** of the collected shoots to a bag carried by the worker. In case of hand plucking, *identification* of the level is done by placing a stick over the bed and using the judgment of the operator. In mechanical harvesters, broad base of the equipment on the bed itself is used for identification of the level. Although *isolation* of different grades of pluckable shoots (*three-leaves-and-a-bud, five-leaves-and-a-bud*, etc.) in hand plucking is easy, in machine plucking this discrimination is generally not done. Rather, over-grown shoots are isolated manually later but before loading the transport vehicle. Mechanized systems do not have identification and isolation steps. This has an effect on the harvesting frequency of the bush and the quality of the harvest. *The mechanized harvesting typically used shearing whereas hand plucking uses a combination of bending and tension for harvesting*. Significance of this difference, direct or indirect, on the quality of the harvest is not established. *Collection* of the shoots in mechanized systems is in a small pouch attached to the device itself. Transferring the harvested shoots into the pouch is a non-trivial operation; vibration of the hand itself is used for the operation in hand shear and in K-Tech an additional vane attached to the rotating blades push the shoots into the pouch. Thus, the design of a new machine for quality crop at high rate require that all these steps be meticulously followed; i.e. *all the **identified** and **isolated** shoots must be **harvested, collected** and safely **transferred** to the collection bag with reduced work load for the operator*.

3. Concepts Generation

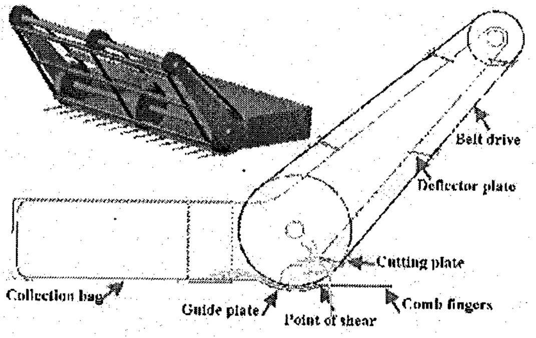
Tea plucking is a sensitive operation; badly sheared leaves have adverse effect on the final product. Only tender shoots need to be plucked as well as the bed level has to be properly maintained; if some shoots are left over the nominal bed-height it not only reduces productivity but since it will mature, it would affect the quality of the next harvest. Thus *harvesting should be as neat and complete as possible*. The device will be carried and used by one person or two persons because of the nature of the terrain and wage structure. Multi-point cutting is preferred to single-point for better plucking efficiency; the device should not require working on the same area more than once and should ***not*** require eye- engagement for the cutting operation. This would improve productivity with reduced mental work-load of the worker. Idle running power should be significantly low compared to working power for better energy efficiency (this is not the case with the existing machines). Keeping the requirements in mind, fifteen concepts are generated. However, since these initial design phases are not the focus of this paper, for the sake of brevity only the figures of a few representative concepts are illustrated in Fig.3. The models created in computer are presented for better understanding of sizes and proportions and not according to details of sizing and fittings.

4. Concepts Evaluation

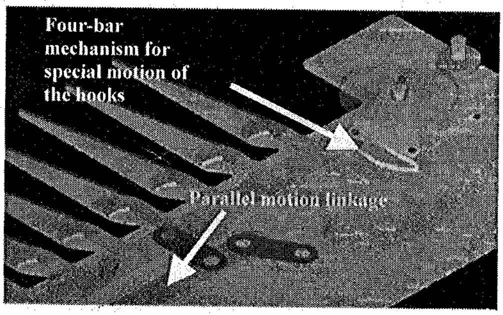
The concepts are evaluated based on the attributes of **feasibility, harvesting efficiency,**



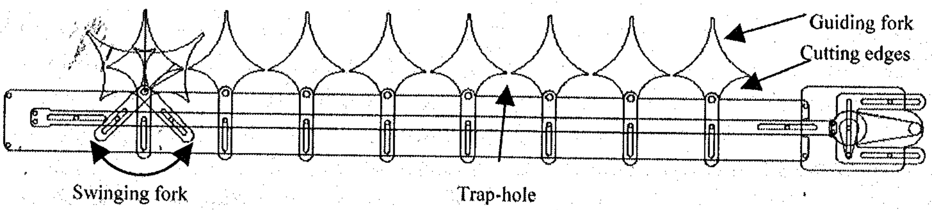
(a) Concept 1: Sensing Plucker



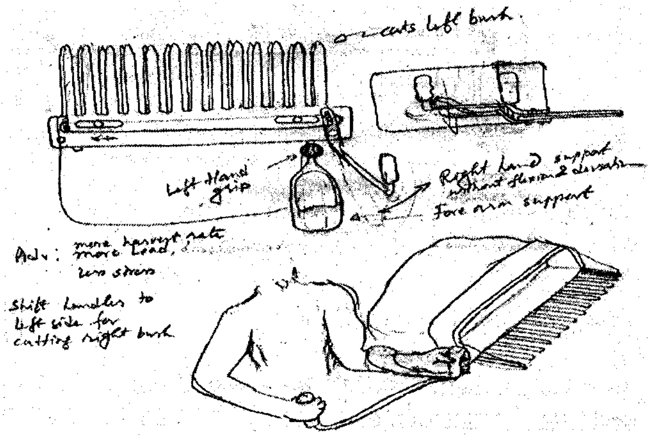
(c) Concept 3: Belted Plate Plucker



(d) Concept 4: Swing Fork Plucker



(b) Concept 2: Swing Fork Plucker



(e) Concept 5: Comb Shear

Fig.3 Concepts for the Plucking Machine

simplicity, **usability**, **safety**, **cost**, and **manufacturability**. The attributes themselves are given weightages based on their relative importance and then each individual concept is evaluated in a five-point scale for each of the above attributes. A weighted sum of the points is the score for a concept. Twenty-three technical personnel from tea industry and design academia participated in the evaluation process. The details of the evaluation process are omitted here also for the sake of brevity. The concept shown in Fig.3(e) scored the highest and is carried forward for detailed design.

5. Detailed Design of the Comb Shear Harvester

The selected concept (Fig.3(e)) has two identical flat plates laid one over the other and each has comb- like fingers or teeth. As one plate slides past the other, the gaps between the corresponding teeth (along their lengths) of the two plates vary. By appropriately attaching blades along the length of each tooth on the faces in contact, shearing of an object placed in the gap can be achieved. A long oscillating lever is used to multiply the applied force of cutting; the motion of this lever is transformed to the sliding plate using a toggle mechanism, which improves the mechanical advantage at the instance of cutting. The major components of the device are illustrated in Fig.4. The existing hand shear is small in size but the configuration is such that the moment generated by the load on hand grip is high; orientation of the blade requires repositioning at every stroke. Collection is through skilful maneuvering of hand and there is no control on the spillage of cut shoots. The new concept, as shown in Fig. 3(e) has better arm support and longer lever such that larger muscles can apply force. This is expected to give an easier harvesting operation. Multiple shearing fingers provides better harvesting rate. Collection can be aided by gravity. Gap between the shearing plates is small preventing spillage. Continuous cutting (without repositioning) is possible in this design. The detailed design is carried out as follows: diameter of tea- shoot governs the gap between two teeth as well as the stroke-length of reciprocation necessary for shearing; the shear-strength of the shoots, the distribution over shoots on the bed, the comfortable arm swing and the operators strength governs the area harvested in a single stroke; the analysis of mechanics of shearing of soft fibrous shoots helps in determining the blade parameters.

5.1 Experimental estimation of parameters of tea (shoots)

An instrument is designed for the purpose of measuring the force required for shearing the shoots, because, firstly, the shoot-strength data necessary for the design is not available in literature and secondly, the shoots tender or fibrous exhibit complicated failure modes making analytical estimation unviable. The functioning of the device (Fig.5) is as follows. When the actuation toggle lever is pressed, the forcing block pushes the shearing block through the spring. When any specimen is placed in the shearing slot, the movement of the shearing block is obstructed and the maximum compression force generated by the spring during any operation is indicated in the scale by the displacement of the pointer. Strength is measured in terms of millimetres of spring compression at the point of shearing. The consolidated result of the experiment is given in the Table-1. Strength-1, Strength-2 and Strength-3 etc are measured at different nodal intervals on the shoots hand plucked from a tea-estate over an area measuring one square meter. It is observed during our experiments to determine the shear force requirement that, whenever the shear force requirement is relatively high, the shoot get significantly compressed before the actual shearing takes place. This occurs due to the presence of fibres in the shoots with more number of leaves. That is, *a shoot with three leaves and a bud requires much more force to shear compared to a shoot with two leaves and a bud*. The larger (25%) shoots from the sample were used in the experiment; the remaining shoots were too tender for the sensitivity of the instrument. Considering the possible variations in different estates, it is decided that the 95 percentile values will be used in the design.

5.2 Design of Overall Sizes

This involves the determination of length, width and height of each teeth, gap between two teeth, number of teeth, actuation lever dimensions etc.

Gap between two teeth: It should be wide enough to allow the shoot to smoothly pass but narrow enough to prevent leaves from getting in. This will reduce the chance of undesirable

Table 1 Consolidated result of tea-shoots shearing experiment

Percentiles	Weight (gm)	Length (cm)	Base Dia (mm)	Leaves	Leaf-Stem Angle (deg)	Strength 1	Strength 2	Strength 3	Failure stress (kg/mm^2)
min	0.31	1.0	1.4	1	20	1.0	0.5	0.5	0.15
5	0.44	5.5	1.5	2	30	1.5	1	1.0	0.28
50	0.98	9.5	2.2	3	50	5.0	3.5	3.0	1.04
95	**1.8**	**14.5**	**3.0**	**3**	**85**	**8.0**	**6.5**	**5.0**	**2.22**
max	2.15	17.0	3.5	4	90	11.0	8	5.0	3.11

shredding of leaves. From Table-1 it is found that for the base diameter of shoots, 95-percentile value is 3mm and maximum value is 3.5 mm. Also we see that the leaves make angle with the shoot (95 percentile value is 85°) preventing its easy isolation for shearing. *The gap is thus decided to be 5mm.*

Operator capability: From ergonomics literature, for the cutting operation at 90° elbow angle using pull, 5th percentile operator capacity is about 17kg and using inward motion, the operator capacity is about 8kg. Outward and push capabilities are generally lower. But these numbers are in a laboratory setting of maximum force that is applied only once. For repetitive work we take 40% of the strength as normal practice. Thus for the design we assume the operator capacity to be 7kg in pull and 3kg in inward motion.

Actuation Levers: In the processes of shearing, the force required towards the end of the stroke suddenly shoots up due to the fibrous nature of the shoots. Hence the toggle lever mechanism is adopted for better mechanical advantage when it is most needed! Let required displacement for the slider be s, angle of the levers with the direction of sliding be θ, then referring to Fig.6, $2l(1\text{-}\cos\theta)=s$ and mechanical advantage: $\eta=F_e/F_l=L/(2l\sin\theta)$, hand movement: $S=2L\sin(\theta/2)$. Considering L=400mm, S= 150mm we get, oscillation angle $\theta=2\sin^{-1}(S/2L)\approx22°$. Assuming total stroke, s=7mm, we get, $l=s/(2\text{-}2\cos\theta)$=50mm. Assuming the compressed thickness of the shoot to be 2mm, we get the mechanical advantage during actual shearing as: θcutting=cos-1($1\text{-}s/2l$) ≈11° and ηcutting $=L/(2l\sin\theta_{cutting})=21$.

Comb Dimensions: Let length of each tooth of the comb be l_{comb} width of the comb shear be w_{comb}, number of teeth in the comb be n_{comb}. The average cutting force required per shoot, F_{av}= 5.0x0.75kg=3.75kg. Number of shoots: N_{total}=320/m². With F_e=7kg (pull). Maximum effective force at blade: $F_{max}=\eta_{cutting}$ x F_e=147kg. Thus the maximum number of shoots that the operator can cut per stroke, $N_{max}=F_{max}/F_{av}$=147/3.75 ≈ 40. Thus area that can be covered by an operator per stroke, $A=N_{max}/N_{total}$ m² OR, *A=40/320m²=1250cm²=*l_{comb} x w_{comb}. Considering l_{comb}*=20cm*, we get w_{com}*=62.5cm.* Thickness of the plates are taken as 3mm. Considering distance between fingers to be 5cm, we get N_{comb}*=62.5/5= 12.5 ≈12 (rounded off)*. Thus the average number of shoots per teeth = 40/12 = 3.33 i.e. between 3 and 4. The worst-case scenario is all 3 of the shoots are of 95th percentile strength being cut by one tooth. Then force per shoot is 8x0.75kg = 6kg. Assuming they are equally spaced over the length of the tooth at intervals of 65mm from the tip, the shape of the cross section is computed. The standard width of blades is 20mm, width of moving teeth are taken as 25mm. Let the clearance between the base-plate and the moving plate be 0.2mm and the thickness of the compressed shoot just before shear be 2.0mm. Further detailing is done based on the following understanding of interaction between the tool and the shoot during process of shearing. Here, the word "blade" used to mean each tooth including the cutting edge, which could be integral, or an insert in the base material of the comb.

6. Detailed Design of the Teeth of the Comb

6.1 Interaction of Shoot and Tool and Mechanism of Shearing

Let *A* and *B* be the two blades shearing a tea shoot *C*, the thickness (diameter) of the shoot be t and the gap between the blades be *d*. We consider the shoot to be vertical and the blades horizontal (Fig.7). The shoot is assumed to be cylindrical. Let the approach distance between the two blades be *D*. Thus for a given machine, d is constant and *D* varies to shear shoots of different sizes. As *D* varies and becomes equal to t, the two blades come in contact with the shoot (Fig.7(b)). The force F_H applied by the blades on the shoot in the horizontal plane generates a moment of F_H x *d*, which causes the shoot to turn. The shoot would turn till the diagonal distance between the blades $\sqrt{(D^2+d^2)}$ = *t*. In that configuration the normal (compressive) force F_c applied by the blades on the shoot become collinear; no further rotation would take place if the shoot were rigid. But, since tea shoot is quite soft compared to the blades and the two opposite forces (F_c) generate compressive load on the shoot as shown in Fig.7(c); as a result t reduces locally as shown in Fig.7(d). This results in further rotation of the shoot. If F_H is further increased, the shoot is cut apart (Fig.7(e)).

6.2 Complex Failure Behaviour of Shoots

The shoot consists of fibrous tissues running along the length of the shoot. These biological building blocks can be idealized from engineering point of view as bundles of hollow tubes filled with liquid sap. This predominant hollow tube structure not only allows efficient fluid transportation but also provides stiffness and strength to the shoot in bending; thus, even the slender shoots of tea can stand erect and maintain its shape against gusty winds over the plantation. However, this special structure makes the process of shearing complicated; when the blades attempt to shear a shoot, it causes local pinching of the shoot due to the compressive load generated as explained above. This causes the microtubules to become oval in shape reducing their enclosed area in the cross section without changing the perimeter of individual tubules. Thus the *predominantly hollow structure of the cross section becomes increasingly solid* by displacing the sap in the tubules. Till this point of compaction the material of the tubules does not fail, although it has absorbed a lot of energy; the shoot can still regain its longitudinal straight shape if the load is withdrawn. The further deformation of the shoot requires significantly higher amount of force, as it now has to work against a compacted mass of the fibre bundle. At this stage when the stress increases beyond the capacity of the material of the fibre, sudden failure takes place. However, since the material of shoot is not homogeneous, we do not observe a single value for the engineering shear stress at failure (Fig.8); correspondingly a statistical measure need to be considered in design of the blades.

6.3 Out of Plane Bending of Blades:

The presence of the clearance d between blades produces out of plane bending of the blades, which in turn could alter the effective clearance at the point of cutting if the blade is not stiff enough. The out of plane bending force, F_V, for an applied load of F_H (Fig.7(c)) on the shoot with axial tilt of θ, is derived as follows.

$$\theta = \tan^{-1}\frac{d}{D}, F_H = F_c \cos\theta = \text{In plane bending force on the blade} = \text{Applied Force}$$

$$F_v = F_c \sin\theta = \text{out of plane bending force on the blade} = \frac{F_H}{Cos\theta}, \ Sin\theta = F_H \frac{d}{D}$$

$$\text{Thus, } F_v = F_H \frac{d}{D} \ F_H \frac{d}{\sqrt{t^2 - d^2}}$$

6.4 Clearance Distance between Blades:

If the clearance distance *d* were very small, the two blades would come in direct contact during operation, which is likely to cause friction and damage to the blades. If *d* is small compared to *t* its effect on the required cutting force is insignificant; but the force required for idle running is significantly lower compared to blades in contact (as in hand-shears). However, if *d* were large it would hamper performance due to possible failure to sever thinner shoots. As *d* increases, the vertical component of the reaction force increases which would bend the blade in an out-of-plane direction and shearing might not happen; this would happen if the blade were too thin. Otherwise, the component of F_H along the axis of shoot could continue gradual severing till effective *d* approaches *t;* then the shoot is damaged but it is not cut completely. This affects the quality of the bed and also productivity. A combination of above two phenomena is likely to create more complicated situations. Since in the present case the diameter of the shoots are less than 5mm, $0.1mm<d<0.2mm$ is considered optimal.

6.5 Blade Width and Thickness:

Suppose w is the width of the blade and h is the thickness of the blade, each of which are supported as cantilever from the driving base plate. Referring to Fig.9 the line joining the cutting edge to the centre of cross section of the blade makes $\alpha = \tan^{-1} h/w$. R_c is the resultant reaction force experienced by the blade. Then $R_C = -F_C$. Let e be the perpendicular distance of the line of action of R_C from the centre (neutral axis) of the blade. Then R_C would generate a torque $T=R_C x e$ that will ***twist*** the blade. If $\alpha > \theta$, (fig.(a)) then, as a result of twisting, d reduces. This in turn reduces θ and increases T by increasing e. The shearing action would fail if, eventually, $d<0$ is reached. If $a<\theta$, (fig.(b)) then, as a result of twisting d increases. This in turn increases θ and increases T by increasing e. The shearing action would again fail if, eventually, $d<t$ is reached, when the freeend of the moving blade would go below the corresponding points on the fixed blade. The actual effect of T, thus, is complicated and needs more rigorous analysis than that can be done within the scope of the paper. To reduce the sensitivity of the design to the resultant twisting, the aspect ratio of the cross section of the blade selected should be such that e is negligible. This condition is achieved when $\alpha \approx \theta$.Thus we should select $h/w \approx d/D = d/\sqrt{t^2 - d^2}$. Since for the present case the most probable range of t is known, we can calculate the safe value for h/w. Actual values for h and w can be determined from their bending considerations. From out-of-the-plane bending deflection consideration due to R_v, which is the reaction of F_v, we get maximum deflection as follows. Here E is Young's modulus, I is the area moment of inertia, δ_{max} is the maximum allowable out-of-the-plane deflection of the blade and σ_{max} is the maximum allowable tensile stress for the blade.

$$\delta_{max} = \frac{R_v L^3}{3EI} = \frac{F_H \frac{d}{D} L^3}{3Eh\frac{w^3}{12}} = \frac{4F_H \frac{h}{w} L^3}{Ehw^3} = \frac{4F_H L^3}{Ew^4} \Rightarrow w = \sqrt[4]{\frac{4F_H L^3}{E\delta_{max}}} = w_\delta \text{ (say)}$$

From failure of the blade due to out-of-the-plane bending consideration

$$\sigma_{max} = \frac{R_v L w}{2I} = \frac{F_H \frac{h}{W} L w}{2\frac{hw^3}{12}} = \frac{6F_H L}{w^3} \Rightarrow w = \sqrt[3]{\frac{6F_H L}{\sigma_{max}}} = w_\sigma \text{(say)}$$

Then we select $w=\max(w_\sigma, w_\delta)$.

With, $F_H=2x6kg=12kg$, $L= 20cm$, $\delta_{max}=0.01mm=1x10^{-3}cm$ and using steel as the material of blade, $\sigma_{max}=480MPa=4.8x10^4\ kg/cm^2$, $E=200GPa=2x10^7\ kg/cm^2$, we get, $w_\delta=2.1cm$, $w_\sigma=0.3cm$. Thus, $w_{steel}=2.1cm$. Using aluminium as the material for the blade support, $\sigma_{max}=220MPa=2.2x10^4\ kg/cm^2$, $E=71GPa=7.1x10^6\ kg/cm^2$, we get, $w_\delta=2.7cm$, $w_\sigma=0.4cm$. Thus, $w_{Al}=2.7cm$. Also,

$h/w \approx d/D = d/\sqrt{t^2 - d^2} \approx d/t$ whe $d << t$. We have assumed $d=0.15mm$. With $t=2.0mm$ (thn shoot), we get d/D=0.075 Thus $h_{steel}=2.1x0.075cm=1.6mm$ and $h_{Al}=2.7\times0.075cm=2.0mm$.

shoot), we get d/D=0.075 Thus $h_{steel}=2.1x0.075cm=1.6mm$ and $h_{Al}=2.7x0.075cm=2.0mm$.

Since design is not very sensitive on the selection of material in the present case, it is recommended ***that thin** (0.7mm) **steel blade inserts be used on the aluminium base material for the shearing combs** (minimum thickness of 3mm and minimum width of each teeth 25mm).*

6.6 Design of the Collection Bag:

The mouth of the bag should cover the blade size; i.e. its width = 60cm. The height of the opening should allow easy entry for the tea shoots; i.e. its minimum height should be 15cm. The depth of the bag should allow required amount of shoot to be accommodated. The present capacity of the collection bag of the K-Tech machine is 800gm. Since the new machine is supported at the forearm, we expect better load carrying capacity from the operator. We plan for a capacity of 1500gm. The loose density of shoots is found to be of the order of 0.04gm/cc. Hence volume of the bag = 1500/0.04cc=37500cc and depth of the bag = 37500/(60x15)cm=40 cm (approx). Thus the overall size of the collection bag is **60cmX40cmX15cm.**

7 Performance Estimates for the Plucking Machine

Plucking Average: Estimated number of shoots cut per stroke = 40, mean weight of a shoot =1.0 gm and estimated number of strokes per minute = 20. Thus, estimated plucking rate = 40x1.0x20gm/min=800 gm/min. Thus, time to fill the collection bag is about 1.5 min. Assuming time to empty the bag= 30 sec = 0.5 min, the estimated plucking average (8 working hours/day)= 0.6kg/min=290 kg/man-day. Existing plucking average is 40-60 kg/man-day.

Weight of the Plucking Machine: The total volume of the parts designed as given in the next section = 1300cc Since most parts are made of Aluminium, the estimated weight of the machine is 2.7 x1300 gm = 3.5kg.

8 Fabrication and testing

The design presented above has been fabricated using 3mm aluminium sheets for flat components, standard 20mmX2mm aluminium box section for the frame, 0.7mm thick carbon steel blades, 2mm steel wire mesh for frame the collection bag and standard fasteners. Nylon fabric has been used for the collection bag. Fig. 10 is the photograph of the product. During fabrication it is identified that with the blade holders screwed on to the cutter plate poses alignment and rigidity problems; bolts substantially add to the weight of the device. Modification of the design is recommended with integral cutter assembly. The functioning of the device, in terms of operation and mechanics of shearing, is found to be satisfactory. Weight of the device, although of the same order as the machines in use, is found not well balanced about the support. Force required for cutting operation is found to be well within the capacity of the workers. The development of the improved plucking machine is in progress.

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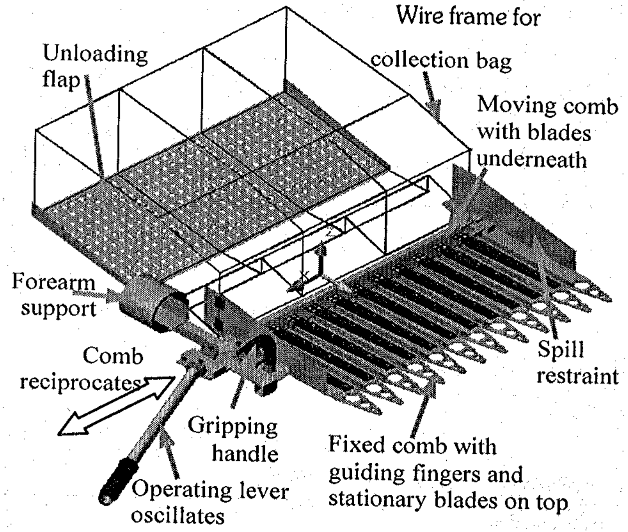


Fig. 4 Comb shear harvester components schematic

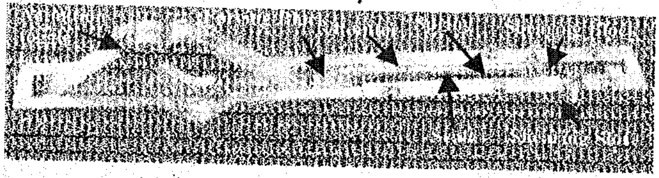
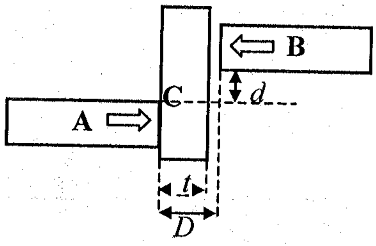
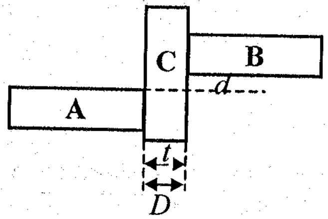


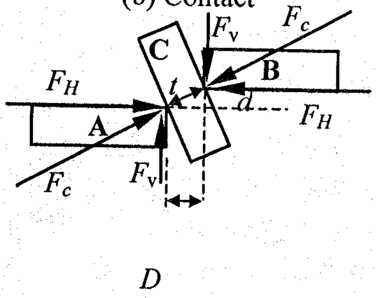
Fig. 5Shoot-strength measuring instrument



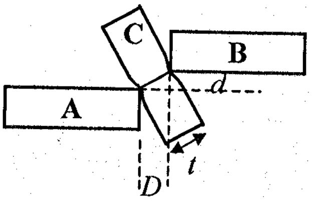
(a) Approach



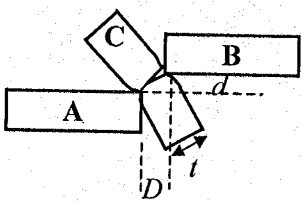
(b) Contact



(c) Rotation



(d) Compression



(e) Cutting

Fig.7 Interaction of a shoot and tool blades during shearing

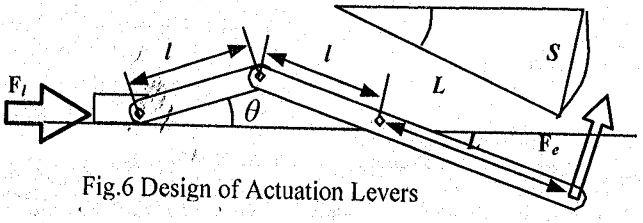


Fig.6 Design of Actuation Levers

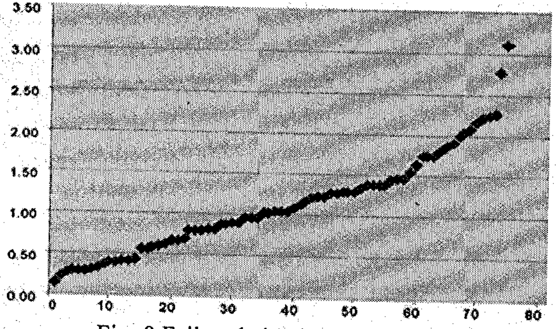
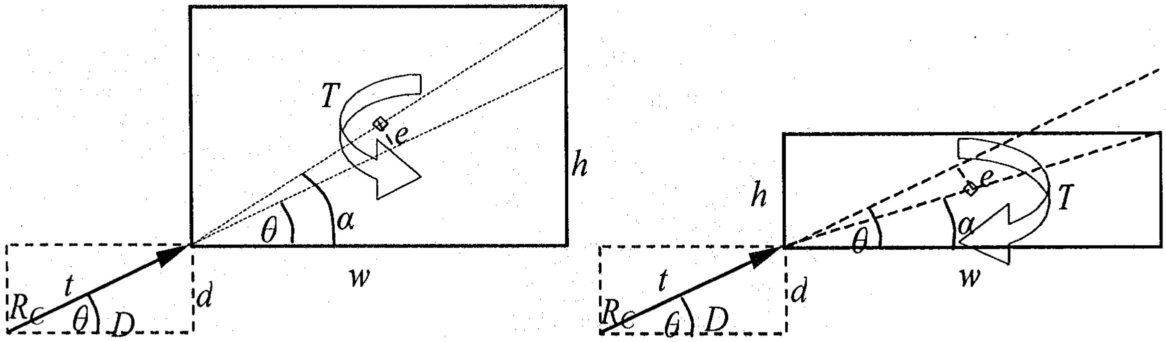


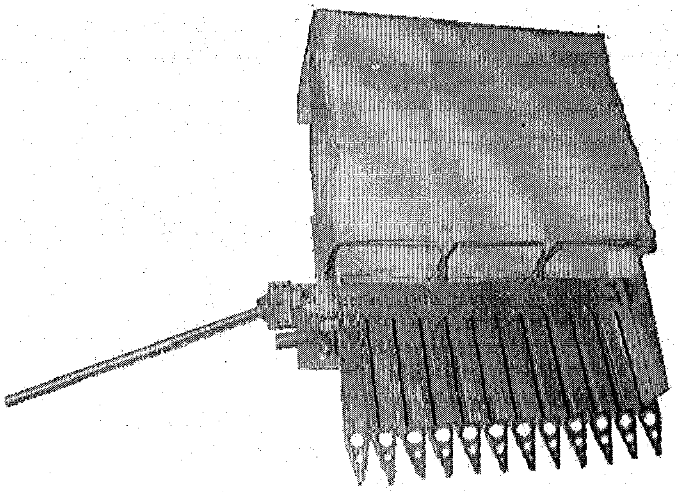
Fig. 8 Failure behaviour of tea-shoots



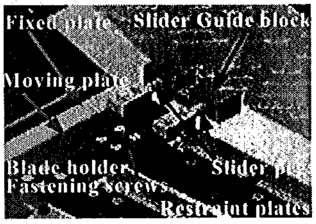
(a) Blade with large thickness

(b) Blade with small thickness

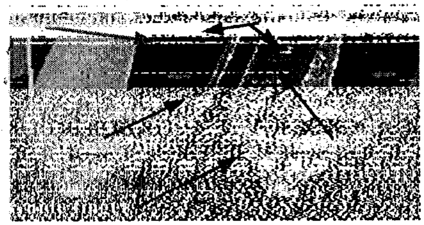
Fig.9 Effect of clearance on blade's performance



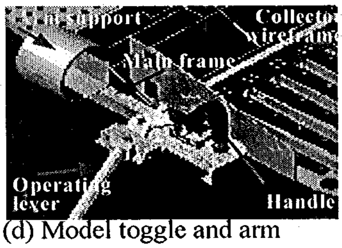
(a) Tea Plucker Prototype



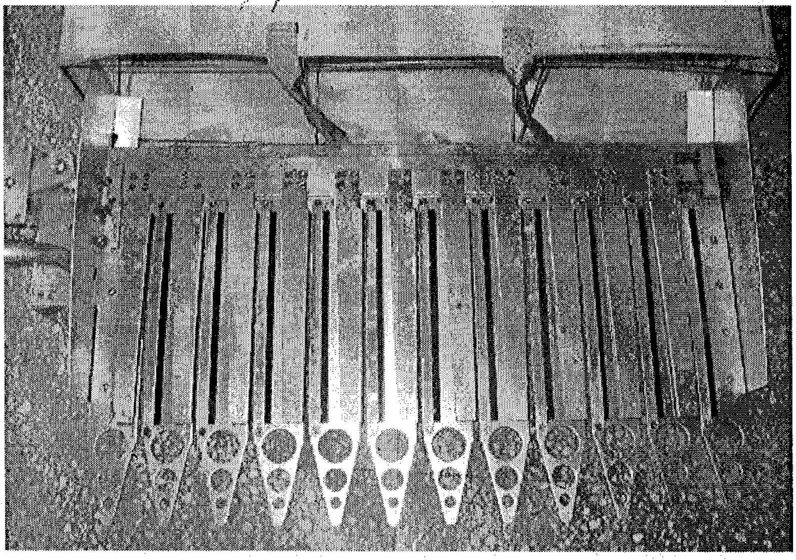
(b) Model slider details



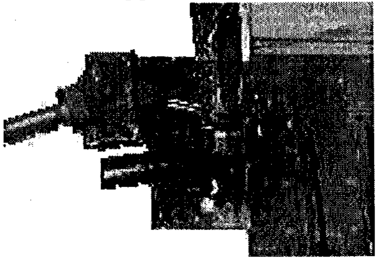
(c) Model blades details



(d) Model toggle and arm support details



(f) Prototype showing details of comb fingers



(e) Prototype toggle and arm handle details

Fig.10 Model details and Prototype of the Tea Plucking Machine

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