THE DESIGN AND DEVELOPMENT OF A SIMPLE CHOPPER HARVESTER

By J. R. PILCHER

SA Sugar Association Experiment Station, Mount Edgecombe, 4300

Abstract

The development of a simple chopper harvester is described and ways in which this complicated machine might be simplified are suggested. The decisions taken and some of the specially designed components used in building the machine are described and the difficulties experienced during its operation and their solution are explained.

Introduction

As long ago as 1979 it was decided that a small, relatively inexpensive chopper harvester for burnt cane should be designed, primarily for use in the northern parts of the South African sugar industry. The machine would be based on a farm tractor and for it to function properly, a hot burn would be necessary to remove most of the trash and top leaves from the crop to be harvested. The remainder would be removed by accurate topping before base cutting.

The essential components of a chopper harvester are the topper, base cutters and the chopping mechanism into which cane is conveyed by feed rollers. The elevator of the conventional chopper harvester was the only section which could be simplied. Alternatives were considered and the first of these was pneumatic conveying but this proved to be impractical and so was abandoned.

The second alternative was to throw the cane into the trailer and this was tested using a rig driven by an hydraulic motor. It consisted of a 1 200 mm diameter rotor with a flat back plate on which paddles were fitted to the outer half of the radius. An annular-shaped front plate with an outside diameter of 1 200 mm and an inner diameter of 600 mm, was attached to the other end of each of the four paddles. This was mounted in a circular housing which had a tangential outlet towards the top. Cane billets which had been cut previously were fed into the opening in the centre and thrown out the top of the drum; a system which worked well.

At about the same time, Santal in Brazil had developed and patented a similar principle but they had made more progress and were operating several self-propelled machines known as 'Rotors'. Santal agreed to co-operate with the Experiment Station in developing a "Mini Rotor" which was based on a standard tractor.

Design

Santal supplied the cane handling machinery which included the base cutters, feed rollers, chopping mechanism and rotor, croplifters and the two extraction fans. The Experiment Station provided the topper, the duct, a Fiat 1300S tractor and the rotor and pump drives together with all the hydraulics.

The construction guidelines provided by the Brazilians suggested driving three of the five pumps off the front of the engine and the other two off the pto. A chain drive to the rotor via a shear pin also from the pto was suggested. Extra pumps cannot be driven off the front of the crankshaft of the Fiat because it accommodates the internal hydraulics pump and an extension shaft cannot be fitted to the front casting. All external hydraulics would therefore have to be driven from the pto.

A slip clutch rather than a shear pin was used on the rotor drive. Santal advised that the rotor would absorb 15 kW but that a shockload of 45 kW should be allowed. The design of the slip clutch was based on these parameters, but torques greater than those corresponding to 45 kW result if the rotor jams.

The clutch was combined with a flywheel type flexible coupling. Behind the clutch which served to protect only the rotor, the shaft passed through a plummer block fitted with a two row, spherical roller-bearing and was extended to carry the triplex sprocket which completed the chain drive from the pto. A pto shaft that was 1¾" (43 mm) diameter, instead of the standard 1⅜" (34 mm) was fitted because of heavy sideloading resulting from chain pull at full load. The rotor drive-shaft with a speed of 240 rpm, was extended behind the plummer block bearing to carry a gearbox which was designed to drive three hydraulic pumps at 1 700 rpm.

The rotor

The rotor consisted of a 600 mm diameter, 500 mm long drum onto which two heavy paddles were bolted radially and 180° apart. Two blades were mounted on an extension of the rotor shaft 150 mm in front of the front face of the paddles, but outside the paddle casing. There was a radial clearance of about 10 mm between the paddles and the casing but this varied because of inaccurate manufacturing. Cane was fed into a rectangular opening below the drum and was cut by the knives which preceded the paddles by about 30° in the direction of rotation, thus only cane which had already been chopped into billets would be picked up and thrown up the chute by the paddles.

The chute

A detailed drawing for this section was received from Brazil but in their design it was fixed to the rotor casing. The height of the chute did not conform with the requirements of the South African Road Ordinance, so a turn-table and hinge were built to allow the chute to fold to within the acceptable limits. This was a very necessary feature and it provided easy access to the rotor when it became blocked.

Base cutters and feed rollers

The designs of the base cutter and feed roller were similar to those of the usual chopper harvester with twin base cutters. The diameter of the top rollers was larger than the lower ones and they were mounted on a common hinged frame. A bundle of cane coming through would have to lift the whole frame and the three rollers mounted on it, thus giving it a positive drive. The rollers were open and had coarse serrations on the bars. They all had one hydraulic motor except two, which had two each. The foremost and lowest pick-up roller which had three bars, was mounted just above the discs of the base cutter immediately behind the shafts.

Croplifters and topper

The croplifters were of a conventional spiral design on parallel shafts, and turned inwards. The croplifter shoes were very large and were later modified because trash tended to accumulate around them. A single hydraulic motor was used in the topper for which a standard design was used.

General

The parts supplied by Santal were for a full sized, self-propelled machine which normally has a 150 kW engine. There were no difficulties in building the machine except that it could not be wider than 3 500 mm which is what the South African Road Ordinance allows for agricultural machines. The 20,8 x 38 tyres supplied with the tractor made this difficult.

During construction, particular attention was given to guarding the chopping knives which were on the left-hand side of the machine and in line with the operator's legs. They were completely unguarded at the front and side so a 10 mm shroud was placed around the periphery and an expanded metal screen in the front. A tangential duct was left on the tractor side and pointed downwards so that trash and debris could be expelled.

Hydraulics

The tractor's internal hydraulics were used to:

- raise and lower the machine so that the height of the base cutter could be controlled
- raise and lower the topper
- raise and lower the croplifters which are allowed to float in the lowered position
- raise and lower the chute
- rotate the duct
- open and close the hood at the top of the duct.

Two double pumps, each delivering 100 and 50 litres oil/minute, were driven off the gearbox at the back of the machine, Of the total volume, 100ℓ/minute was used to drive the two fans which were run in parallel, and the 100ℓ/minute which was used to drive the feed rollers, was halved by two motors on a common shaft. Fifty litres/minute was used in one base cutter, croplifter and topper and another 50ℓ/minute in the other base cutter, croplifter and later, the comb.

The whole mechanism, except the rotor, was reversed by dumping the 100ℓ of oil per minute from the feed roller drive into the tank, and by passing the 2 x 50ℓ of oil per minute to the base cutters, back through the feed roller drive in the reverse direction. This was achieved by the simultaneous operation of two levers.

Cassappa gear pumps were used. All the feed rollers, the croplifter and topper were driven by SAM hydraulic motors; the base cutters by 3 000 series Charlyn motors; and the fans by Commercial gear motors. A Ross MAE motor was used to slew the duct.

Early Development

The design of the cane handling part of the machine was proven so no difficulties were expected. It was therefore disappointing when the machine was used for the first time to cut green cane and it stopped after travelling a few metres because it was choked.

This was due partly to the fact that the clutch was slipping early, but mainly because the pick-up roller would not feed individual sticks into the machine. Cane was accumulating on the base cutters before the whole bundle was fed in, with the result that the machine would choke. This also occurred in burnt cane where it was found that the cane stuck sideways just behind the pick-up roller, thereby increasing the likelihood of a blockage.

The feed was significantly improved by fitting butt-lifting hoops onto the base cutters and by lowering and moving the pick-up roller behind the base cutters. Deflectors were also fitted to prevent the cane coming out sideways.

The quality of the billets was unacceptable because the ends were being bruised and they were being split longitudinally. The latter was found to be caused by the knives but the cause of the bruising was not so obvious. It was thought that the billets were perhaps not being thrown far enough in front of the paddles. This contention was supported by the fact that a number of billets were being knocked out of the machine. The effect was worse when single rather than large numbers of sticks were fed into the machine. To minimise the damage, a 12 mm 'linatex' rubber pad was fixed to the face of the paddles but it had no effect. A curtain of the same material was then hung 100 mm in front of the paddle and damage to the billets was reduced.

Once billet quality and the feed had been improved, an attempt was made to increase the amount of cane cut. Many tops and broken sticks accumulated in the space formed by the knife guard and the expanded metal aggravated the situation so it was taken off. The tangential chute was enlarged and its position changed but large quantities of debris accumulated on the machine around the opening to the rotor, especially on the left hand side. A cab was built so that the driver could be protected from the dust and ash.

Despite the modifications, billets were still being bruised and split longitudinally and their leading ends were being frayed as they were pushed against the knife. Some of the fraying was avoided when new blades with greater back-off were made to allow for the difference in the speed of the knife and the cane approaching it.

Longitudinal splitting of the billets was thought to be due to a knife speed that was too low. This was confirmed by work done by Novais[1] on the optimum speeds for base cutters. The knives were speeded up which had the added advantage of throwing the billets further into the rotor housing and of improving their attitude in relation to the paddles. The paddles, however, could not be speeded up because this was governed by the throwing requirements up the duct. The position of the knives relative to the paddles was important when cutting, so they had to be timed. This was done by means of an epicyclic gearbox mounted on the rotor shaft which had a speed of 240 rpm. This speed had to be carried through the gearbox to drive the rotor drum also at 240 rpm and at the same time, the shaft had to be extended beyond the drum to drive the knife.

The smallest whole number ratio which can be obtained with an epicyclic gearbox is 3:1, which gave a cutting speed higher than necessary but it was considered to be manageable. Three paddles and a single knife on the drum gave a much more even feed of billets into the trailers. Previously when there were only two paddles, the chopped cane fell from the chute in noticeable pulsations. A new knife with a 7° back-off and a 15° included angle, was also developed at this stage.

Santal suggested that the rotor housing should be slewed 7° to the line of approach to the cane. A motorcar tyre was used as a flexible coupling because the chain drive prevented the drive shaft from being moved. Billet quality is now acceptable and the rotor is responsible for very few losses.

To improve the flow of recumbent cane into the machine, a 'comb' roller was fitted in front of the base cutters and the direction of rotation and scroll of the left-hand croplifter (which usually operates in an anti-clockwise direction), was reversed.

When the epicyclic gearbox was installed, the hydraulic circuit was improved so that there would be less of a drop (heat build-up) in pressure across the reverse valve which was specially made in Brazil. This was done by passing the oil from each 50ℓ pump through 25 mm control valves operated by solenoids and from one of the 100ℓ pumps through two similar control valves. The other 100ℓ pump fed the fans as before. The pump feeding the drive train was increased by 17,5% to give a longer billet.

The flow control valves were operated by a single small valve which was fed with oil from the fan circuit to allow the machine to run forward, stop or reverse. This has eliminated the problem of a drop in pressure and hence wastage of power.

Commercial Operation

After the machine had been modified it operated on a commercial basis in sugarcane fields of the Hulett Tongaat Group. An attempt had been made to lay out some of the fields for mechanical harvesting, but conditions were not always favourable. The awkward shape of some fields with long rows at one end and short rows at the other meant that a lot of time was spent travelling between rows. Other factors which proved to be unsuitable for mechanical harvesting were lodged cane, low yields, steep slopes, damp patches and washaways, and very sandy soils. These meant that the machine had to operate in first gear for much of the time so fuel consumption was very high and productivity very low. (See Figures 1, 2 and 3).

Where the harvester operated in erect cane and on reasonable ground, fuel consumption improved as did the hourly output.

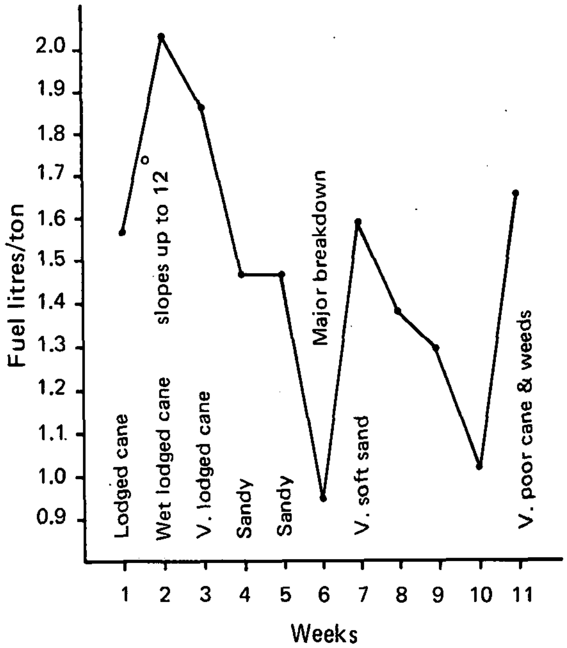

FIGURE 1 Harvester fuel consumption

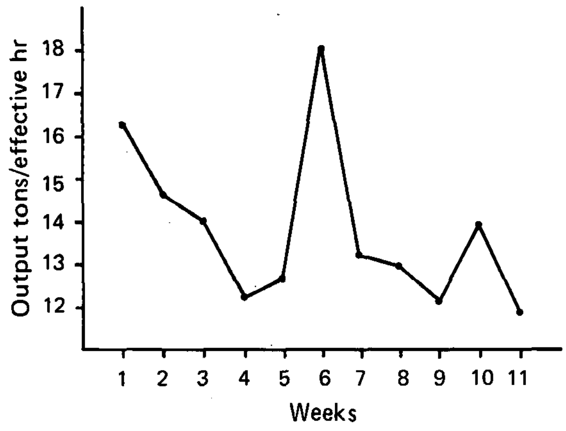

FIGURE 2 Harvester output

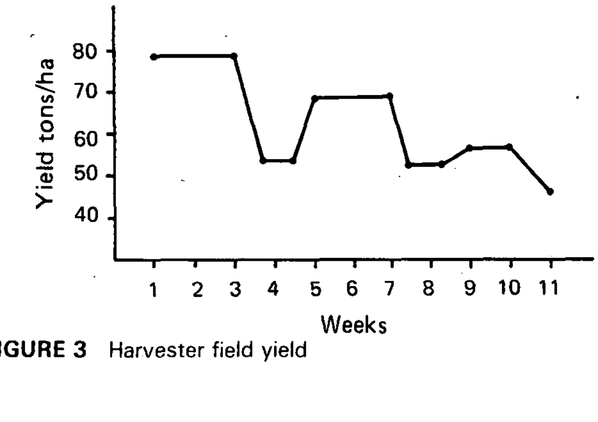

FIGURE 3 Harvester field yield

Because of the terrain and layout of the fields it has not been possible to assess losses caused by the harvester, as was done by de Beer *et al*[2] in Swaziland. Examination of the field in the wake of the machine indicated that the losses are minimal provided the machine is operated and maintained correctly. Trash is ejected from the two fans and by the knife, but most losses resulted from the trailers being overfilled.

Problems Encountered

After operating for six weeks, a bolt sheared off inside the epicylcic gearbox. The main gear of the pump drive gearbox had also worn so both were rebuilt.

Stones were responsible for most stoppages of the Mini Rotor, since they damaged or broke the knife. A blunt blade caused the rotor to jam if a large quantity of leaf was left after a poor burn. It wrapped around the blunt knife or was trapped between the paddles and the casing. The leading edges of the paddles became rounded with wear and created an effective wedge where fine material was trapped. Hardfacing and grinding a sharp edge on the paddles and backing them off 10°, has helped to overcome this problem.

The bearing housings of the top blower fan have also presented problems and although they have caused very little time to be lost, they need to be re-designed. The fan is a double entry, forward bladed unit, with the rotor carried on outboard spherical seat bearings inside a housing which forms part of the inlet shroud.

A row spacing of 1,5 m is the minimum required for the satisfactory operation of chopper harvesters. At Tongaat, rows were spaced 1,4 m apart and some cane in the adjacent row was trampled. Provided the base cutters are set low and the cane is not growing in a furrow, it is picked up when the next row is cut. Most of the cane cut has been from narrow stools and if the row spacing was any narrower the machine would have to be redesigned. Despite its width of 3,5 m, the Mini Rotor is very manoeuvrable. The wheel base is 2,27 m and its length, including the topper is 7,3 m.

Conclusion

Apart from the problems with the epicyclic and pump drive gearbox, the Mini Rotor has been reasonably reliable mechanically but it is too soon for long term shortcomings to be determined.

The output of the machine has been disappointingly low, but even when conditions are good it is doubtful whether more than 25 tons cane per hour will be harvested. This has been achieved for short periods, but a lack of horsepower is evident at this rate of harvesting.

The wide range of field conditions in which the machine has operated and which are not ideal for chopper harvester is typical of South Africa. The Mini Rotor is able to operate in these conditions but their effect on output and fuel consumption can be clearly seen in Figures 1 and 2.

Further development is required so that factors such as trash wrap and narrow row spacing can be overcome so that reliability can be improved.

Acknowledgements

Mr. L. Kramer kept records on field conditions and operating problems; Mr. M. M. Boast gave valuable opinions and advice on the cane handling parts of the machine; and the Hulett Maidstone Mill operated the machine on its lands and provided the necessary infrastructure.

REFERENCES

1. Novais, G. R. (1977). Establishing optimum standards for the lower cutting device of the sugar cane harvester. *ISSCT Proc* **16**(2): 2011–2022
2. De Beer, A. G. and Boevey, T. C. (1977). Losses incurred when chopper-harvesting sugarcane. *ISSCT Proc* **16**(2): 2115–2126.