DESIGN & DEVELOPMENT OF A COCONUT DEHUSKER

by

R.A. Dennis and C.V. Narayan

SUMMARY

Owing to a critical labour shortage in the Caribbean coconut industry, certain operations in the copra production process need to be mechanised to improve productivity. One such operation is the removal of the husks (dehusking), for which at present no fully mechanised machinery exists. Various mechanisms for performing this operation have been investigated and the most promising tested in a laboratory prototype. These tests have proved the design concept and supplied the data for development of a commercial prototype.

INTRODUCTION

The coconut industry forms an important sector of the economy of the CARIFTA countries. It is estimated that there is currently an annual production deficit of fats and oils equivalent to 30,000 tons of copra. Output at present averaging 0.3 to 0.5 tons of copra per acre per year could be doubled by using more intensive production techniques. Apart from the biological problems such as disease in young plants, a major barrier to production increase is the present character of the overall system involved in producing copra. The majority of the operations involved are manual. The work is tedious and agricultural wages are low. Thus there is a growing shortage of labour on coconut estates. This last factor has forced coconut growers in the region to review their production methods with a view towards the mechanisation of certain operations. An overall view of a typical estate production system indicates however that mechanisation where applicable would not only offset the labour shortage but by handling the more tedious and difficult operations increase the productivity of the workers. In addition, proper scheduling of operations could increase the general production efficiency of the estate with lower operating costs per unit of copra produced. The overall project undertaken by the Department of Mechanical Engineering, U.W.I., in conjunction with various Grower Associations in the region is to examine present production techniques with a view towards achieving this efficiency increase.

COPRA PRODUCTION SYSTEMS:

The production system involves all the operations between collection of the nuts from the trees to the transportation of the product, copra, to the marketing outlet. The overall objective must therefore be to design a system which will handle a specified volume of nuts at minimised production costs within constraints imposed by such factors as existing installed equipment, the required output products e.g. copra, fibre, etc. and the availability of labour and capital. The individual operations such as materials handling, processing and transportation must therefore be considered within the context of the total production system to ensure that they combine to satisfy the overall objectives.

A flow-block diagram of possible systems is shown in Fig.1. The major differences are (i) whether to process the nut in the field or at a central factory; (ii) whether to dehusk the nut or to slice through the entire nut; (iii) whether to extract the meat before drying or to dry the meat in the shell. It the coconut husks are to be further processed into fibre it will probably be necessary to transport the nuts to a central factory, but if not it may be feasible to have some form of field harvester which will extract the meat and discard the husks and shells, the meat then being transported to a central drier.

At present the most common processing method employed in Trinidad is to slice the nut into three sections and scoop out the meat by hand. Slicing may be done by hand with a machete, but the larger estates have slicing machines capable of handling up to 20 to 30 nuts per minute - the meat is scooped out with self-fashioned hand tools. The major criticism of the process is that the slicing is accompanied by some shattering of the nut so

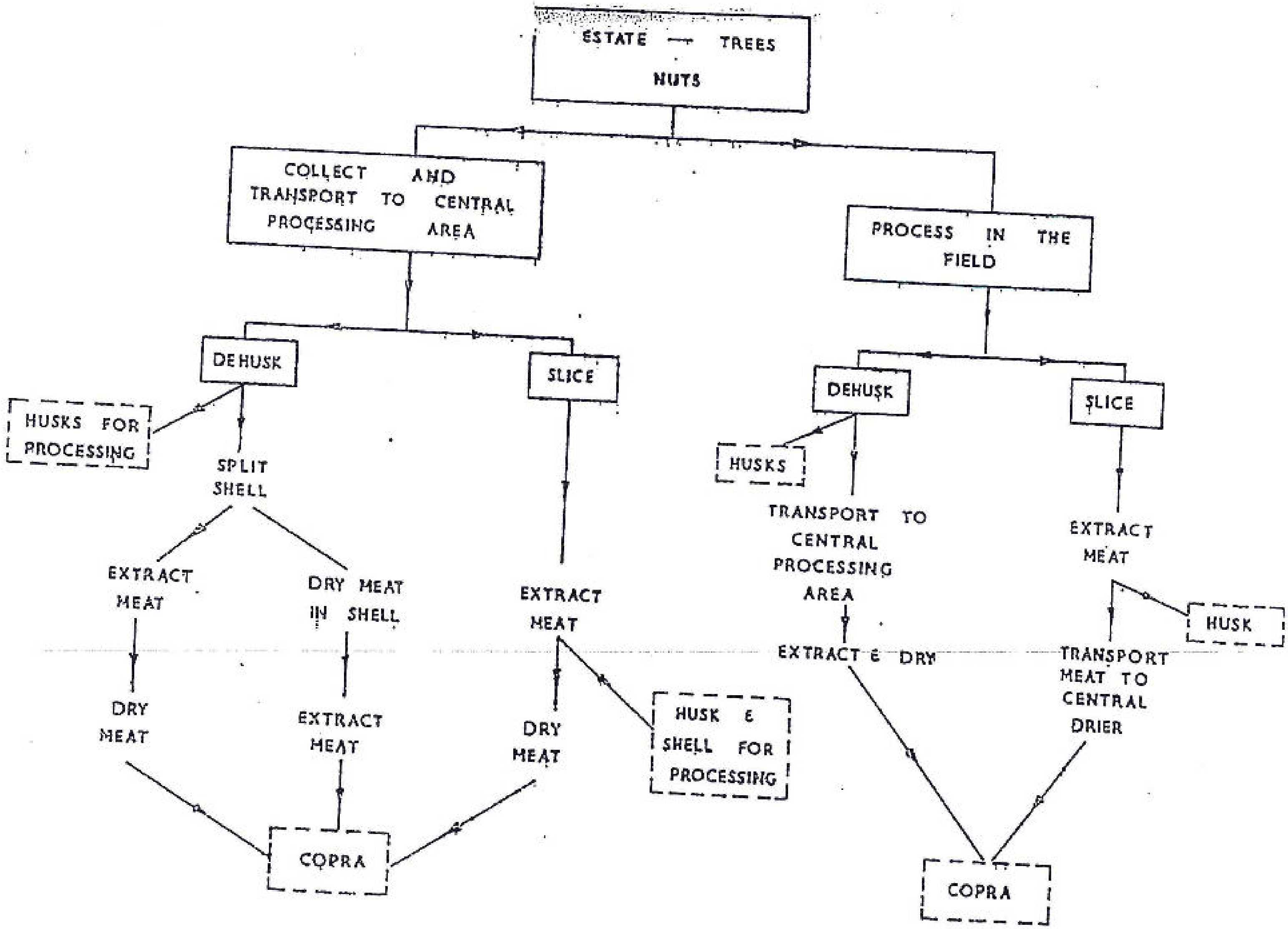


FIG. 1 COPRA PRODUCTION SYSTEMS.

that a small percentage of copra is lost in the form of small pieces of meat inseparably mixed with small pieces of shell. This problem could be overcome by an improved slicing machine and the productivity of the process could be increased considerably by organising the flow of material and by providing powered tools to assist with gouging out the meat.

In some of the Caribbean islands the nut is dehusked before the meat is extracted. Dehusking is carried out by hand usually by pressing the nut onto a vertical stake and twisting until the husk becomes loose and can be pulled off. The dehusked nut is then cut into two sections and dried which causes the meat to shrink away from the shell and allows it to be easily removed. The problem here is that drying the meat in the shell reduces the capacity of the drier, i.e. the weight of copra handled per batch, by approximately 40%.

Both the processes described are labour intensive, but working conditions are poor so that almost all the Caribbean Islands are faced with a shortage of labour. The situation is particularly serious in the case of estates using the dehusking process since the production capacity is almost entirely dependent on the dehusking operation and the number of experienced dehuskers is gradually decreasing. Obviously productivity must be improved to increase production levels and to allow higher wages to be paid. This may be achieved by the introduction of mechanical tools and by improving the organisation of operations. The design of a mechanical dehusker is therefore seen as an immediate need but as mentioned above this must be considered within the context of an overall production system.

DERIVATION OF DESIGN SPECIFICATIONS

Economic Feasibility and Machine Capacity

Agricultural wages in Trinidad vary across the island. A widely used wage however, is $6.00 per day. Estate owners have agreed that an experienced worker working at full capacity can dehusk 2000 nuts per day. Estimating a 75% worker efficiency over an eight hour day, the expected output per worker per day would be 1500 nuts. Thus the machine will have to be compared with manual production on the basis of a cost of \$4.00 per thousand nuts.

The variables that must be considered are as follows:-

(a) No. of nuts per year to be dehusked N

(b) Capacity of machine, nuts per hour C

(c) First cost of machine X.

(d) Capital cost factor k

Other factors to be considered in the analysis are:

i) Fuel and lubrication cost of the machine-using the average rating based on a 5HP gas engine, for small engine fuel consumption of 0.4 lb/HP hr, the fuel consumption for a working hour will be 0.25 gallons at a cost of \$0.125/hr. Lubrication consumption averages 3% of fuel consumption giving an hourly cost of \$0.03. Thus total fuel cost, f = \$0.155/hr.

ii) Annual Maintenance and Insurance cost m. For agricultural equipment m is taken as 5% of first cost.

ii) Annual Operator cost A. Assuming the machine to employ two men, an operator at \$2000 per year and a helper at \$1500 per year, A = \$3500 or approximately \$1.80/hr.

With the above factors we can calculate the annual operating cost of the machine.

$$\text{Annual fixed cost} = \frac{(k + m) X}{N} \quad \text{per nut}$$

$$\text{Annual fixed cost/1000 nuts} = \frac{(k + m) X}{N/1000}$$

$$= \frac{1000 (k + m) X}{N}$$

Allowing a 12% return on capital over 5 years

$$k = 0.277$$

$$\text{Thus, fixed cost/1000 nuts} = \frac{(0.277 + 0.05)\ X}{N/1000}$$

$$= \frac{327\ X}{N}$$

Now let the design throughput of the machine be T_m and efficiency of machine/operator be 70% over a 240 day working year.

Then Capacity, $= T_m \times 240 \times 8 \times .70 = 240 \times 8 \times C$ nuts/year

Thus the operating costs are given by f + A dollars per hour or $\frac{f + A}{C}$ dollars per nut

$$f = 0.155$$

$$A = 1.800$$

Therefore operating cost $= \frac{1955}{C}$ dollars per 1000 nuts

and the total dehusking cost is given by the relation

$$\text{Cost/1000 nuts} = \frac{327\ X}{N} + \frac{1955}{C}$$

We can now select values of C, N and X to find required capacities and costs by using the two constraints:-

a) Manual cost = \$4.00 per 1000 nuts

b) When $N/C > 2000$ hours a second machine will have to be used

Figures 2 and 3 show the variation in dehusking cost for two values of C and four values of X From these it can be seen that a

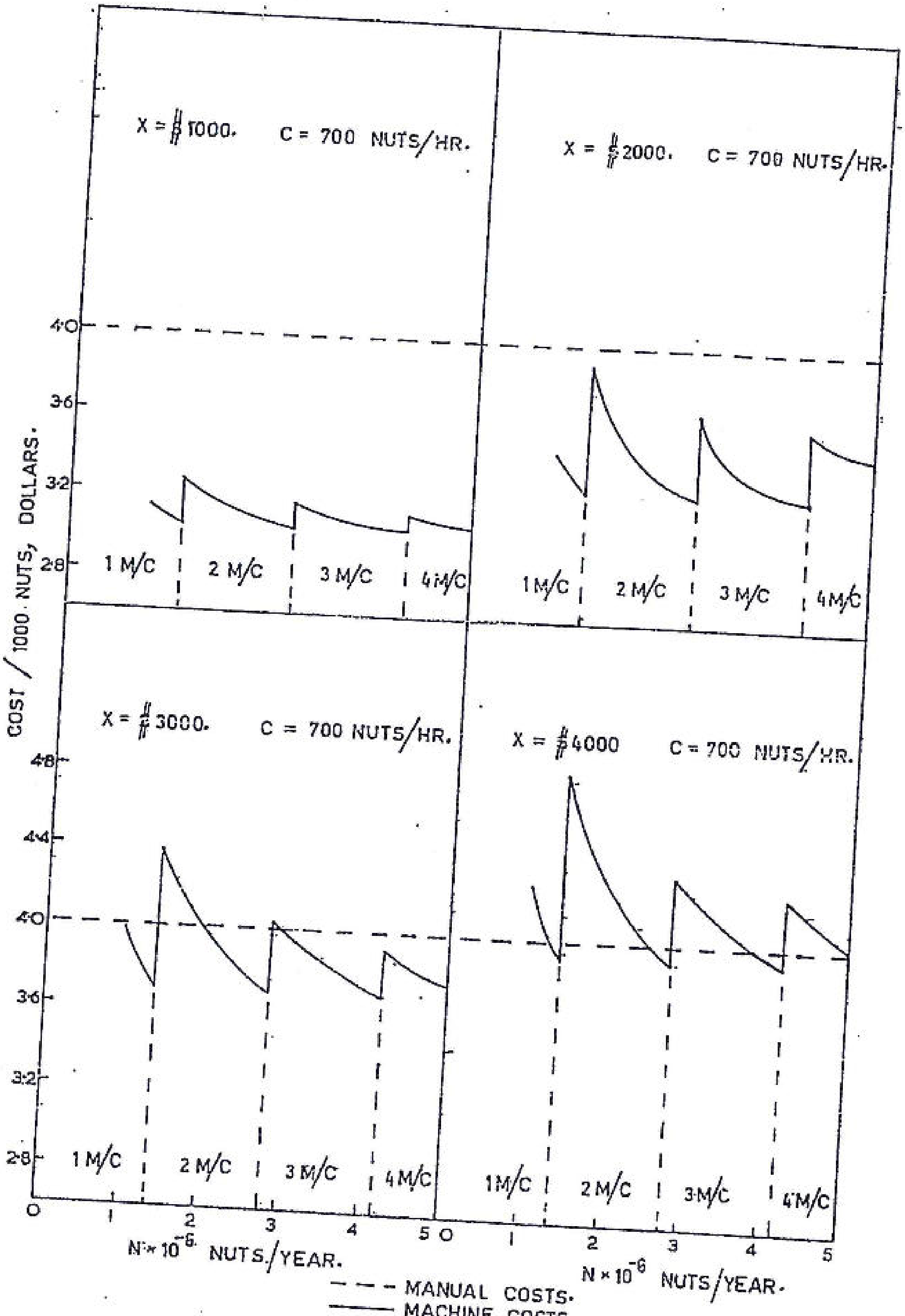
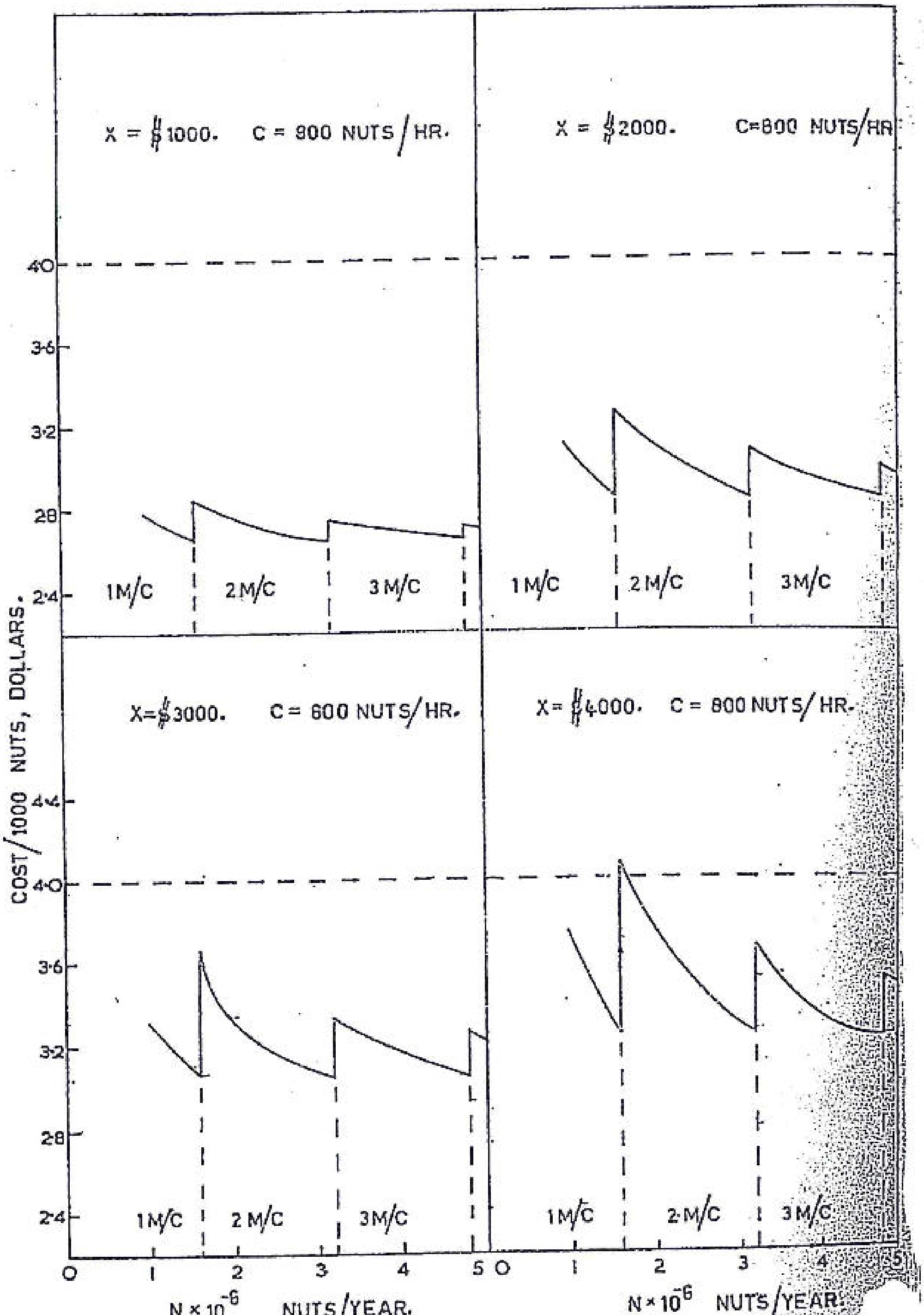


FIG.-2 COMPARISON OF DEHUSKING COSTS.



----MANUAL COSTS.
——— MACHINE COSTS.

FIG.#3 COMPARISON OF DEHUSKING COSTS.

field capacity of 800 nuts per hour would be an economical design over a wide spread of values of estate production N, even at a first cost of $4000.00 per machine.

Nut Dimensions

A large sample of nuts taken at random from various estates throughout Trinidad was used to determine the variation in nut size.

Each nut was sawed in half longitudinally as shown in Fig. 4. and the lettered dimensions were measured.

Table 1 shows numerical values for the dimensions giving the expected nut size variation that will have to be accommodated by the dehusker.

Maximum Design Forces

A sample of nuts was used to determine the minimum average force required to crack the shell of the nut.

Nuts were subjected to a direct force by a sharp blade 2 "wide, the blade being driven by the cross- head of an Avery testing Machine. The average minimum load to crack the shell was found to be 625 lbf. Thus the maximum force that will be exerted by the dehusking mechanism on the shell should be below this figure.

Summary of Design Specifications

a. The minimum design throughput of the machine should be of the order of 1000-1200 nuts per hour, giving an expected field capacity of 700-800 nuts per hour.

b. The cost of the machine should not exceed $3000.

c. The machine should be versatile enough to accommodate a variation of 5 "in nut diameter.

d. The maximum force exerted by the dehusking mechanism on the hard shell of the nut should not exceed 600 lbf.

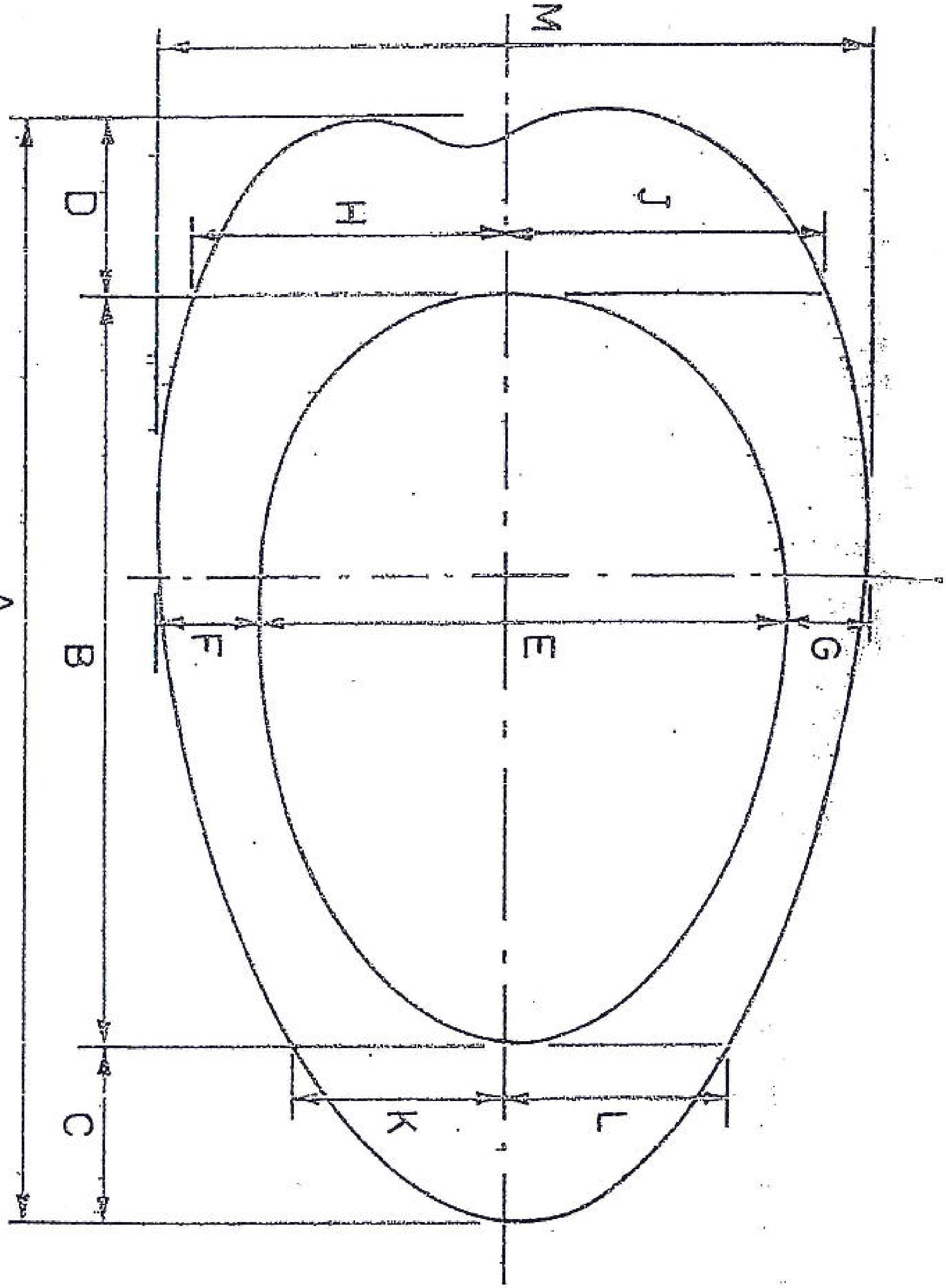


FIG. 4 NUT DIMENSIONS.

CONCEPT DESIGN:

The machine was considered to consist of three basic operations:

i) The input feed of nuts

ii) Removal of the husk from the nut

iii) Separation and removal of husks and nuts

Although the removal of the husk from the nut is the major function of the machine, the constraints imposed by the other two operations must be considered as important factors in the design of the dehusking machanism. The initial part of the study therefore concentrated on the synthesis and evaluation of possible dehusking mechanisms.

Evaluation of Dehusking Mechanisms:

After some preliminary assessment and elimination, a short list of possible dehusking mechanisms was drawn up. The mechanisms selected for further evaluation are shown in Fig. 5 where they are classified according to the primary action of the mechanism. The evaluations of the various mechanisms, which in some cases included testing of simple experimental models, are discussed below.

A. Compression Mechanisms:

Preliminary tests to investigate the basic characteristics of the husk showed that when the nut is compressed along its axis the husk tends to split along three axial sections. This observation led to the idea (A1) in which the nut is forced down over three profiled blades by an upper three-bladed prong. The prong first penetrates the husk and locates itself on the shell to prevent the shell from tipping laterally - increased loading then causes the husk to split along the lines of the lower blades so that the husk opens out and allows the nut to pass through the circular opening around which the blades are

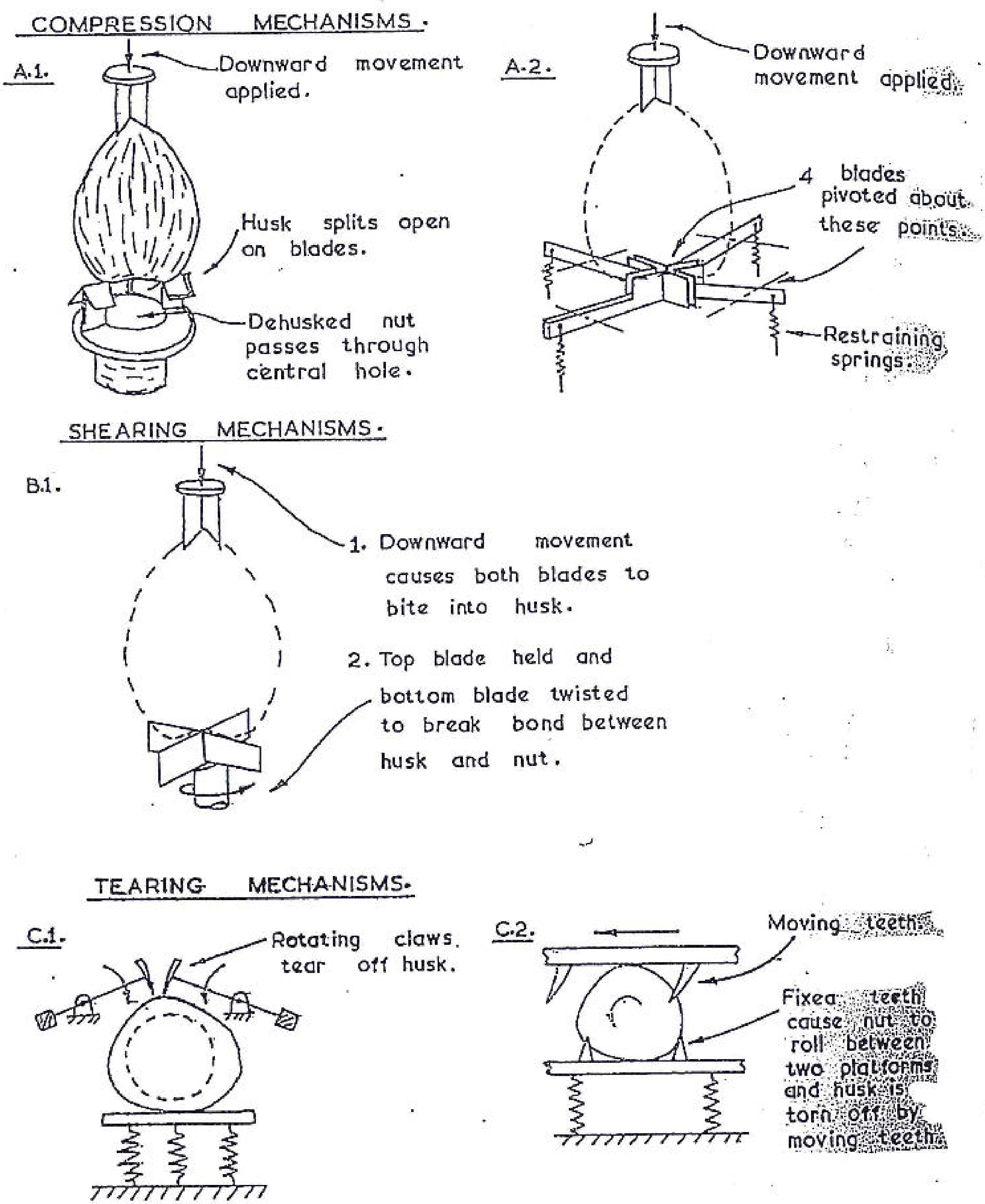


Fig.5 DEHUSKING MECHANISMS.

aligned. The performance of the mechanism is very dependent on the diameter of the central opening - a series of tests on a model with an opening diameter of 4¼ for example gave successful dehusking for a range of nut sizes from 5" to 5.8" equivalent diameter (dimension "M" in Fig. 4).

Comparing this range with the overall size range (Table 1) shows that three or four units of different sizes would be required and that it would be necessary to grade the nuts before dehusking.

This problem could be overcome by arranging for the blades to open radially when the load on them builds up due to contact with the hard shell thus allowing the larger nuts to pass through without fracturing. A mechanism of this type is shown in (A2) where four blades are arranged to open out against a restraining spring force.

Tests on this mechanism were not entirely successful since in some cases the shell tended to adhere to one section of the husk causing the whole nut to tip sideways in the blades, in other cases satisfactory dehusking was achieved.

The compression type mechanisms are very simple and are very adaptable to power operation, but the following problems are apparent.

a) the need for a feed mechanism to place the nut in the required orientation on the blades and to be synchronised with the dehusking operation.

b) the tendency for the nut to tip sideways under load

c) the removal of the husks from the blades

Problems (a) and (b) are made more difficult by the large variations in size and shape of the nuts.

Shearing Mechanism:

This mechanism (B1), most closely simulates the manual husking operation and in fact forms the basis of a commercially available hand-operated machine. The twisting action is very effective in breaking the bond between the husk and shell but a further operation is required to separate the shell and husk. Since three basic operations are involved, compression, twisting and separation, the drive mechanism would be more complex than in (A) above and the same feed problem exists.

C. Tearing Mechanism:

One of the simplest devices to drive mechanically consists of rotating teeth or claws arranged to tear off the husk of the nut. (C1) shows a simple model which was tested in which the variation in nut size is allowed for by a spring-mounted table. These tests indicated that the major problem with this type of mechanism is to ensure a positive separation of the husk from the nut since the nut tends to be pulled through attached to one section of the husk.

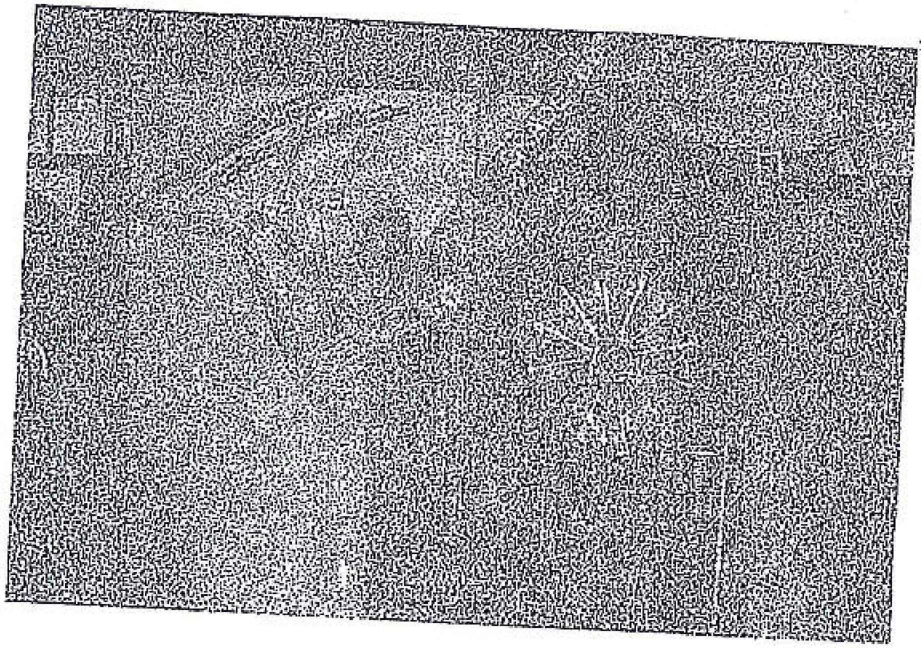
Several other ideas based on the principle of tearing off the husk were considered and the one which was felt to have the most promise is outlined in (C2). In this the nut is forced to roll between two sets of teeth, one moving and one stationary. The gap between the two sets of teeth is made self-adjusting to take up nuts of various sizes and by careful attention to the shape of the teeth it is possible to ensure positive separation of the husk from the nut.

Selection of Design Concept:

The evaluation of the various mechanisms indicated that any one could possibly be developed into a functionally efficient dehusking machine. The final selection of the concept to be developed was therefore made primarily on a basis of the mechanism which offered the simplest method of effecting the basic operations of feeding, dehusking, separation and removal of nuts and husks, since this would also satisfy the requirements of low cost, reliability and robustness. On this basis Concept (C2) was chosen since the dehusking mechanism requires only a simple drive to power the movement of the teeth, hand feeding can be used without any safety problems, and the dehusking operation can be designed to separate the husk from the nut.

PROTOTYPE DEVELOPMENT

A laboratory prototype of the machine was first constructed to investigate the efficiency of the dehusking action and to obtain information on the important design parameters. This prototype, shown in Fig. 6, consists of a cylinder and concave mechanism in which the moving teeth are attached to a cylinder rotating about a fixed axis while the fixed teeth are attached to the concave. The



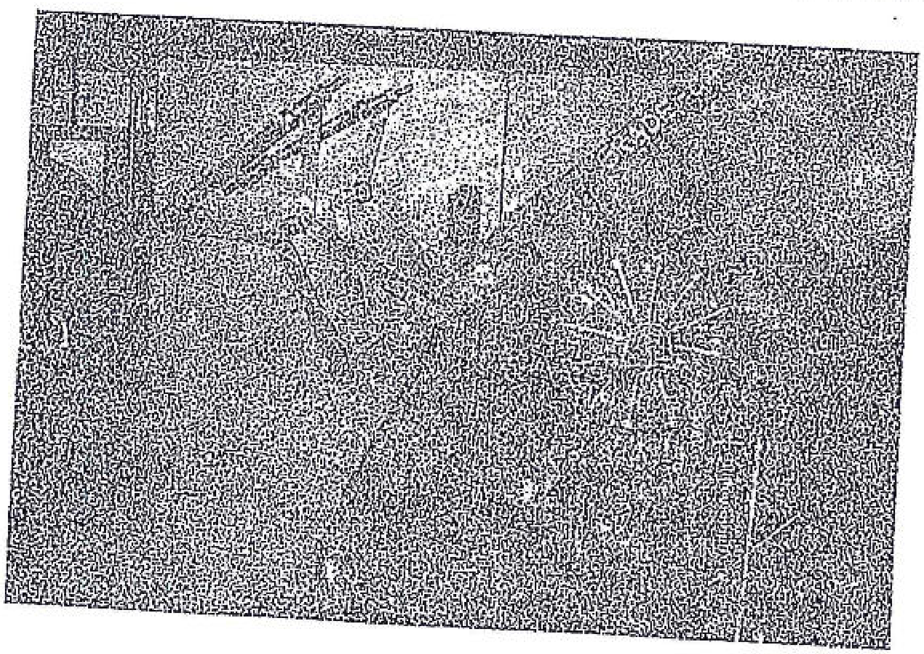


FIG.-6 EXPERIMENTAL PROTOTYPE DEHUSKER.

coconuts are fed into the annular space between the cylinder and concave and since the concave is mounted on springs the radial clearance is self adjusting to allow for nuts of different sizes. The cylinder is manually rotated through a 5:1 chain drive reduction which allows close control over the operation of the machine in order to study the dehusking action.

Testing of Prototype

The coconuts used in the test programme were roughly divided into the grades shown in Table 1. Several hundred nuts of Grades 1 - 4 were tested to assess the performance of the mechanism, and although the largest nuts, Grade 5, were not tested owing to limitations in the movement of the concave, the tests gave a good appreciation of the characteristics of the dehusking action and yielded data on the effects of design parameters needed for further development of the machine.

The test programme included the following studies:

1. A general observation of the characteristics and performance of the dehusking mechanism.
2. A study of the effects of design variations on the dehusking action.
3. A photographic study of the passage of different sized nuts through the dehusker.
4. Measurements of the driving torque required to dehusk different sized nuts.

Results

The overall performance of the prototype proved very encouraging. In many cases complete dehusking was obtained (apart from a tuft of end fibre discussed below) and any cases of incomplete dehusking could usually be attributed to deficiencies in the design of the prototype as follows:-

i) The path length of the dehusking section was too restricted so that in some cases dehusking was not completed. On repassing the nut, dehusking was usually completed within the first third of the path length.

ii) The circular path used is not very satisfactory because of the problems of suspending the concave to give a uniform radial force/displacement characteristic over the whole path length. Some of the concave blades near the middle of the path were therefore not fully effective and the nut sometimes skidded over them without achieving the required husking action.

Since both deficiencies could be rectified by design modifications it was decided that the results justified further development of the mechanism into a commercial prototype. The detailed results of the test programme are discussed below.

Dehusking Action

From observation and the photographic study it was seen that the most effective dehusking was achieved when the nut rolled smoothly between the two sets of teeth. The required action is illustrated in Fig. 7 which shows that the husk is torn off in sections which become quite firmly impaled on the moving teeth and hence effectively separated from the nut. Not all of the fibre can be removed in this way and a tuft of fibres is left attached at the stem end of the nut. A secondary cleaning device may therefore be needed to remove all the fibre from the shell if this is required for the further processing of the nut.

Torque Measurements

Torque was measured using electrical resistance strain gauges attached to the crank used to rotate the cylinder. During the tests the output from the strain bridge was continuously recorded on a strip recorder. The chart was initially calibrated by hanging weights onto the crank with the cylinder prevented from rotating. Some typical traces representing the torque variation during the dehusking of different sized nuts are shown in Fig. 8, and the range of

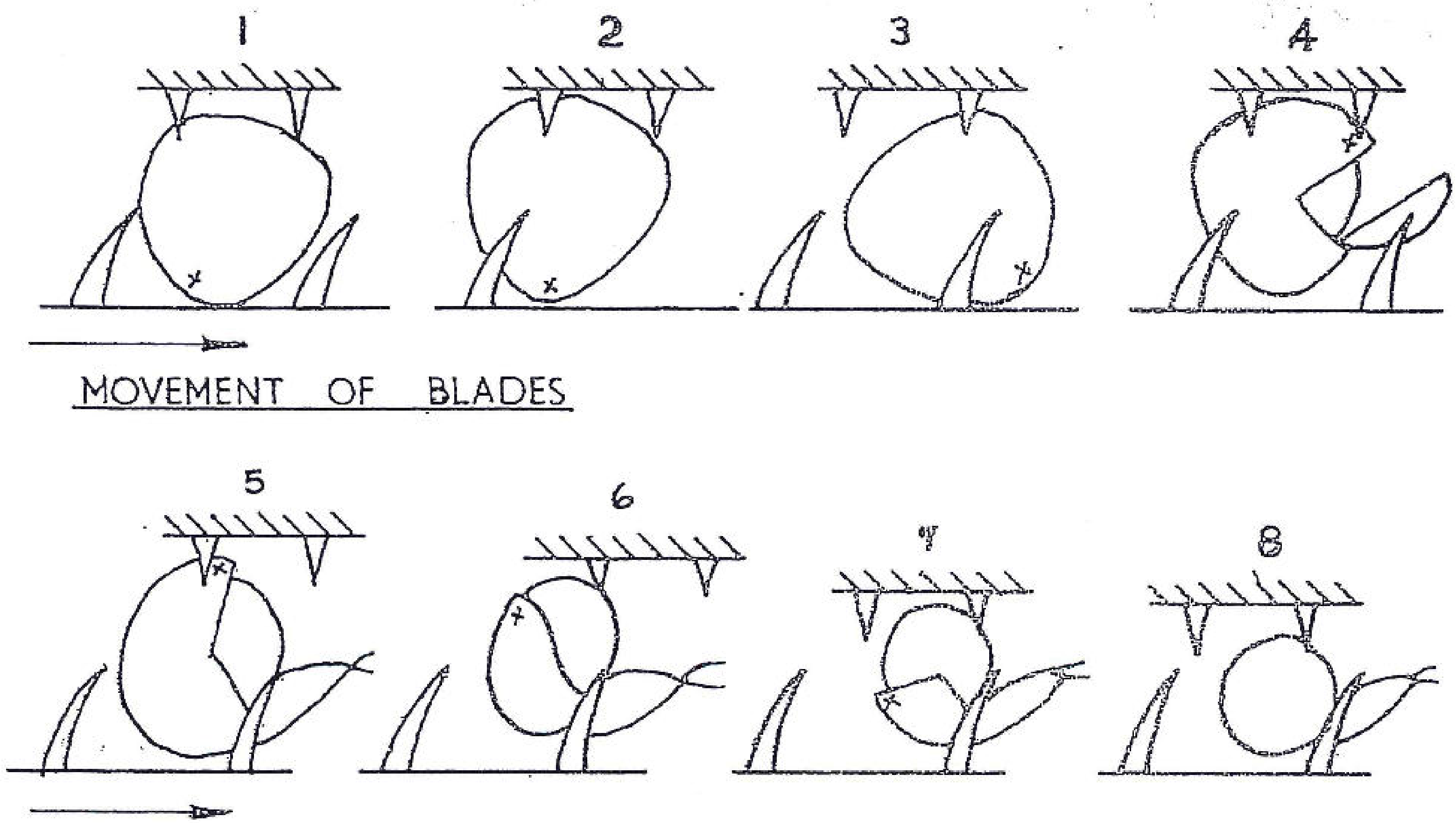


FIG. 7 DEHUSKING ACTION

maximum torques found for five nuts of each size range are given in Table 2. The upper torque values tended to be caused by slight jamming of the nut and under smooth dehusking action these values would be lower. However, the figures indicate an upper limit of 50 lbf.ft. which when translated to the cylinder represents a torque of 250 lbf.ft. and a maximum tangential force on the teeth of about 400 lbf. Thus for a dehusking rate of 20 nuts/minute, say two nuts per rev. and 10 rev/min., a motor of about 0.5 H.P. would be needed to drive the dehusker.

Design Parameters

Moving Teeth - the design of these teeth was found to have a very significant effect on the dehusking action. The design eventually developed from the test programme is illustrated in Fig. 9. which shows two main teeth located so as to bite into the thickest section of the husk at either end of the shell. To achieve the required tearing action it was found that the teeth should be curved and about 2½" long - excessive curvature or length resulted in the husk becoming so firmly embedded on the teeth that the rolling action of the nut was impaired whilst too little resulted in incomplete separation of the husk. The required relative positioning of nut and teeth is achieved by locating the pointed end of the nut against a guide since Table 1 shows a limited variation in the thickness of the husk at this end (dimension "C"). Two secondary blunted teeth are used to push through the nut when the husk has been removed.

Fixed Teeth - initially, restraining blades were used on the concave but although these worked reasonably well the resulting dehusking action was "jerky" and to overcome this, teeth were introduced as shown in Fig. 9. Matching of the teeth with the moving teeth is important since they must apply sufficient restraint to cause the nut to roll, but excessive restraint tends to result in fracture of the hard shell of the nut. When the nut has been partially dehusked the restraining teeth act directly against the hard shell and to avoid fracture of the shell central rounded teeth are added during the latter stage of the dehusking path.

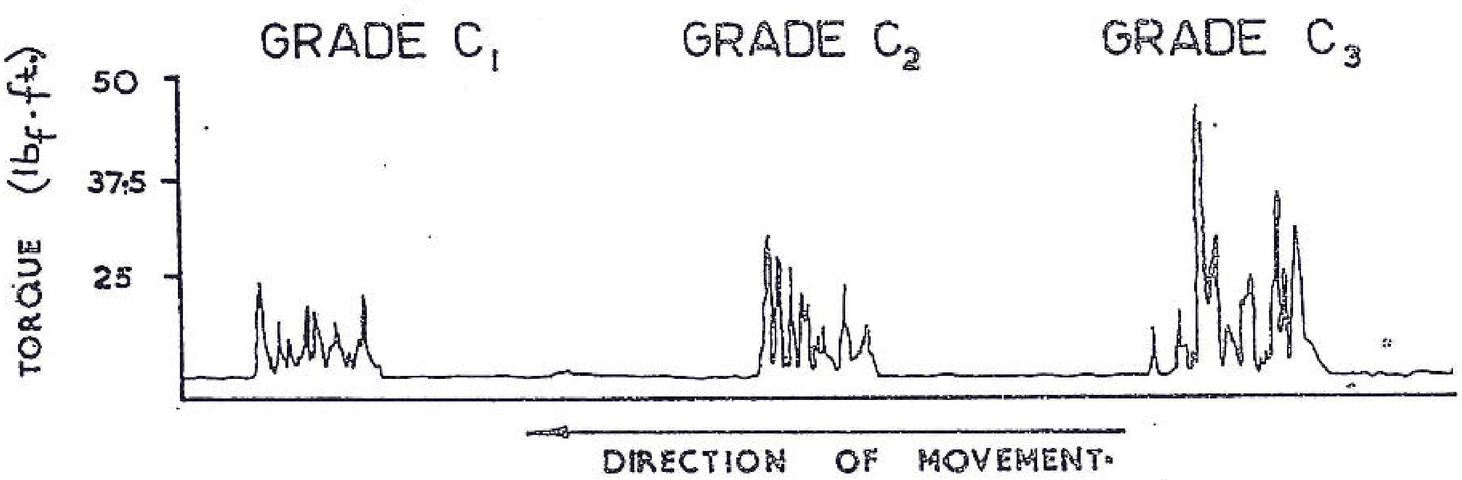


FIG. 8 TRACES SHOWING TORQUE VARIATION DURING DEHUSKING.

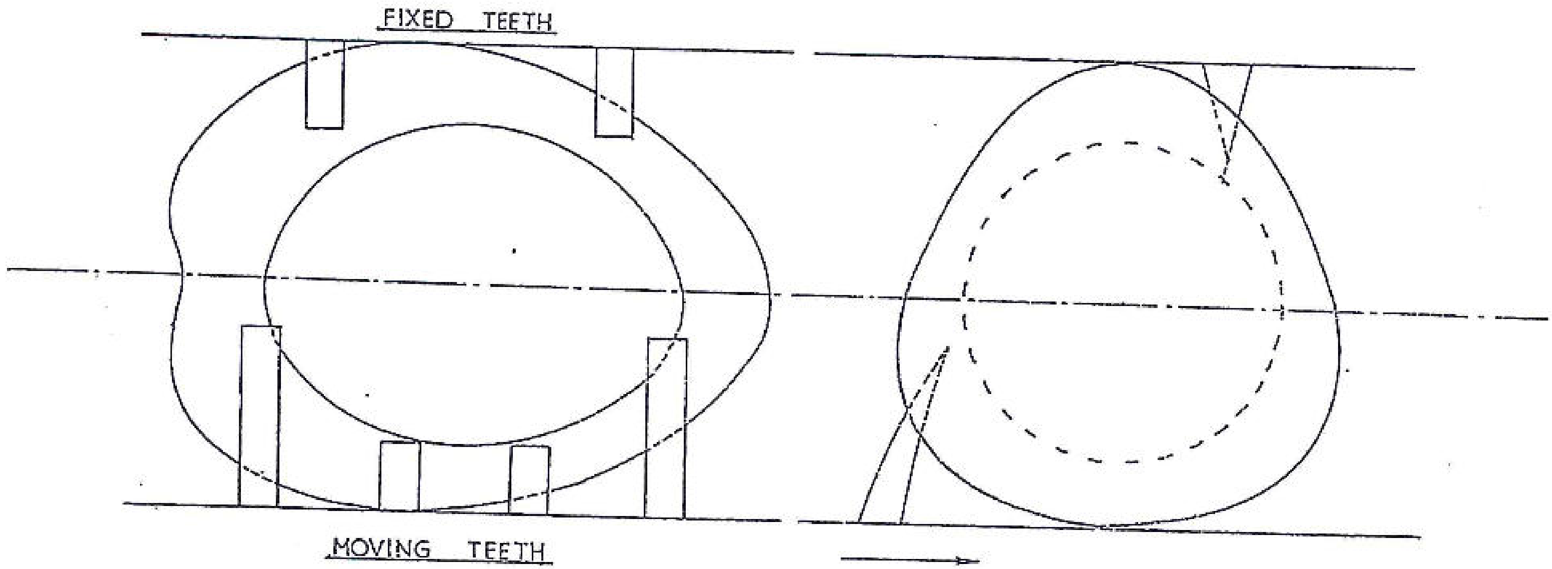


FIG. 9 ARRANGEMENT OF DEHUSKING TEETH
GRADE 3 NUT SHOWN

Suspension system - the suspension system for the fixed platform must allow sufficient movement for the different sized nuts to pass whilst offering enough restraint for the teeth to bite into the husk. If the initial clearance between the moving and fixed platforms is set just less than the minimum nut size, i.e. about 4", then a lateral movement of about 5" is needed to accommodate the largest nuts. A minimum restraining force sufficient to cause the teeth to penetrate the husk must be exerted over the whole of this movement, so that the suspension springs must be pretensioned and at the same time allow the 5" movement without a large increase in restraining force. This was achieved in the first prototype by coupling the springs through a scissors arrangement which gave a restraining force varying from 40 lbf. to 60 lbf. for the total movement of the concave. It was found that this restraining force was slightly too low and it is estimated that a force of 60 to 80 lbf. is needed to achieve satisfactory penetration of the teeth into the husk.

FUTURE DEVELOPMENT

The results from the testing of the laboratory prototype confirmed the feasibility of the basic design concept and provided data on the design parameters required for the development of a commercial prototype. The first prototype is now under construction, the only major design change being the use of a linear instead of a curved dehusking path in order to overcome the problems associated with the suspension of the concave. The fixed teeth are therefore attached to a flat spring-mounted platform and the moving teeth to a chain-type conveyor arrangement. The machine is very compact, which makes it suitable for either field or factory use, and may be driven from any available power source such as a small petrol engine, electric motor or tractor p.t.o. The overall construction is simple and it is expected that the cost of the machine will fall well within the specified limits for the design capacity of 1200 to 1500 nuts per hour.

GRADE	C1	C2	C3	C4	C5
A	6 - 7½	7½ - 8½	8½ - 9	9 - 9½	10 - 11
B	3½ - 4	5 - 6	5 - 5¼	5¼ - 5½	5½ - 6
C	¾ - 1¼	1¼ - 1½	1¼ - 1½	1½	1 ¾
D	¾ - 1½	2 - 2¼	1½ - 2¼	2 - 2¼	2½ - 3
E	3 - 3½	3½ - 4	4 - 4¼	4½ - 5	5 ¾
F	3/8 - ½	¾ - 1	1 - 1½	1	1 - 1½
G	½ - 1	½ - 1	1	1	1 - 1 ¾
H	2½ - 3	2¼ - 2½	3 - 3¼	3 - 3¼	3½ - 4
J	2 - 2¼	2¼ - 2½	2 ¾	3¼ - 3½	2¾ - 4¼
K	1 - 1½	1½ - 1 ¾	¾ - 2¼	1½ - 2	2 - 2 ¾
L	1¼ - 1½	1 - 2	1 - 2	1½ - 2	2 - 2¾
M	4 - 5	5 - 6	6 - 6½	6½ - 7	7 - 9
J + H	4½ - 5¼	4½ - 5	5 ¾ - 6	6¼ - 6¾	6 ¾ 8¼
L + K	2¼ - 3	2½ - 3 ¾	3 ¾ - 4¼	3 - 4	5½ - 5¾

TABLE I VARIATION IN NUT SIZES

Grade	Equivalent Diameter (inches)	Range of Maximum Dehusking Torque (lbf.ft.)
C1	$4 - 5^1/_8$	18.0 - 31.0
C2	$5^1/_4 - 6$	31.6 - 49.0
C3	$6 - 6^1/_4$	19.6 - 46.6
C4	$6^1/_2$	44.2 - 49.5

TABLE 2. VARIATION IN DEHUSKING TORQUES FOR DIFFERENT SIZED NUTS