THE FOUR-ROLLER MILL

By R. H. RENTON

The limitations of the conventional three-roller mill have become increasingly apparent over the last few years. These limitations have prompted the Darnall Mill Management to design a mill to overcome all the main disadvantages of the existing mills, and by using the existing rollers, bearings, etc., either an existing mill could be converted virtually for the price of a pair of headstocks, or if a new unit is installed, the spares would all be interchangeable. The object of this short paper is to present this design in the hope that it will promote some discussion and constructive criticism.

Let us look at the conventional three-roller mill with a vertical hydraulic. It will not be disputed that the thrust on the hydraulic is certainly not vertical but inclined considerably towards the discharge roll. This means in effect that the top roll rides on the blanket between it and the discharge roll. Unfortunately as the top roll lifts the feed setting opens and lets in more bagasse which lifts the top roll further. This system is obviously unstable; the top roll will go on rising until the feed opening has lost sufficient grip to feed the discharge opening. The mill will slip until enough fibre is cleared through the discharge opening to allow the top roll to drop and start the process again. This is in fact what happens at Darnall and is shown quite clearly by the hydraulic pressure recording charts.

It is felt that this is a fundamental drawback. We are trying to maintain a system in equilibrium, i.e. with the top roll "floating", and the system is basically unstable. This problem is appreciated at least in Australia, where either fixed rolls or discharge hydraulics are apparently quite common. Another idea is to limit the width of the feed chute.

The other main factor, and undoubtedly the most important, in pointing the way to a redesigned mill is the considerable success with which the underfeed roller has been applied at Darnall. It has been found repeatedly that the closer the setting of this feed roller the better the mill performance. The only severe limitations on settings at present is in making a strong enough drive.

The step from the existing underfeed rollers to a fourth mill roller is not a big one and is only a logical development. However, it is felt that the design of the four-roller mill overcomes all the snags of the three-roll mill, without introducing the complication of a pressure feeder, and having the same or perhaps better performance than the pressure fed mill.

The design is shown in the illustration. The unit is fed through a vertical gravity chute, the feed roller being set slightly below the top roll to facilitate the drainage of the first expressed juice, particularly from the front of the feed chute. A conventional trashplate transfers the bagasse to the second squeeze on the bottom roll and then a second trashplate transfers it to the discharge opening. The discharge direction is practically vertical upwards so that maximum use is made of gravity in draining the meschaert grooves.

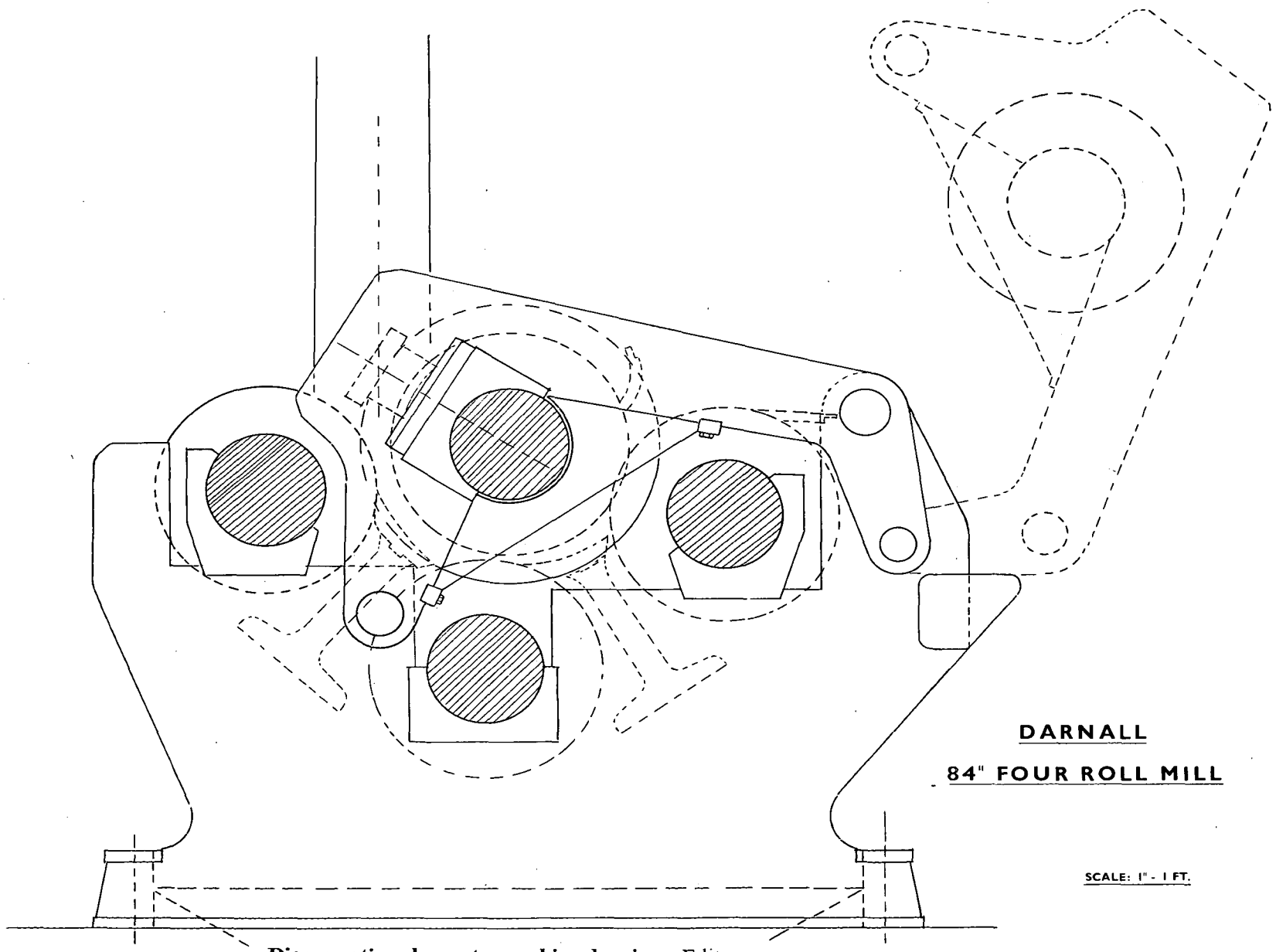
The hydraulic is inclined towards the discharge roll so that when the top roll lifts it actually closes the feed opening. This form of negative feed back will make the system absolutely stable.

The drive for the feed roller would be through a set of gears from the pintle end of the top roller.

A lot of thought has been given to stripping the mill quickly and this has been achieved by providing a hinge pin so that the whole top roll assembly can be swung back into the position shown in dotted lines. This exposes all the bottom rolls for easy removal and more especially the trashplates. The ease of replacing trashplates is of prime importance when these have to be replaced about three times during the season as is the case at Darnall.

It is obviously impossible to forecast results for such a unit, but as the existing Darnall first mill has achieved 70 per cent extraction, it would be reasonable for a unit such as this to achieve between 75 and 80 per cent in the same position and with the same fibre loading.

It is worth comparing this mill with the conventional mill fitted with a pressure feeder. Both mills effect three squeezes on the bagasse but it is felt that the four-roller mill has considerable advantage in simplicity and cost.



Diagramatic only—not a working drawing—Editor.

Mr. Gunn (in the chair): I do not quite agree with Mr. Renton that the three roller mill is unstable. Admittedly when the top roller lifts, the feed opening does increase, and you therefore should feed more bagasse or cane into the mill, but the discharge opening has also increased, and the ratio of increase of opening of the front, or the feeder opening, to the discharge opening is totally different. If one assumes that the top roller lifts a quarter of an inch, the effective opening on the fee droller in relation to its total opening will be far less than the effective opening of a quarter inch on the discharge opening. In itself this gives you negative feed-back, because the moment the roller lifts you are altering the ratio between your feed opening and your discharge opening.

Mr. Renton: This is not negative feed-back—it is actually positive. Although the ratio does help, it is reducing all the time as the roll lifts. If the feed opening on the roll opens, then without any further slip the amount of bagasse left in there must go through the discharge opening. The further the feed opening opens, the more bagasse it lets in, which still has to go through the discharge opening, and if this causes the discharge roll to lift further, then the system must be unstable, because as it lifts more, it will in turn let more in the front. The only way to get it stable again, is to stop the lift on the feed roller letting in more bagasse, or in the case of a negative feed-back, let less in if the discharge lifts. Mr. Gunn has pointed out that having a negative feed-back is a little confusing, because it does help the effect of the differing ratios as the top roll lifts, it helps to stabilise it, but it still does not make it stable, because the discharge roll still has got to lift to accept the wider opening of the feed roll. As soon as it starts lifting, it goes on lifting until something slips.

Mr. Gunn: Mr. Renton, I heartily approve of the design of your mill, but for the sake of discussion I wish to elaborate on this difference in the openings of the feed and the discharge of the mill. The fibre index of the bagasse going through the feed opening is such that it is possibly half that of the fibre passing out the back of the mill. Now, if you increase the feed opening by a small amount, which is the lift of the roller, and keep the same fibre index going into the mill, that increase on the discharge opening of the mill will decrease the fibre index of the bagasse going out of the mill. The relative increase in size of your opening of the discharge of the mill, to your initial setting, is relatively bigger on discharge than it was on the feed side. To confuse the issue this again gives you a negative feed-back. I do not disagree with you at all, I think your design is very good indeed, but I cannot accept the fact that a three roller mill, as it is, is unstable. I would like to put the point of view that your hydraulic charts which have shown great improvements, have possibly done so because you have improved the feeding.

Mr. Renton: I mentioned that we were always faced with a violently fluctuating hydraulic chart, and the only way, apart from letting a mill slip, in which case you get a beautiful straight line, the only way we have been able to get a fairly stable chart has been by limiting the feed chute. We have not gone quite as far as Mr. van Hengel recommends, but on our last mill we have had a chute with a ratio of about 10 on the work opening. That did decrease the jumping or fluctuations on the hydraulic chart. As regards your other point about the fibre index, I do not think that the change in fibre index on the feed makes any difference to the discharge, I think the fibre index on the discharge is pretty well fixed by the general feeding arrangement of the mill.

Mr. Main: I think we all owe a vote of thanks to Mr. Renton for the discussions he has started over this. As you know, this has been a thorny problem for many years in the sugar industry, and engineers have tried to solve it in various ways. If this Darnall design now provides the answer that engineers have been looking for, it is a terrific feather in the cap of the South African industry, and particularly you, Mr. Renton, and your colleagues. I have looked at this design, and one thing that worries me a little is the angularity of the hydraulic pressure arm on the top roller. That indicates that you are putting far too heavy a load between your top and discharge rollers to get good feeding conditions. If you have an excessive proportion of load to your top and discharge roller, it does tend to block you feed. Unless you have a compensating hydraulic on your feeder roller, I am rather worried about how you are going to achieve your balance.

Mr. Renton: Mr. Main, that angle is drawn with a ratio of five to one. That is, the load between the discharge and the top is five times that between the discharge and the bottom roller. This is a guess. Apparently Walkers in Australia have done some measurements on this, and they quote between five and seven times as much load between the discharge and the top and the discharge and the feed rollers. I think it should go down to about four. The point is that the load is actually there whether you have got the hydraulic in that direction or not. With our vertical hydraulic, it is the front part of the bearing that always gets worn out, the bearing is always hot. Just from having a look at the wear pattern, you can get a good idea where the thrust is, and it is very much like that.

Mr. Main: You offset the roll to get the balance, and by off-setting an hydraulic at the top of your pressure plate you can get a balanced bearing?

Mr. Renton: The hydraulic is usually offset a little to the front to balance the bearing. In our case it is, but it is still not enough, this bearing runs at that angle, and the wear is here.

Mr Ashe: In reply to Mr. Main, I would like to suggest that he just tips his paper up slightly, and he will find that the angle is not excessive at all. It is an ordinary conventional two roller mill, turned slightly on its side. It looks excessive because it is not drawn in the plane in which we are accustomed to see a two roller mill. Regarding Mr. van Hengel's paper, I would like to ask him what provision to make for the sudden changes of fibre that we get at Umfolozi, for instance, one minute our mills will be running on a low fibre, then we switch over to S.A.R. and are on to high fibre cane, and everything starts choking up so we have to start adjusting all round. We have not got a

chute, but is it the bin capacity of the actual chute that would take care of that?

Mr. van Hengel: I hoped these questions would be asked. With a conventional chute, as it gets empty, we have to slow down, or if we have a very high rise of the roller we speed up a little bit. Now, if we have a feed chute which limits the amount of cane going into a mill at a set speed, we are at times going to get more fibre because of the fact that the cane might have 1 or 2 per cent. more fibre. Therefore the bin becomes fuller, and the mill should be speeded up. Instead of trying to run a mill on a varying lift at a constant speed, we are going to have a constant lift at varying speeds. It should be tried out first, because it is at present only in the blue print stage, but it is a very easy way of eventually having a mill automatically driven, for as soon as the bin is full, it speeds up the turbines, or the engine, and if the bin is empty, it slows down until more bagasse or more fibre arrives. It requires rather a sensitive and easy system of speed variation. This shows the big advantage of these narrow chutes.

Mr. Pole: Do you think that with closer-set feed chutes, bridging at the top of the feed chutes will be a problem, especially where preparation is not adequate, and if so, what measures or designs would you suggest could be incorporated to prevent bridging, especially in the front part of the milling frame? At Illovo where we have fairly good preparation, with trashy cane we do have fairly serious bridging on the first and sometimes second mill chutes, although there are some other factors in design which also influence this.

Mr. van Hengel: Bridging could be a problem—with a narrow chute and a carrier running at a speed of 120 feet per minute, the bagasse may not go down easily. Maybe imbibition liquid washing down the cute would prevent bridging. Or possibly a moving conveyor or rubber belt could be fitted to the top of the chute.

Mr. Gunn: I have seen designs of the latest chutes as used in Australia. Of course Australia is not four-roller mill conscious, but rather five-roller mill conscious, and is tending towards seven-roller mills. At the very top of the discharge side of the feed itself they have a small feeder roller which is driven through gearing from the head shaft of the carrier. When there is a tendency to bridge this small feeder roller pushes down the bagasse.

Mr. Bentley: I certainly support this design, and would like to see Darnall put it into practice. But is this, as the author says, much simpler and cheaper than the pressure feeder design. You are going to find that the geometry of this set up is going to be a little tricky, and in a mill today the one thing that gives you more trouble than anything else is the trash plate. When you put two trash plates there, you are going to have twice as much trouble as you already have in your mill. Added to that, you are going to drive a fourth roller through your existing top roller. We think you require something like 250 h.p. to feed the cane into the mill, over and above the 600 h.p. you are now putting into the mill to crush the cane. If you are going to put that additional force through the top roller, I think you are going to break quite a lot of top rollers during the season, unless you can get a very much better quality material than we have at present. I do not think it will be long, as you have just mentioned, before another two rollers are placed in front to pressure feed this four roller mill.

Mr. Renton: In connection with the trash plates. With our existing feed rollers juice is expressed with the first squeeze, especially in the mills after the first mill, and the juice is easy to get out because it goes through the drainage of the feeder roller and is re-absorbed in the expansion of the blanket before it gets to the feed opening. That is why we have put in another trash plate, to try and keep the juice from being absorbed in the blanket.

As regards the stresses on the top roller, most of the hydraulic pressure is in bending, which is taken by the shell and not the shaft. There is more torque on the shaft but even if 250 h.p. is required to drive the feed roller a 21-inch shaft should be able to carry this.

Mr. Kramer: I would like to add a few words in connection with the additional torque on the top roller. Mr. van Hengel and I attended a seminar in Australia in 1962 and we were given formulas to calculate stresses taken by a feed roller shaft. We did some calculations and we got figures in the region of 6-8 inches for a normal 66-84 inch roller mill. To my mind the actual loading on the feed roller shaft is small compared to the loading taking place between the top roller and discharge roller, so we do not have to fear too great an additional load on the top roller.

Mr. Dent: Most of us are not in a position to buy new head stocks for our mills so we must make the best use of what we have, and will therefore have to use feed chutes. We at Tongaat have had success in decreasing the width of our chutes, the mills have fed better with the narrower chutes, and I agree whole-heartedly with Mr. van Hengel, because the limiting factor does come in the feed opening at the top of the chute, and not at the bottom. If one was to design a chute with a theoretical opening, one would have to put two feed rollers or something like that on the top, and thereby create a vertical pressure feeder chute. We are trying one scheme this year which I hope will be successful in eliminating this bridging problem and that is continuing the back plate of the feeder chute vertically, and having the slats actually clear that plate, so that anything that does not go down the chute will be tumbled back into the carrier again. I hope that we eventually will not be landed with a ball of bagasse going round at the top, but that remains to be seen. I hope that Mr. Renton and the Darnall team are able to have one of these mills manufactured, and that in the not too far distant future Mr. Renton will be back reading a paper on the performance of his mill.

Mr. Renton: In our chutes the slats are already behind the front plates of the vertical chute, and we now are moving them further still behind, so that the bagasse has got more time to disengage before it gets pushed up against the front.

Dr. Douwes Dekker: Mr. Renton speaks about the limitations of the conventional three-roller mill, and about the snags of the three-roller mill. He does not make quite clear what he actually wants to achieve with the four-roller mill. It has one important difference from the three-roller mill, and that is three squeezes instead of two, so does he want to achieve a better extraction by applying, in one unit, three squeezes instead of two, or is that not his first aim? Now we all know we cannot get maximum performance from a mill unless the feeding is perfect. We have fluctuations in feed and we have fluctuations in fibre content of the material which is fed in. Does this four-roller mill aim at improved feeding on the three-roller mill in order to get a better extraction, or do you want to achieve a better extraction by applying three squeezes? In the normal mill we have three rollers, and to get better feeding we add a fourth roller, and we have a feed chute, and now that there is the danger of bridging it is suggested we should have two rollers on top of the feed chute. I think we should try and keep these things separate in our minds. What are we aiming at? Is it better feeding, or is it better extraction by more squeezing?

Mr. Renton: The two are bound up with one another. Generally, if one can stop a mill slipping, which is virtually making it feed properly, then it produces better figures. We are aiming at higher throughputs, because we are forced to have higher throughputs, that is what started this whole thing off. We want to improve the feeding, we want to put more tonnage through, in fact we want to do all that is claimed for the pressure feeder.

Mr. Cargill: The size of mill chosen by Mr. van Hengel as an example is just about the same as Natal Estates. If we refer to the last table in his paper, the width of the feed chute on the last unit, in our case, feeding just about 180 tons an hour, would be about 8 inches wide. Now I would hesitate very strongly before I considered using a feed chute 8 inches wide. I think we would have great difficulty getting it down the chute, or into the chute, even with imbibition washing it down. Has any one attempted putting in a high feed chute 8 inches wide and feeding 180 tons through it?

Mr. van Hengel: In the paper it is assumed no slip occurs, although there will of course be some. The ratio of 8 is purely theoretical and I think 10 would be more reasonable. But it does not matter what it is as long as the bagasse goes into the chute, because once it is in, it will slide down under its own weight. The difficulty is in getting it from a rather steep fast moving carrier, with upward movement, over a small angle and down into the chute. Possibly a small vertical apron carrier, driven by a single motor, could be used to force it in the correct direction. It might also help to force the imbibition liquid higher.

It is quite certain that a feed chute that is wide enough to take the feed easily will be the wrong feed chute as it will allow too much cane into the mill, causing sudden frequent changes in lift.

Mr. Cargill: Won't the set opening of the feeder roller obviate this heavy feeding? A setting of $7\frac{1}{2}$ or 8 inches should prevent excess bagasse being fed in.

Mr. van Hengel: I do not think so. Illovo last season had a heavy feeder roller on first mill feed chute, slightly smaller than the top roller. The feeder opening was seven times the discharge opening. The chute was set, following the Australian formula, at $\frac{D}{2}$. Tremendous choking occurred in the mill at unexpected places.

Mr. Cargill: Would not reducing the feeder opening also reduce the tendency to choke?

Mr. van Hengel: No, because a reduced feeder opening would increase the feed. Similarly, a wide feed chute will increase the feed so much that it will not go through. The novoid volume of bagasse, for the last or first mill, is about $3\frac{1}{2}$ times the escribed volume of the mill. With a ratio of five, you have 50 per cent. more volume than there is bagasse. Assuming your speed is constant, the more you bring in the more solid your feed will be, because you will not be squeezing out juice.

Mr. Bentley: If Mr. van Hengel is correct, if a mill has hydraulics on the back roller, then the back roller should move out to its maximum position and let the fibre pass through. I think the problem of mill feeding is more complicated, and that choking starts at the discharge opening, then the feed opening chokes and then the chute. Designers of chutes are nowadays advised to have an easily removed front opening, particularly if it is narrow, to facilitate digging out the bagasse when it chokes.

Mr. Rault: Darnall seem to have mastered the art of feeding as they get excellent results. Are they doing anything special apart from their large amount of imbibition?

Mr. Renton: We set the feed roller very close, i.e., 4.6 on the discharge work opening. The chain drive to the feed roller is set to break at 120 h.p. and it frequently does break, illustrating the power going into the roller. We have also virtually eliminated choking by using rough rollers.

Mr. Gunn: What is the correct position for the feed chute outlet? We have had a feed chute not working at all in one position and yet when it is moved a couple of inches it has worked perfectly.

Mr. van Hengel: Where a feeder roller is almost as big as the top roller, and the speed is constant and the opening horizontal, I think the centre line of the chute should go through the centre of the opening. If the feeder roller is smaller, the opening can be offset. There are different ideas about this.

Mr. Dent: What should the peripheral speed of the feed roller feeder drum be relative to the top roller?

Mr. van Hengel: The feeder roller should be moving faster than the rop roller.

Mr. Main: I agree with Mr. Bentley about the discharge roller. Closing the discharge opening definitely helps the feed roller.

Except in respect of vertical chutes, a lot of the work being done now in Natal was carried out years ago by Dr. Meinicke. My company banned the use of chutes and we got higher extraction without feeding troubles. I feel we are going to a lot of trouble and spending a lot of money investigating a problem which has already had a lot of attention in this country and elsewhere.

Mr. van Hengel: It is unfortunate that the Mutual Milling Control Project Progress Report No. 3 was not included for discussion with these two papers. In that Mr. Buchanan has introduced a new value, namely, Pounds Fibre per Cubic Foot of Total Roller Volume, crushed per hour, is divided by Lost Absolute Juice % Fibre, and this gives some very interesting figures. The paper also shows that although fibre throughput last year increased about 10 per cent., there has been no drop in efficiency. This surely indicates that we are on the right path to solving our milling problems, and as far as Lost Absolute Juice % Fibre is concerned we are possibly leading the world. When the size and cost of our milling tandems is considered, and the expense of additional fuel, then there is not much doubt that we can afford to spend money on feed chutes, particularly as some of them have proved extremely successful here. I must remind you that my paper is entitled "Suggestions for the settings of vertical feed chutes". The S.M.R.I. is trying to find the basic relationship between feeding and crushing; but all the evidence is not yet available. Finally, I must mention that both Darnall and Illovo have tried narrower settings with successful results.