A REVIEW OF ROLLING METHODS IN TEA MANUFACTURE

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Investigations on the rolling of tea have followed two main lines. On the one hand, traditional methods have been studied with a view to understanding the mechanics, the chemistry, and the physics of the process with a view to ultimate improvement of efficiency. On the other hand, methods radically different to the traditional methods have also been explored with the object of simplification and cheapening of the cumbrous traditional methods which, even at present, are no more than mechanised versions of the hand rolling methods practised for centuries. This review is therefore divided into two sections :—

Section One.—Traditional rolling methods.

Section Two.—Modern attempts to depart from traditional rolling methods.

SECTION I—TRADITIONAL ROLLING METHODS

Under the heading of "Studies on the Rolling of Tea" *(Tea Quarterly,* 1938: Vol. XI, p. 131) I described our rolling experiments up to 1938. After stressing the utmost importance of carefully planned rolling programmes, the principal conclusions arrived at up to that time were, to quote paragraphs 7 and 8 of "Summary and conclusions."

"Paragraph 7.—The application of heavy pressure to force dhool out-turn is undesirable. The explanation advanced is

that very heavy pressure impedes circulation of leaf in the jacket and defeats its own object since the principle of normal tea rolling is the twisting action to which the leaf is subjected and this cannot be provided correctly without circulation of leaf.

Paragraph 8.—" 'Twisting' battens are preferable for early rolling. The 'cutting' type of battens should be used for reducing the bulk of later rolls."

These conclusions stand fast and whatever developments are described later it is essential to remember that it is the circulation of leaf which provides twist, and that it is this twisting action which wrings juice out of the leaf (like water from a damp cloth). The action is slow and is only effective on relatively intact leaf. As soon as leaf is cut into dhool the twisting action becomes ineffective and it follows that rollers which give a high percentage of dhool in the first roll cannot be effective. In 1938 my idea of requirements was expressed as follows :—

"The ideal batten, at least for preliminary rolls, is one which would allow considerable pressure to be applied without excessive dhool formation and without restriction of circulation. An examination of the various types available was commenced in order to collect information on this matter. It is hoped that it will eventually be possible to design a batten which will meet these requirements and at the same time prevent throw-out."

Practically the whole of subsequent developments have depended on a chance observation during the course of the investigation of the various available types of battens. To quote again from "Studies on the Rolling of Tea." "Recently we commenced investigation of a type of batten very widely used which is even more severe than type X and the danger inherent in reference to batten types by name is very well illustrated by the enormous difference in performance when the battens on the door were changed. (Note.—The makers offered three alternative arrangements on the door). Aluminium battens on the door were substituted by similarly shaped and sized battens of teak and the result was that the dhool percentage fell as follows."

	No Pressure	Pressure applied by 1st set of weights.
Before alteration to door battens ...	21% dhool	29% dhool
After alteration to door battens ...	8% „	16% „

From the relatively high wear and tear over the door area we had suspected that a good deal of the work was restricted to this area, but this chance observation indicated that the design of the battens in the centre of the table was more important than was first supposed. In 1939 we commenced a detailed investigation on batten action starting from a plain table and adding battens in stages from the centre outwards. Quoting from our Annual Report for 1939: "Since the twisting action of normal battens is undoubtedly responsible for the main changes in the rolling process it is considered desirable to study the factors involved in this action. We have been fortunate in receiving a kind offer from Messrs. the Colombo Commercial Co., Ltd. to make for us a number of different types of tables and battens as our experiments progress and in this we have the very able advice of Mr. F. J. Whitehead. Accordingly we have started from a plain table without battens or obstruction of any

kind and are adding various types of projections starting from the centre of the table where, as previously reported, the larger proportion of batten action takes place." A large number of different cones both smooth and grooved as well as a hexagon and other solid figures were tried out in 1939 and 1940.

At this stage it is desirable to refer to the development of commercial types of batten which exploit this zone of activity in the centre of the table. In addition to assisting us as described above, the Colombo Commercial Co. have carried out their own experiments and have developed "Column Rolling." Again, working quite independently, Messrs. Keel, Craig & Baker developed "K'bacra Cone Rolling" which is marketed by Messrs. Davidson & Co. Actually we only learnt of Messrs. Keel, Craig & Baker's experiments in 1944 and of Messrs. the Colombo Commercial Co.'s "Column" device a little later. Since then we have had the much appreciated opportunity for testing both devices on our experimental rollers and it is most interesting to find how similar are the conclusions drawn by these three independent investigators. Our own experiments have been sadly impeded by the war through absence on military duties, mechanical difficulties and restriction of facilities for getting samples tasted.

To return to the course of our own experiments. The discovery of this active zone at the centre of the table coincided with our experiments with the Clivemeare Roller which have been reported in the *Tea Quarterly* and will be referred to in detail in the second part of this review. The Clivemeare experiments strongly suggested the possibilities for simplification and reduction of rolling time, and our own experiments rather concentrated on the exploitation of what I have referred to as the "Active Zone" in a roller with the object of increasing efficiency rather than bringing about any particular improvement in teas manufactured. Thus in the Annual Report for 1940 I stated: "There is no apparent reason why twisting should take three or four operations of half-an-hour each to work the leaf into the desired condition and the subsequent cutting operation need not be prolonged. Roller tables and battens designed to give the maximum twisting or maximum cutting effect may therefore allow a more rapid completion of the rolling process with improvement in fermentation similar to that obtained in the Clivemeare process, and, at the same time, enable the orthodox appearance of the leaf to be retained." In the Annual Reports for 1942 and 1943 we reported the results of a large number of experiments designed to explore the possibilities of reducing the number of rolls by making the best use of twisting and cutting battens and increasing rolling effect by devices such as the Clivemeare Roller and "Plain Table Rollers," *i.e.*, devices exploiting the active zone in the centre of the table. Softer withers were employed when using combinations of ordinary rollers with the Clivemeare Roller or combinations of Clivemeare plus plain table rollers. Heavy pressure on ordinary rollers with shortening of the fermentation period was also investigated.

Employing normal rollers only, it was found possible to obtain good results from three-roll programmes. The teas from the three-roll programmes were required to be slightly better or equal to those from a standard five-roll programme.

At this stage of our experiments the practice of sending teas to London had to be entirely abandoned and it was no longer possible to submit teas to a "Team" of Colombo Tasters. However, in spite of difficulties, individual Colombo Tasters were kind enough to deal with experimental samples and it was possible to get the

opinion of a broker and a buyer. In all our further experiments the aim was to produce teas at least equal to those produced by a standard five-roll programme on ordinary standard types of battens Having succeeded in producing normal teas in three rolls by making the best use of twisting and cutting battens, it became desirable to explore the possibilities of further simplification by a modification of battens. It was known that almost any projection on the door would produce dhool even if the rest of the table was quite plain. Also, it was easy to produce high percentages of dhool by using devices with sharp edges. For instance a device shaped like a cotton reel (Fig. 1), comparatively very small in size, gave 78 per cent of dhool in one 30-minute roll. Teas manufactured in this manner, however, were choppy and flaky. Against this, a good circulation could be obtained with any smooth comparatively shallow projection but dhool out-turn was very poor so long as the device was smooth. By employing the pressure cap these smooth projections could be forced to produce dhool but it was of a flaky and choppy nature and was obviously produced by dragging a block of leaf compressed in the jacket by the pressure cap over and over the table. The action under these circumstances was almost entirely abrasive. By restricting battens to the centre of the table we had discovered types which gave only twisting or only cutting action and to that extent clarified the whole position with regard to the mechanics of rolling. It became evident that the commonly used batten arrangements (depending almost entirely on the door battens and on the arrangement on the table immediately round the door) give a combination of twisting and cutting action. Some types accentuate twisting effect and some cutting effect, but for commercial purposes any batten in general use must produce both effects to some extent. All our experiments up to 1943 had pointed to the desirability of separate rollers for twisting and for cutting but we had not envisaged battens which produced so little dhool as the plain table and shallow cone arrangement or so much as the cotton reel device. The application of twisting action applied by a shallow cone arrangement followed by final cutting on the cotton reel fitting would no doubt have produced quite reasonable results, but even quite well twisted leaf was inclined to be rather choppy after treatment with the cotton reel and so it was considered desirable to search for a cutting device which would at least keep the twist on the leaf.

Both the cone and cotton real devices worked independently of the pressure cap. Application of pressure to the shallow cone in fact stopped circulation of leaf as already mentioned, stopped twisting action and caused the formation of choppy dhool by a mere dragging abrasive action. We had long known that the pressure cap restricted circulation and had experimented with various pressure intervals designed to alternate free and restricted circulation to the best advantage. We now began to suspect that the action of the pressure cap was almost entirely detrimental. Apparently the use of a pressure cap on tea rollers is of comparatively recent origin, the earliest rollers having an open jacket. It now appears that the introduction of the pressure cap was indeed a retrograde step. As often pointed out, the effective action of the tea roller is entirely dependent on imparting a twisting motion to the leaf. This twisting motion depends on circulation of leaf and anything which restricts circulation is detrimental. In actual fact I believe the pressure cap is a most undesirable attachment.

MECHANISM OF TEA ROLLING

The later part of the story is difficult to tell because it means summarising the results of a very large number of trial and

PLATE I

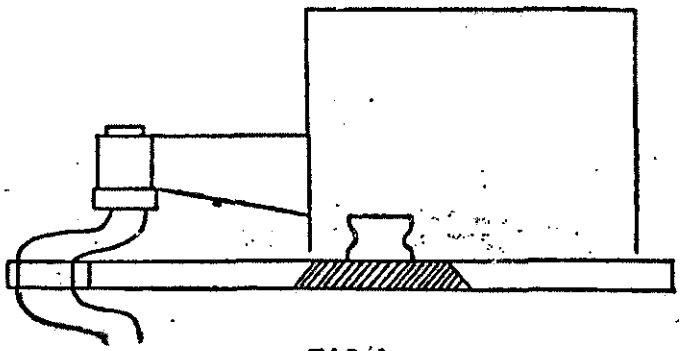


FIG 1

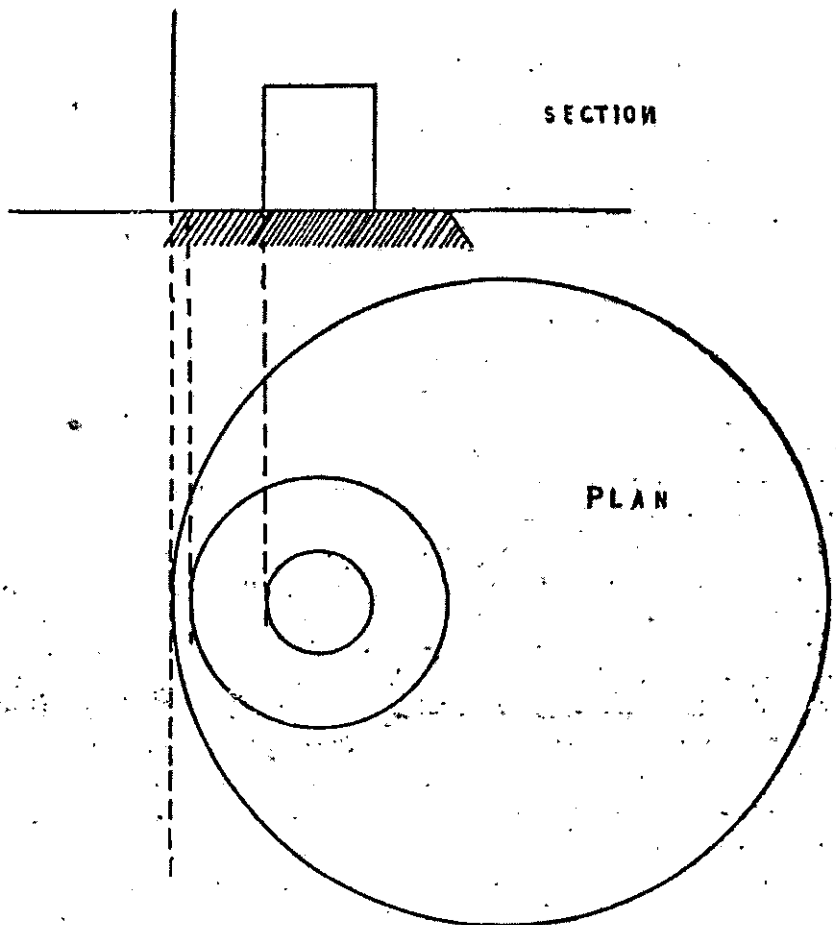


FIG 2

error experiments and also because we cannot yet give it a final happy ending. We have not reached the end of our search for the ideal arrangement but we are probably fairly close to something which will constitute a useful advance in the technique of tea rolling. From the details of the mechanism of tea rolling already discussed it is evident that circulation is considered to be one of the most important factors. Any projection from the door into the jacket will obviously have a stirring effect on the leaf. On the other hand, if this projection has any sharp edges it will cut and the trials with the cotton reel device shewed that this cutting effect can be very marked. The smooth cone was too smooth and the cotton reel too angular. A projection from the door into the jacket not only stirs the leaf but also may exert considerable pressure (in the form of a squeezing action) on any leaf caught between it and the jacket. Figure 2 illustrates this point.

This squeezing action is important. The Annual Report for 1933, p. 59, gave figures shewing actual pressure exerted by a pressure cap device. Under the hardest rolling condition the pressure exerted by the cap is only of the order of 1 lb. per sq. inch which is negligible in its effect upon leaf. The pressure cap clearly exerts its effect by stopping or restricting circulation and causing the bulk of the leaf to be dragged over the battens which are thus used as an abrasive device. The experiments with the Clivemeare roller shewed that direct pressure could be employed with advantage to liquors and infusions. The Annual Reports for 1942 and 1943 describe experiments in which this direct pressure was combined with normal rolling in an attempt to speed up the process as a whole. Teas equal or better than those from the standard five-roll programme were by this means made in two 30-minute rolls.

The application of pressure in the gap between the projection and the roller jacket therefore offered the possibility of introducing a "Clivemeare" effect in an ordinary roller. An attempt to accentuate this effect was made with a device indicated in Fig. 3. The inclined plane had the effect of concentrating the leaf on one side of the roller and feeding it into the pressure gap designed to apply the squeezing action. The theory of this device worked well but it proved to be too hard on the roller which would have to be strongly built and fitted with a counterbalanced fly wheel to counteract the irregular motion caused by this sudden resistance when the jacket closed on the pressure gap. It became obvious therefore that all projections must be of regular shape and placed centrally so that the motion in the roller is regular ; otherwise severe mechanical difficulties arise. The pressure must therefore be applied in an epicycle. Subsequent experiments have shewn the pressure gap to be the most critical part of the device. It is therefore proposed to refer to this method as Epicylic-Pressure Rolling which term will cover all our experimental devices, as well as the commercially developed fittings. Epicyclic-Pressure Rolling can be conveniently abbreviated to E. P. and covers all devices which are symmetrical in form and which are fixed in the exact centre of the roller table. The abbreviation "E.P." is preferable to the use of the loose term "cone" as a preface to this particular form of tea roller. E.P. Rolling is therefore a general term embracing the commercially developed "Pressure Column" and "K'bacra" or Cone fittings as well as all our experimental devices. The essential differences between these various devices are more in methods of fitting and support for mechanical strength than in principle.

The pressure which can be applied in the gap between the projection and the jacket is of a very much higher order than

the 1 lb. per sq. inch or so applied by the ordinary pressure cap, and opens up possibilities for considerable improvement of liquor and infusion. At the same time the smashing effect easily spoils the appearance of rolled leaf and the whole question of design eventually reduces itself to an adjustment of these two factors. Until teas are sold on the open market it will be difficult to find just what the market value of fine appearance will be in post-war circumstances and where to strike the balance between making the best possible liquors and maintaining a traditional appearance. Tradition in the appearance of black teas is the bugbear of all experimental work in tea manufacture. It is well to emphasise these antagonistic factors because, until teas are sold on a free and open market, it is impossible finally to fix or advice on any final design, and estates contemplating the conversion of normal rollers to E.P. rollers should bear this in mind. In our experiments we decided to work on designs which would give normal appearance or in which appearance is only slightly inferior to normal but more than compensated for by improvement in liquor. It must be remembered, however, that it is asking a lot of tea tasters under present circumstances to give an opinion on the extent to which improved liquors can compensate for choppy or brownish appearance. The factors influencing design of E.P. devices for further experiments were therefore :—

1. The gap between the projection and the jacket which must ensure a positive squeezing action. This action must not be severe enough to cause any marked amount of smashing and tearing.

2. The projection must be large enough to cause a rapid and complete circulation of leaf without any areas of stagnation.

3. The device must be shaped so that it does not present any severe cutting edges (at least for the first stages of the rolling programme).

The inclined plane shewn on the device illustrated in Figure 3 had a very successful scoop-like action and was incorporated in the next design. One requirement, namely that there shall not be any stagnant areas, was met by this scoop which eliminated any tendency towards caking of leaf at the foot of the projection. The projection was therefore sloped at the bottom and gradually merged into the roller table as shewn in Figure 4. As the jacket moves towards a projection with a slopping bottom, the leaf tends to be pushed up the inclined plane. In order to prevent this from nullifying the squeezing effect it was found desirable to provide a recess or pressure gap of the form shewn in Figure 3 ; only it was of course necessary to adhere to a symmetrical figure. The only possible way of doing this was to continue the slope of the inclined plane and turn it in an outward direction to form a recess as shewn in Figure 5. The figure formed by doing this again resembled the cotton reel which was found to be too vigorous in action and so it was necessary both to restrict the size of the top and to round it off. The figure so obtained resembles a collar stud and is shewn in Figure 6. Most of our experiments during the past eighteen months have been with the Collar Stud Device.

DIMENSIONS OF E. P. ROLLING FITTINGS

Having arrived at a suitable shape, the next thing was to decide on size. It is well to emphasise straight away that size will vary considerably from roller to roller, and also to stress the fact that we have not up to the present time been able to tackle the problem of working out the optimum sizes for all different types of roller. Our work has been almost entirely restricted

PLATE II.

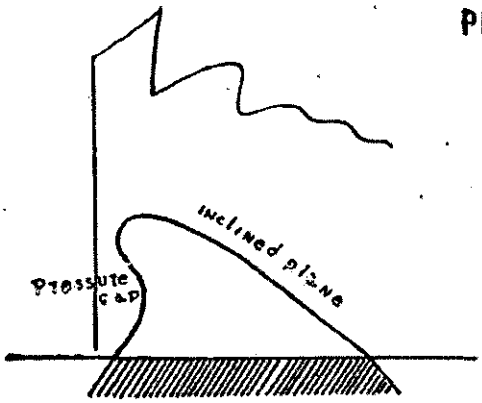


FIG. 3

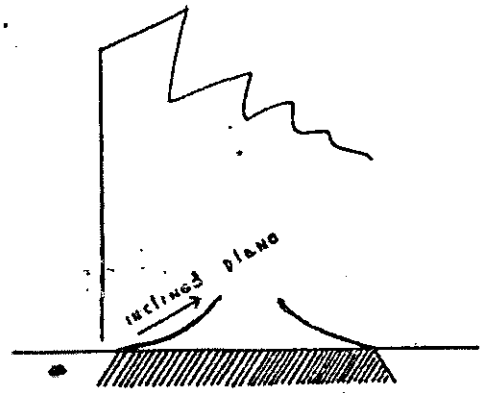


FIG. 4

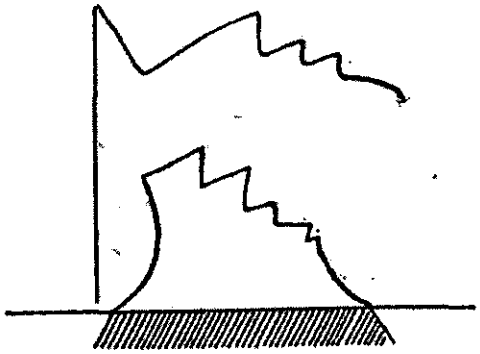


FIG. 5

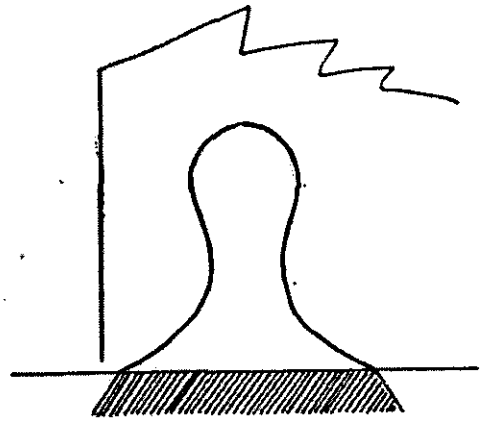


FIG. 6

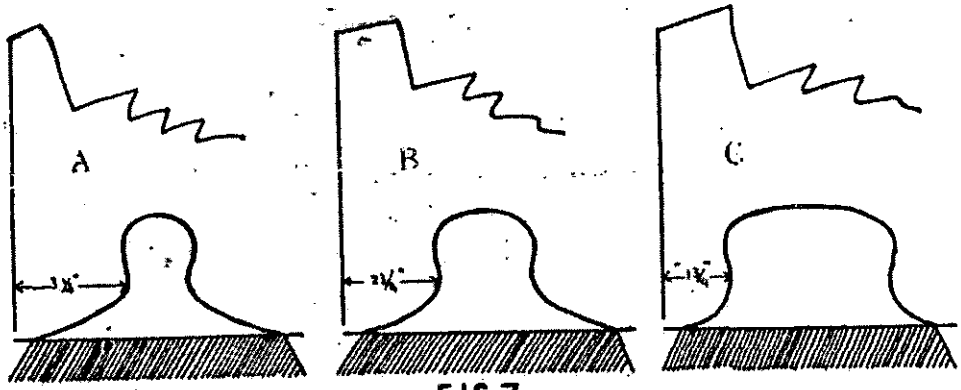


FIG. 7

PLATE III

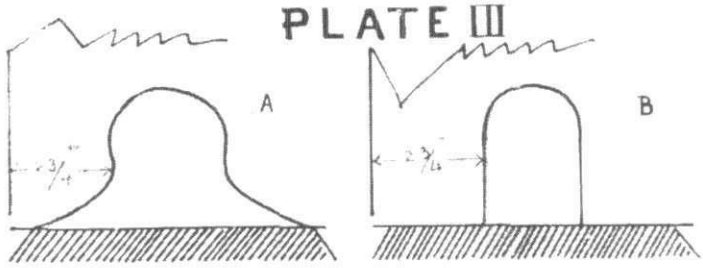


FIG. 8

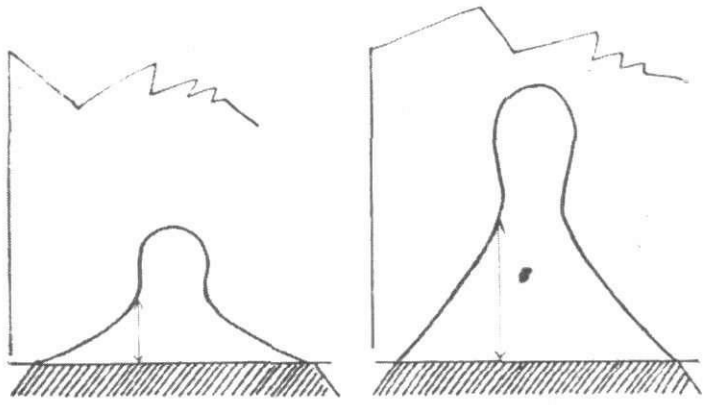
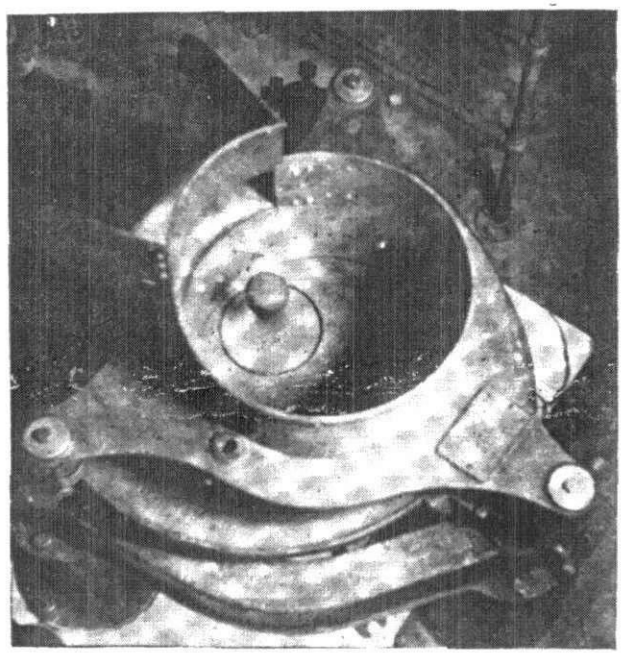


FIG. 9



"Collar Stud" Device in Small-Scale Roller.

to our experimental rollers and to investigations of general principles. Size will vary with the following characteristics of a roller :—

(a) Action — Double or Single.
(b) Crank throw.
(c) Dimensions of jacket.

It should be noted that E. P. rolling is only applicable to circular jackets. It may be possible to apply it to an octagonal jacket but results would be at variance with those in a similar size of roller fitted with a circular jacket. The general principle appears to be that width and not height of the projection is the most important dimension. The height may be restricted so that the door will open without hindrance and also to minimise strain, since a tall projection will put much more strain on the door than a short one unless supported in the manner of the C.C. Co. "Column." A height approximating to half the diameter of the normal door appears to be sufficient. Doubling this height was found to have a negligible effect on dhool production. The width is most important in so far as it affects the gap between the projection and the jacket. Figure 7 illustrates a series of battens tested on one of our experimental rollers and shews three different sizes of gap. The performance is shewn in Table I

TABLE I

Gap size	% 1st Dhool
A 3¼ inches	29
B 2¾ „	60
C 1¾ „	Much too severe action

If the gap is increased much beyond 3¼ inches. The dhool production falls rapidly. The slope of the inclined plane also has an effect on dhool out-turn. If the inclined plane is eliminated, dhool production falls. The two devices shewn in Figure 8 both allow a 2¾ inches gap but Table II shows a marked difference in performance.

TABLE II

Device	Dhool
A ...	60%
B ...	42%

It will be noted that the slope on all three of the devices shewn in Figure 7 is identical. If an increase of slope is incorporated on a projection of increased height, then dhool out-turn will be increased and this may be mistaken for an effect due to height. The devices shewn in Figure 9 will differ in dhool out-turn by about 15 per cent. The steeper slope also, in effect, reduces the average width of the gap. Investigations of factors influencing design are complicated by a further characteristic of E. P. devices which is the variation of dhool out-turn with charge. E. P. rollers are much more sensitive to charge than ordinary rollers and Table III shews the variation of dhool out-turn with charge in a typical E. P. roller.

TABLE III

Charge	Out-turn of dhool
40 lb.	56%
30 „ (Normal charge)	60%
20 „	43%
10 „	10%

The performance of an E. P. roller must therefore be judged on a standard charge otherwise results will be found to be very confusing.

SPEED AND POWER CONSUMPTION

The initial power consumption for a first charge in an E. P. roller tends to be rather high. It falls rapidly and at the end of 20 minutes attains a comparatively low level, considering the effectiveness of the rolling. Speed markedly affects power consumption but there are no compensations by way of increased dhool out-turn or quality. The relation between power consumption and speed and dhool out-turn are shewn in Table IV. They refer of course to a small scale roller.

TABLE IV

Speed of roller (Double Action)	Peak power consumption	Power consumption at end of 20 min. roll	Power consumption in second roll	Dhool out-turn over standard period
76 r.p.m.	2 K.W.	1.25 K.W.	0.6 K.W.	53%
49 r.p.m.	1.5 K.W.	0.75 K.W.	0.5 K.W.	47%

(The Tasters did not find any difference between the teas made).

In future experiments we must investigate slower speeds. There is nothing to be gained by running rollers above 49 r.p.m. while the initial power requirements are greatly increased by increased speed. It is possible that the initial power peak would be lower at even slower speeds which is most important because sharp peaks in power requirements are uneconomical. Certainly, it is useless to attempt to increase the efficiency of the rolling process by increasing the speed of rollers.

different methods on dhool out-turn and grading percentages was negligible. Working with a single standard charge and feeding the bulk back into the same roller after each roll breaking the results shewn in Table V were obtained. The total dhool out-turns were low because the charge fell below the normal 30 lb. in the second and third rolls. As only one roller was available at the time of the experiment it was not possible to combine charges.

TABLE V

Rolls	Total Dhool	Grading of Dhools (by Standard Method) B.O.P. %	F.P. %	Fannings %
1 × 60	60%	35	5	7
2 × 30	59%	37	9	6
3 × 20	63%	41	10	4
4 × 15	64%	38	12	4

ROLLING TIME

A total of 60 minutes' rolling time appears to be sufficient for normal results. Four different methods of use have been explored.

1. 1 × 60 min. roll
2. 2 × 30 min. rolls
3. 3 × 20 min. rolls
4. 4 × 15 min. rolls

Tasters gave slight preference to the teas from 3 × 20 minute rolls. The effect of the

The figures shewn in Table V were obtained on different days with different type of leaf. Each method of rolling was repeated at least six times and compared with a normal programme of 4 rolls on ordinary rollers. The interesting point of these experiments is the reproducibility of the results. Using a given quantity of leaf, the amount of work is directly proportional to the length of rolling and the effect on

grading percentages is constant and reliable. The actual percentages of 1st dhool were :—

(a)	4 × 15 min. rolls	32%
(b)	3 × 20 „ „	38%
(c)	2 × 30 „ „	42%
(d)	1 × 60 „ „	60%

The reduction of charge in the cases where there were second, third or fourth rolls, was automatically compensated by reduction of dhool percentage so that the total dhool production for 60 minutes rolling, whatever the rolling programme, was the same and the grading percentages unaffected. This characteristic is approximately common to all types of E.P. rollers and makes standardisation of dhool out-turn and grading percentages a simple matter in a rolling programme employing E. P. rollers.

GRADING PERCENTAGES

Over a very wide range of designs E.P. rollers give normal grading percentages. Two typical cases are shewn in Table VI where the grading percentages of teas made with a medium and severe type of collar stud projection are shewn.

ECONOMIC ASPECTS

The possible economic advantages of E.P. rolling are considerable. Our experiments have been planned to take the fullest advantage of them whilst turning out teas of quality equal to those made with rollers fitted with ordinary battens. The possible advantages are :—

(a) The output of each roller is practically doubled since rolling is completed by three 20 minute rolls (60 minutes total rolling) against the normal practice of rolling at least four periods of half-an-hour each (120 minutes total rolling).

(b) The elimination of the pressure cap and the necessity for application and release of pressure at frequent intervals makes it possible for one man to manage more than one roller. The pressure cap hinders charging, especially first rolls, and with an open top a chute can be made to discharge straight into a roller without any manual assistance and without spillage.

TABLE VI

Type	% First Dhool	% of leaf graded (Dhools)	Grading % B.O.P.	F.P.	Fannings	Dust
Collar stud, gap 3¼ in.	29	63 (from 3 rolls)	41	10	4	2
Normal battens 4 roll programme	13	59 (from 3 rolls)	38	9	6	2
Collar stud, gap 2¾ in.	59	80 (from 2 rolls)	49	10	10	3
Normal battens 4 roll programme	11	80 (from 4 rolls)	51	11	9	3

The introduction of E. P. rolling need not therefore cause any marked changes in grading percentages.

(c) Using a plain table the jacket of the roller may be lowered to within a very small clearance of the

table and any possibility of "throw-out" is eliminated. Taking this into consideration together with (b) one man should manage three rollers.

(d) The power consumption although higher than normal in first rolls is by no means increased in proportion to increased output. It has been pointed out that the power peak may be reduced by running rollers at lower speeds.

SUMMARY AND CONCLUSIONS

Emphasis in this final section must be laid upon the fact that E.P. rolling (E.P.= Epicyclic Pressure which principle is employed in "Column" and "Cone" rolling) is still in its earliest experimental stages. There is little doubt that this method will eventually displace rolling on tables studded with battens but the method may be brought into disrepute by over-hasty conversions. Our most earnest advice to any one wishing to make the change is first to be patient and secondly to consult Messrs. the Colombo Commercial Co. or Messrs. Davidson & Co. who have accumulated a considerable amount of experience of the commercial application of E.P. rolling and who have more actual experience of the *commercial* application of this method than we have at the Tea Research Institute. Our work so far has been mainly concerned with the fundamentals of rolling in general and latterly with E.P. rolling in particular as a logical development of fundamental investigations. We have no hesitation in claiming that since this fundamental investigation started we have succeeded in clearing up much of the mystery and misunderstanding which surrounded the rolling process, and even if we have not been able so far to make definite recommendations for specific designs of tea rollers, we have at least stimulated, encouraged and co-operated with both individuals and engineering firms interested in tea manufacture. We hope that our further experiments will enable us to recommend specific designs for new rollers or for alteration of existing patterns. Types of rollers now in use are however so diverse that much will depend on co-operation and advice from engineering firms concerned with tea machinery. Apart from our advice to avoid undue haste in converting rollers, there are two further conclusions which arise out of the work described in this article :—

1. The first is that the E.P. rolling is most suitable to a batch of rollers The conversion of single rollers to "see how it works" may prove most unsatisfactory. Since dhool out-turn is so dependent on charge, a properly planned rolling programme is essential. E.P. rolling is most unsuitable where the "muddle through somehow" type of rolling programme is employed and again emphasis is laid on the fact that *the rolling programme must be carefully and accurately planned.*

2. The second conclusion is that separate rollers are desirable for first and last rolls, that is for twisting and cutting. Both Messrs. Davidson & Co. and Messrs. the Colombo Commercial Co. are experimenting with devices which may be changed to enable the conversion of the roller from a twisting to a cutting type for rapid reduction of bulk. We are not entirely in agreement over this matter but engineering firms must of course supply customers' demands. We think it is wrong to expect a tea roller to do two different types of job "at the touch of a change-over lever." Almost any projection with sharp edges will give a high dhool out-turn but tend at the same time to cause a choppy

appearance. The regulation of the intensity of the pressure in the gap between the projection and the jacket, employing a relatively smooth shape of projection, is in our present view the best way of regulating dhool out-turn.

Generally speaking, estates are advised against their own experiments with E.P. rolling unless the Superintendent is prepared to spend a good deal of time on personal supervision and to keep very careful notes and records. From the description of our own experiments it will be obvious that rolling experiments are fraught with many pitfalls, and that much arduous repetition is necessary before there can be any certainty about a result. A fraction of an inch on the size of a fitting where it affects the pressure gap is very critical over a certain range and the mechanical strain is also severe unless the fittings are properly designed and supported. The average estate carpenter is unlikely to make a success of such fittings and the chances of doing severe mechanical damage are considerable. Our advice in brief is therefore to consult an engineering firm with experience of the method rather than attempt to use "home-made" fittings.