HGCA

PROJECT REPORT No. 18

HEADER LOSS SENSING AND COMPUTER MODELLING OF THE GRAIN STRIPPING PROCESS

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HOME-GROWN CEREALS AUTHORITY

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Header loss sensing and computer modelling of the grain stripping process

by

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NOTE A summary version of this document is presented in HGCA project Report No. 11.

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HEADER LOSS SENSING AND COMPUTER MODELLING OF THE GRAIN STRIPPING PROCESS

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Summary

Investigation of the header loss in relation to the grain distribution within the hood enclosure, was carried out using the laboratory grain stripping rig. The main variable that was used, was the vertical hood height in relation to the crop height. It is known from previous work that header losses can be mainly affected by the relationship of the hood inlet edge relative to the crop height. The header loss measurements in the laboratory conditions, were found to be approximately 0.5 to 1.0% higher than those measured in field conditions. The distribution of the number of grains impacting per unit area on the underside of the hood, has been shown to have a positive correlation with the grain loss level. This means that if the distribution of grain impacts on the hood can be continuously recorded, then this can be used to give the operator an indication of the amount of grain that is being lost on the ground. In particular, the header losses increased as the number of grains impacting on the area of the hood nearest to the inlet section, also increased. Thus an impact sensor at the hood inlet could indicate the level of grain loss. In order to determine optimum position of the hood, however, it is necessary not only to measure the grain impacts at the hood inlet region, but to determine the distribution of the grain over the whole hood area. This means that a number of grain impact sensors need to be distributed over the hood area. The information from these sensors may be fed into a microprocessor which will indicate to the operator information which will allow him to select the best position for the stripper header settings.

Conventional loss sensors, as used to determine straw walker and sieve losses, can be used, provided that a suitable filtering and damping system is included in the circuitry. However, benefits will be obtained by developing a purpose-built impact sensor that is not sensitive to the velocity at which grains impact.

header was evaluated in a variety of crops. In the barley crops the stripping header losses were considerably lower than those measured when a conventional cutterbar was working. This is thought to be due to the effect of the stripping rotor lifting badly necked crop from near to ground level. In wheat crops the header losses resulting from the stripping header were higher than those measured with a conventional cutterbar, but were not considered to be excessive. The same is true for oats. The minimum losses are given in Table I.

Table I

Comparison of minimum header losses, kg/ha (1986)

Crop	Stripping	Cutting
Winter barley	72	390
Spring barley	100	228
Winter wheat	32	12
Spring wheat	38	5
Winter oats	96	45
Average	68	136

In laid crops the performance of the stripping rotor was usually better than that achieved by a conventional cutterbar particularly when the crop was leaning towards the stripping rotor.

The measured increase in the combine grain throughput when the stripping header was used and compared with that of the performance of the combine with a conventional cutterbar fitted, is given in Table II. The improvement in output at the 1% loss level ranged from 12 to 135% and at a loss of 100 kg/ha ranged from 5 to 91%. The average improvement in grain throughput was 54% and 45% respectively.

measured when the stripping header was attached, compared to the cutterbar header, was much greater than that achieved with the straw walker type combine. The results are given in Table III.

Table III

Increase in combine grain throughput using the stripper header on a combine with multi-cylinder separation, compared to a cutterbar, %

Crop	Combine grain loss, 1% of yield	Combine grain loss, 100 kg/ha	Grain yield yield, t/ha
Winter wheat	75	84	6.3
Spring wheat	86	74	6.8
Winter oats+	96*	-	3.5
Triticale	147**	-	3.5
Average	101 ± 32	79 ± 7	

+ cutterbar limited by cutting efficiency

* for these samples, losses were >1% using the cutterbar and this figure is the best estimate

** for these samples, losses were <1% using the stripper and this figure is the best estimate

Because the headers were only 3.6 m wide, it was sometimes not possible to load the combine to the point where 100 kg/ha of grain were lost. No measurements were carried out in barley in 1987.

The straw residue dried rapidly after rain; it could be burned effectively, and because it remained attached to the ground, it could be ploughed in with minimal adaptation of the plough. For harvesting it specialised equipment will need to be developed. One alternative is a this to the measured grain loss, and if necessary, to develop a loss sensor specifically for this purpose. As the grains stripped by the stripping rotor can have a large range of velocities, it is necessary to have a grain impact sensor that is unaffected by the actual grain velocity impacting on it. In addition to this, it is necessary to filter out the background vibrations of the machine running in the field, and the signals caused by straw and other material which is present beneath the stripper hood.

The problem was approached from two directions; firstly measurement of the distribution of grain around the stripping rotor hood and the relationship of this distribution with the measured grain loss, and secondly, the construction of a computer model which, when fully operational, will be used to determine the effect or the interdependence of one setting upon another. The computer model would also have the ability to investigate the effect of rotor speed, rotor diameter, rotor height above the ground and several of the other interesting aspects of the stripping system.

Because of the amount of work involved in the development of a header loss indicator, the contract funds were unlikely to allow a complete solution to the problem to be found, however, it was intended that the initial loss sensing system could be investigated to determine the potential. Likewise, it was likely that the computer model would only reach a stage where it was operative but would probably not be at a point where it could produce effective output data.

The stripper harvesting system developed at the AFRC Institute of Enginering Research has reached the stage of commercial uptake. Shelbourne Reynolds Engineering have been licensed by the British Technology Group to build and sell stripping headers for attachment to conventional combine-harvesters. Twenty-four of these stripping headers were placed on farms in 1988, fourteen of these being in the UK, the remainder being exported to various countries.

passes beneath the stripping rotor at speeds ranging from 4 to 8 km/h. The height of this trolley relative to the rotor can also be varied. Behind the rotor is a short length of conventional crop delivery auger, as is used on all conventional combine-harvester headers. The stripping rotor was equipped with the same type of keyhole stripping elements as used on full-scale headers. These elements are designed in such a way that there is an opportunity to strip grain from the forward part of the ear and there is no point at which the straw is gripped. A standard stripping element is shown in Fig.1.

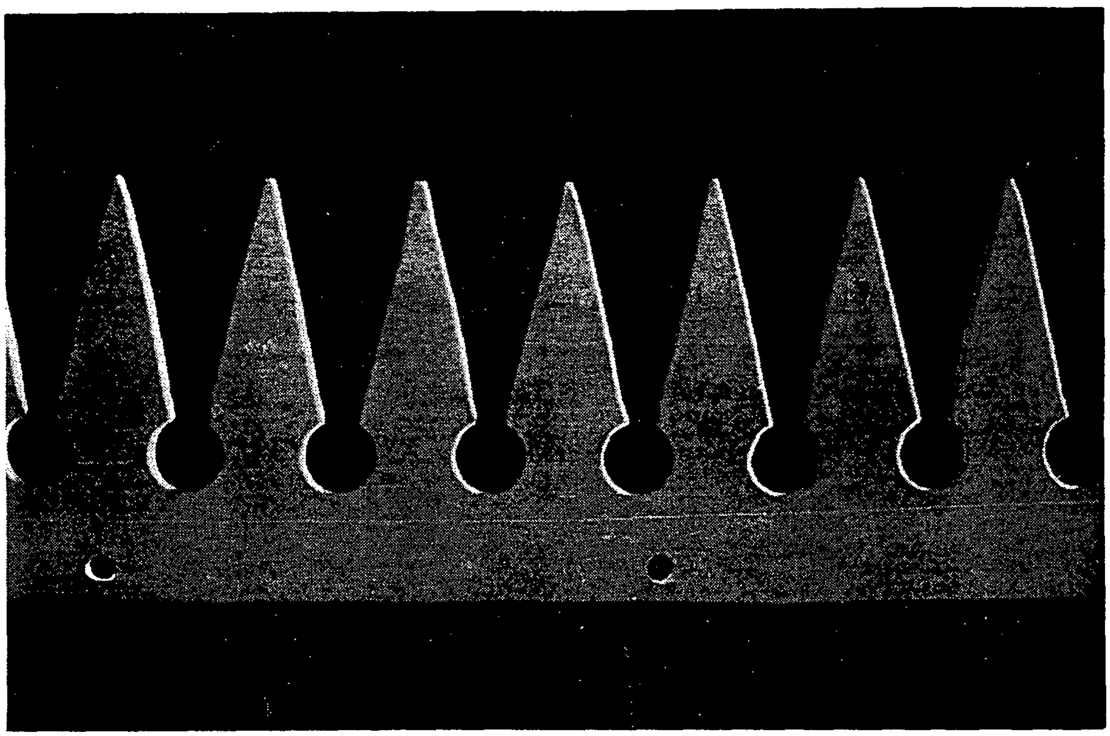

Fig.1. Grain stripping element made of moulded polyurethane

3.2 Crops

When crops of wheat or barley are used on the laboratory rig it becomes very difficult to distinguish between the chaff and grain components. In

3.3 High-speed video films

High-speed video was used extensively to investigate the performance of stripping elements and to determine the trajectory that the grain takes. For these films, simulated crop is always used. The speed at which the video camera was operated was 200 frames per second, and the playback speed was 25 frames per second. During playback, the path of stripped grains leaving the stripping elements and the distribution of the grains on the rotor hood, can be viewed.

3.4 Grain distribution

In order to determine the actual distribution of grains around the rotor hood, a dummy hood, covered with a thin layer of grease, was fitted. For these measurements, simulated crop was used and the number of grains per unit area collected in the grease, was counted. The grease pads are shown in Fig.3.

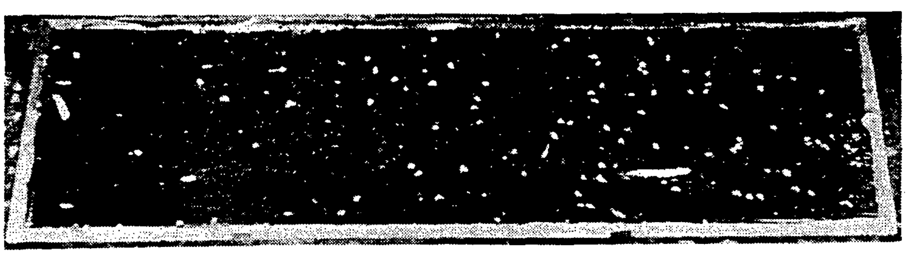

Fig.3. Grease pad that can be moulded around the inside surface of the hood

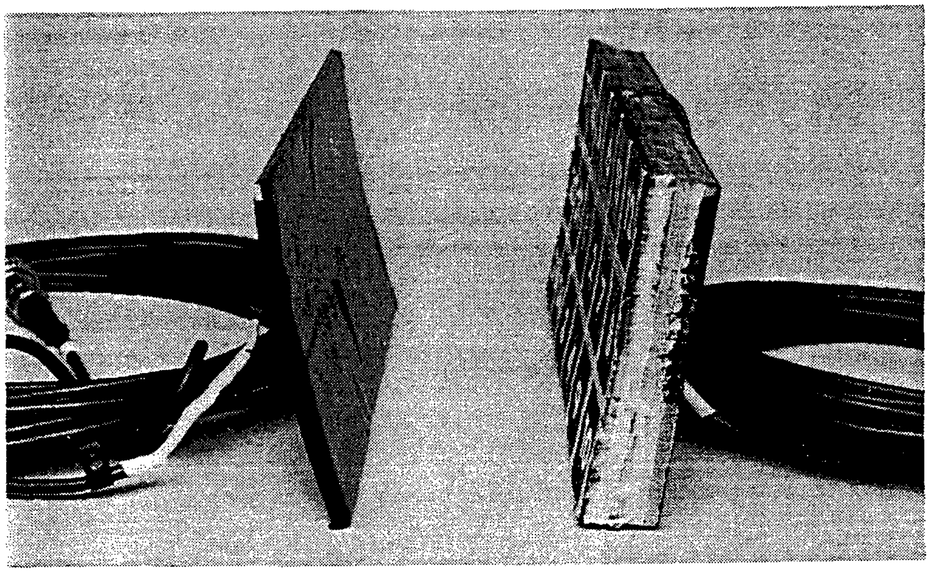

Fig.4. Grain impact sensor (Left - Type A, Right - Type B)

3.6 Computer simulation model

The grain stripping program was designed primarily to compute the possible stripping positions with respect to the stripping tooth from the tip to the recess at the base of the 'V'. A basic assumption made in the program was that the straw behaved linearly as a light rod, after it had been deflected by the inlet nose cone, or as a flexible rod which was able to wrap itself around the rotor core. The stripping element tip and base circles, and the path taken by straw entering the stripping rotor, are shown in Figs. 5 & 6.

The model is designed to determine the position around the stripping rotor circumference where the stripping process takes place, relative to the variables of crop height, stripping rotor height, vertical hood height above ground level, rotor to hood horizontal clearance and forward speed of travel.

Four possible points of grain stripping were selected. These were at the tip and at the base, assuming that the straw recovered to its initial position after being deflected by the hood inlet, and also, assuming that the straw wrapped around the rotor core. Other positions were at the tip and at the recess, without the effect of the straw recovery, or the effect of wrapping around the rotor core.

4. Results and discussion

4.1 Grain distribution and header loss

The distribution of grain around the hood was measured at various settings of the vertical hood height using the grease pads. This variable was selected because it is known that it has the greatest effect on the header losses. The other header settings were set at the best known position[1,2] in relation to the crop height. The settings were as follows:-

Crop height	500 mm
Height of the stripping rotor above the ground	100 mm
Horizontal clearance between the hood and stripping rotor	100 mm
Stripping rotor speed	700 rev/min
Forward speed	7.2 km/h

Figs. 7, 8 and 9 show the grain distribution relative to the header loss level at three settings of the vertical hood height. The hood heights were relative to the datum of crop heights of 500 mm, 490 mm, 300 mm and 400 mm. The distribution of the grain around the hood is given relative to the angle from the hood inlet point. Thus an angle of 0° is equal to the point on the hood at the inlet. The header loss figure is given at a point below

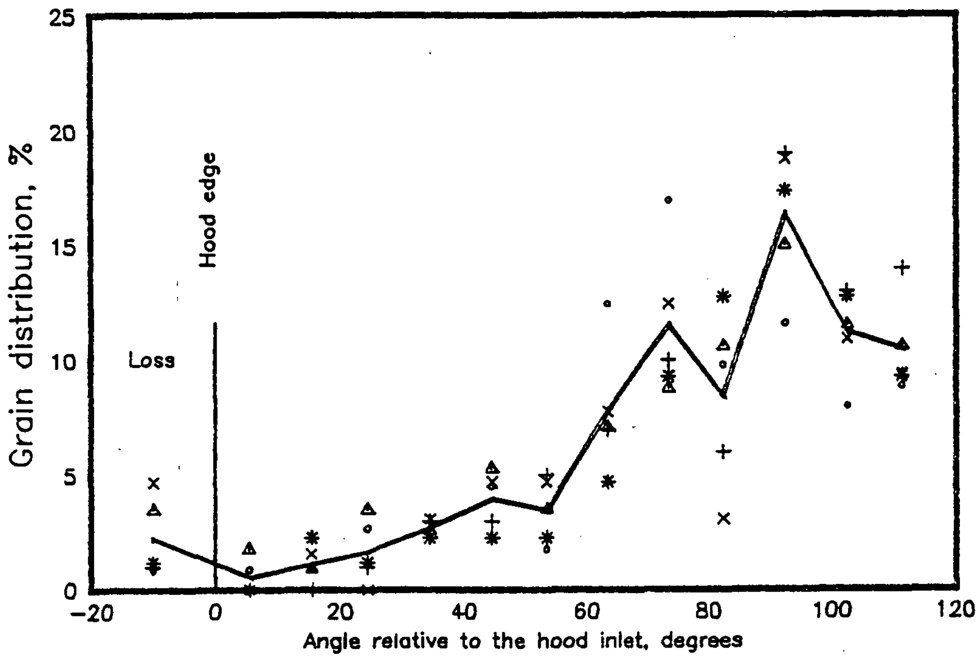

Fig.9. Effect of grain distribution relative to header loss (Vert.hood height 490 mm above the ground)

The first thing that may be noticed from the results given in Figs. 7, 8, and 9, is that the percentage of grain impacting in the region of 100 mm above hood inlet point (i.e. 300 x 100), is approximately half the recorded loss level. It may also be seen that the peak in the grain distribution around the hood, moves towards the inlet point as the hood is lowered relative to the crop height, which also results in an increase in lost grains. Fig.8 has a relatively flat distribution but it has a higher proportion of grain impacts beyond the 80° position. The minimum header loss occurred when the peak of the grain distribution was in the range of 85 - 95° relative to the hood inlet point and therefore this would be the best setting in this particular harvesting situation. If the grain distribution pattern around the hood is to be successfully related to header losses, then a series of sensing points around the hood are necessary in order to make it possible to determine the peak of the has been stripped at a mid-point along the stripping element. The tip circle of the stripping rotor is shown and the position of the relevant stripping elements. The solid lines indicate the tangent of the stripping rotor tip circle at the point of grain discharge. The broken line shows the grain trajectory and the diffusion cone is shaded. In Fig.10, the first diagram shows the initial contact between the grain and the stripping element AB. The grain resides on the stripping element for 10 ms before being discharged at A_2B_2. The diffusion cone is 15° backward of the tangent to the tip circle at this point, as shown by the shaded area. The second diagram in Fig.10 shows the effect of the same ear being stripped by a following stripping element, DE. Again the grain resides on the element for 10 ms and is discharged at position D_2E_2. The diffusion cone is now wider, being 10° in front of the tangent line and 20° behind it. This is because the position of the root of the straw relative to the rotor has changed, and the ear is being stripped at a slightly lower position on the stripping element circumference. Video film of grain stripping in this position confirms that the grain is well contained within the hood envelope, and losses are unlikely to occur.

Fig.11 shows a 4-step sequence of the stripping obtained when the inlet hood edge is set too low in a standing crop. In this situation the hood height was 200 mm below the crop height. Diagram No.1 shows the trajectory of grain that is stripped virtually at the tip of the stripping element and does not reside on the element, but is immediately projected from it. Diagram No.2 occurs 10 ms later and shows the effect of the second stripping element DE. At this point in time the grain resides on the element for approximately 5 ms, and is projected in a diffusion cone of approximately 15° behind the tangent of the stripping circle. The third contact of a stripping element with the ear of grain projects some of that grain immediately in an upward trajectory. However, as shown in Diagram 4, some of this grain which is stripped at the recess of the stripping tooth, remains on the stripping element for 10 ms and is then projected in a 15° diffusion cone backwards from the tangent to the circle where the grain leaves the stripping element. Comparing Fig.11 with Fig.10, it can be seen that if the hood inlet is positioned too low, the angle of the trajectory of grain from the stripping rotor is much less safe. However, as the hood

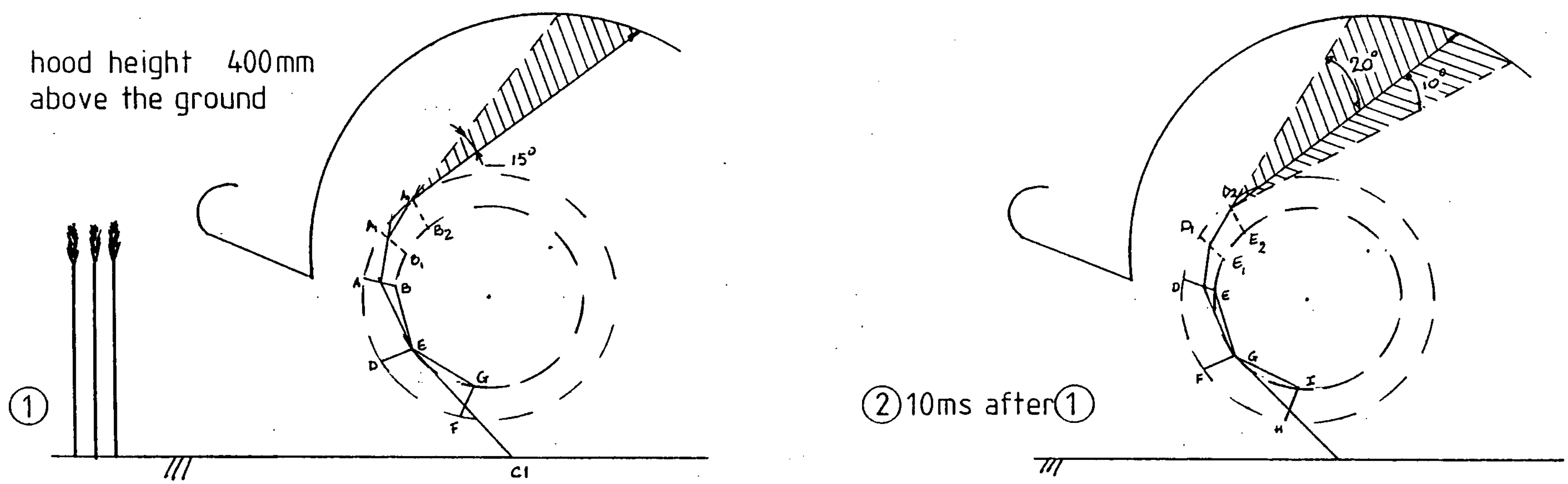

Fig. 10 High-speed video analysis of the grain trajectory when the grain is stripped mid-way down the V portion of the stripping tooth

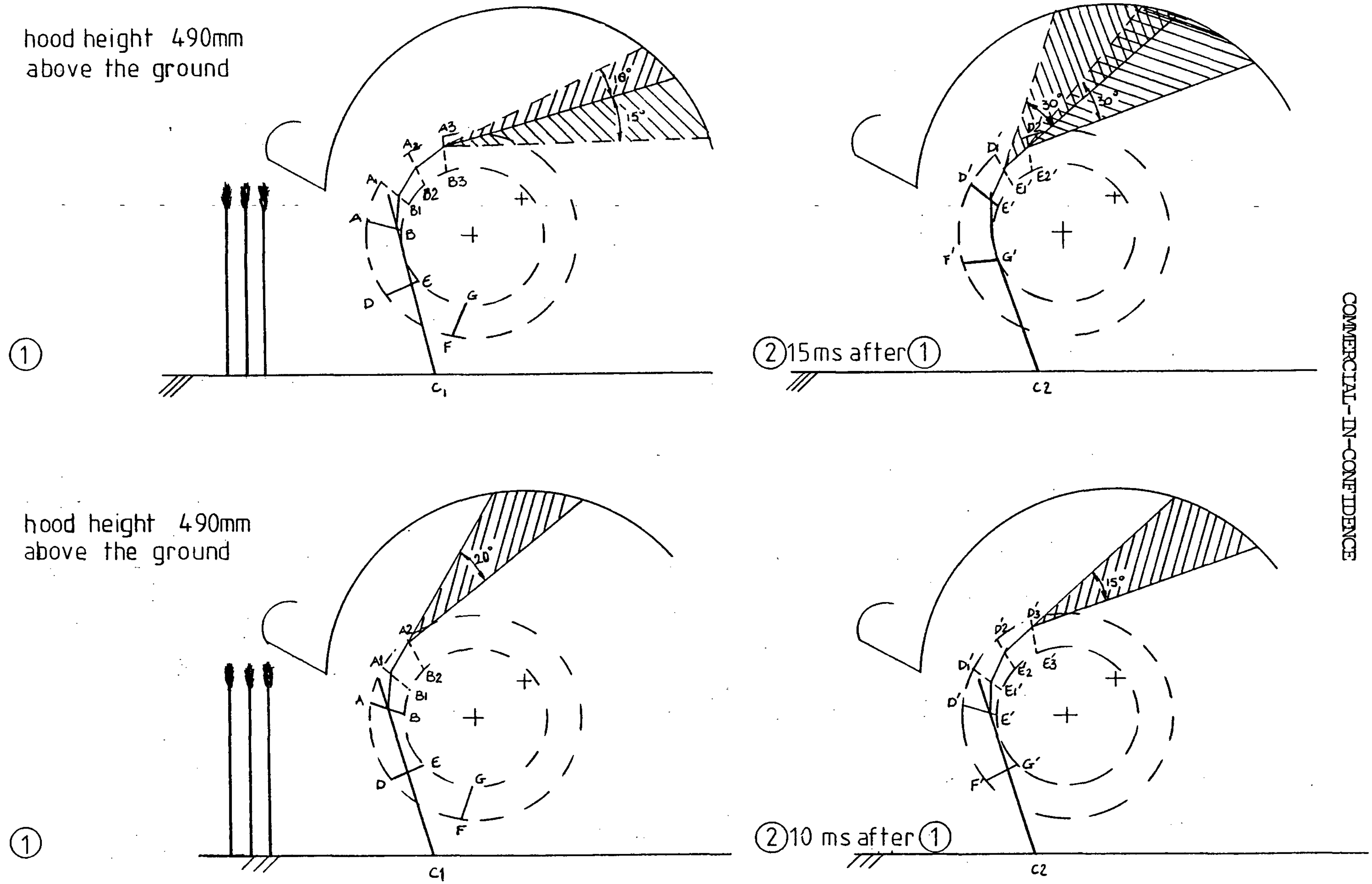

Fig. 12 High-speed video analysis of the stripping process when the hood is set at the crop ear height

This circuit processes the signal received from the grain loss sensor plate, such that grain impacts can be counted relatively independently of the grain velocity. The effect of this circuit on this system can be seen in Fig. 13c. With this circuit the grain impacts can be clearly identified and the response time is within 6 ms.

Fig. 15 shows that several grains impacting on the sensor, can be counted individually without confusion. When the equipment is attached to a stripper header on a combine-harvester, extra filtration of the signal will be required in order to eliminate background noise. However, this is not considered to be a serious problem. With a series of grain impact sensors fitted both circumferentially and transversely across the hood of the grain stripping header, an average distribution of grain impacts can be calculated within an on-board microprocessor.

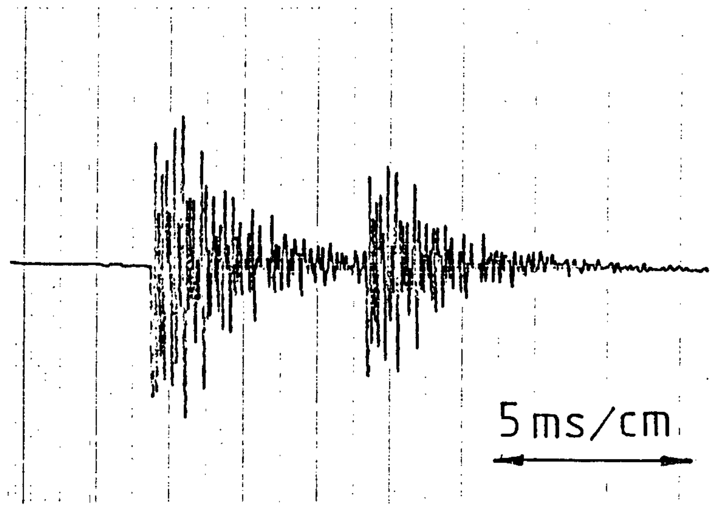

Fig. 14(a) Signal from a conventional grain loss sensor

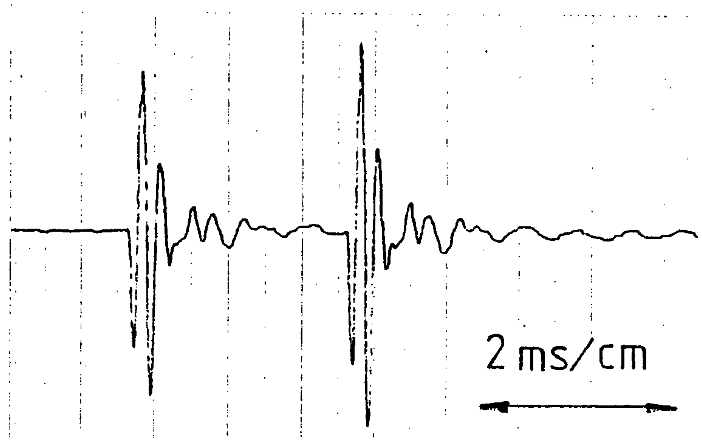

Fig. 14(b) Signal from an impact sensor with mechanical damping

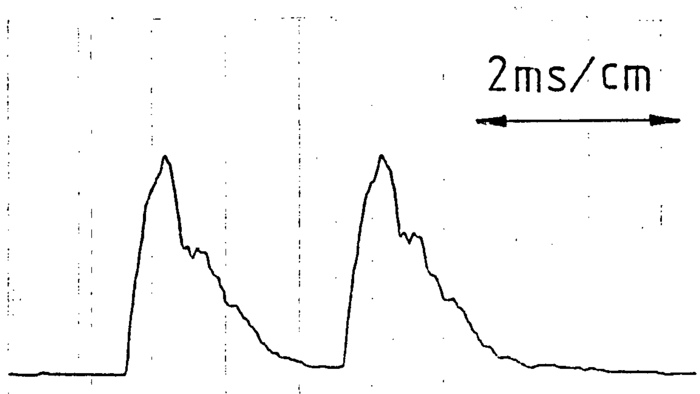

Fig. 14(c) Final sensor output after signal conditioning exit. This has been confirmed in general terms by the analysis of high-speed video recordings of the stripping process, although there is diffusion both forward and backwards from the tangent of about 10° to 40°.

The computer model is only in its basic form at the present time, but is already able to show the importance of stripping the grain at the correct position around the stripping rotor periphery in order to obtain a safe grain trajectory. When the diffusion cone of the stripped grain is added to the basic trajectory line, then there will be some settings in which losses can be seen to occur. When this is successfully added to the computer model, then the effect on header losses caused by changes in the setting of the hood height and rotor height, will become visible.

The computer model is already showing that grain stripped at the base of the stripping element is very much safer than grain that is stripped at the very tip of the stripping element. This suggests that design changes or mechanical means ought to be developed to ensure that the majority of stripping is carried out at the recess of the keyhole element.

A block diagram of the computer program is given in Appendix A.

If a micro-computer is mounted on the combine-harvester, and the grain impact sensing information relayed directly to it, it should be able to compare the distribution with known information, and alter the setting of the rotor height and hood height, in order to achieve the optimum positions. This would mean that the operation of the stripping header can be automated and operated to give optimum performance at all times. However, this only means that header losses will be at a minimum level and not eliminated altogether.

5. Basic settings of the grain stripping header

Ideally, stripping of the grain from the straw should be done at the 9 or 10 o'clock position on the rotor and within the space between the rotor and the hood. If this is achieved, then the trajectory of the grain is upward

5.3 Hood height

The hood height should be positioned so that the ears of the crop are deflected downwards by the inlet deflector. After passing under the hood inlet, the clearance between the hood inlet and the rotor tip should allow time for them to recover so that they enter the stripping rotor above the height of the hood inlet. This means that stripping takes place within the hood enclosure. The position of the hood needs to be continually assessed relative to the ear height of the crop, and adjusted so that the ears are always deflected downwards by the inlet deflector. Header losses can increase considerably if the hood is set too low or too high in standing crops.

In partly laid crops, the hood needs to be adjusted relative to the laid portion of the crop. In these conditions the hood can be set very low so that laid corn is still compressed by the inlet deflector. The same applies to badly necked barley crops.

5.4 The clearance between the hood and the rotor

This clearance needs to be set so that the crop has time to recover a little after it has been deflected downwards by the inlet deflector. It is usually set at between 100 and 150 mm from the tip of the stripping teeth. A larger clearance is preferable to a narrow clearance, but upward transfer of the crop is reduced if the clearance is more than 200 mm. The clearance can be set for a particular crop condition and has a relatively small effect on header loss levels.

5.5 Forward speed

Header losses are reduced as the forward speed of travel is increased. Speeds of 8 km/h or faster should be maintained if the separation losses from the combine allow.

Work with grain loss sensors, has shown that it is possible to filter out much of the noise that is generated by the impact of high velocity grains. With suitable electronic circuitry, grain impacts can be counted irrespective of their impact velocity. However, it would be advantageous for more work to be carried out in this respect, with the intention of developing a specific sensor which is also sensitive to whole or part ears of grain as well as free grains. Because a relatively large number of grain impact sensors will be required in order to determine the grain impact distribution, a small microprocessor will be needed in order to present the data to the operator in a useful form.

The computer simulation model of the grain stripping process is in a very basic form and still requires further data with respect to the grain diffusion angle. Work will continue to improve the versatility of the program, so that it will be able to estimate the grain losses from various configurations of the stripping rotor. This will be particularly useful in determining the number of blades that are required for efficient stripping, the angle of the striping elements relative to the rotor axis, and also items such as rotor speed and height of the stripping rotor above the ground relative to the crop height.

7. Future developments of the grain stripping system

The benefits of the grain stripping system that have been shown to be available when using conventional combine-harvesters, suggest that the system could be exploited even further if a purpose-built threshing and separating system was incorporated. During 1987 a small rig was built consisting of a stripping header followed by a side delivery crop auger which was also used as a separator to separate out the majority of the grain that had been threshing during the stripping process. This pre-separator was followed by a conventional threshing drum which has 180° of concave wrap, passing the straw into a rotary separator for the final grain/straw separation process. This very small rig, with a harvesting width of 2 m and powered by an 80 kW tractor, produced a measured grain throughput of 10 t/h in wheat and between 5 and 8 t/h in barley at a

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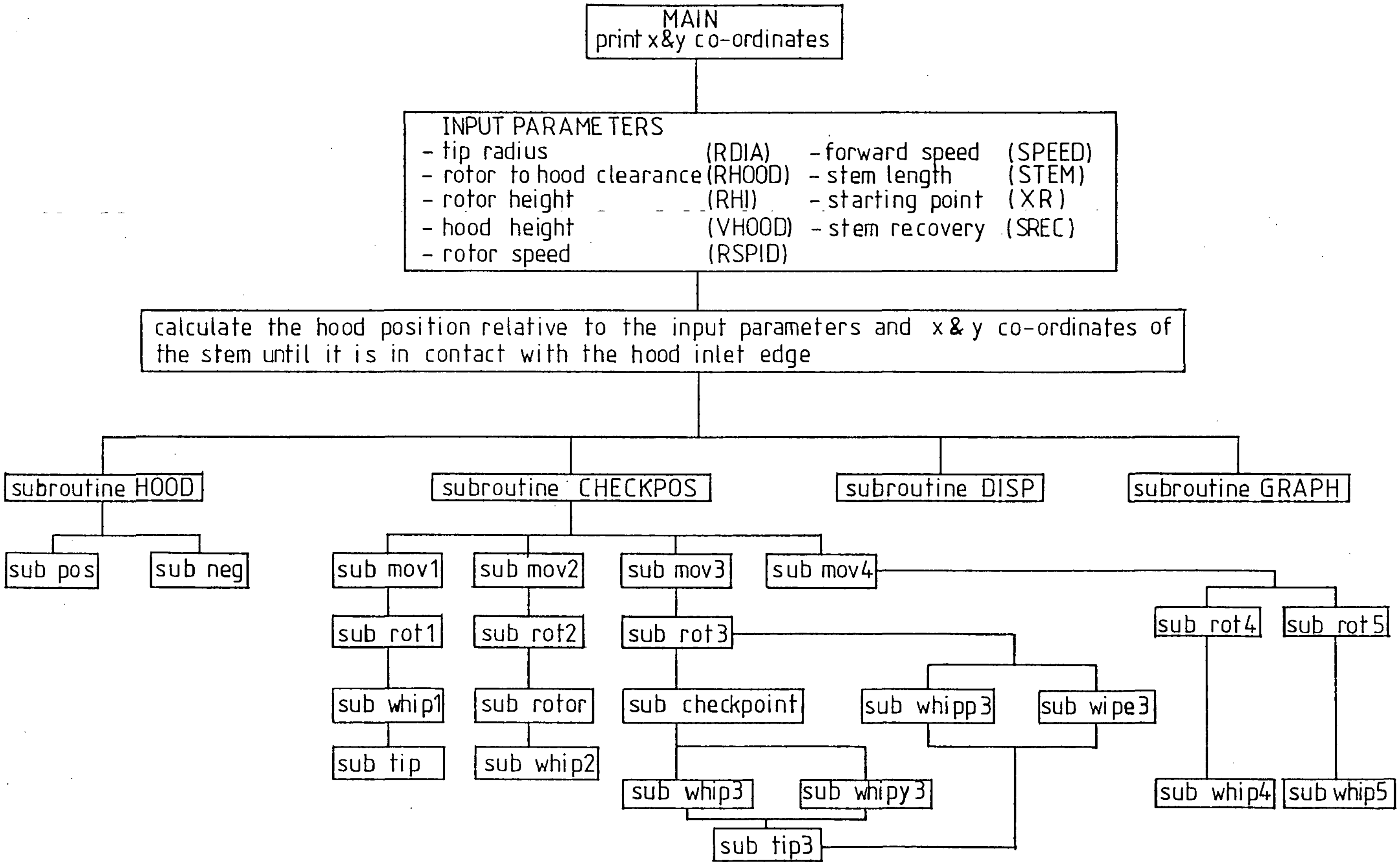
APPENDIX A

FLOW CHART OF COMPUTER MODEL OF GRAIN STRIPPING



- If the stem length is = the tangential line then go to subroutine "MOV2".

- If the stem length is < the tangential line and > the vertical hood height then go to subroutine "MOV3"

- If stem length is < vertical hood height then go to subroutine "MOV4".

6. <u>Subroutine "MOV1"</u>

Case 1. Stem length is > the tangential line with respect to the vertical hood height position.

Calculate the X-Y co-ordination of the stem until it reaches the tangential point (XTGL) in X-direction then go to subroutine "ROT1".

7. <u>Subroutine "ROT1"</u>

- Calculate the maximum vertical movement required for the top part of stem to be free to swing without touching the edge of the hood.

- Calculate X-Y co-ordinates of the top part of the stem, rotor tangential point and ground displacement.

- If the Y co-ordinate is $\leq$ the Y movement required (YMOV) then go to subroutine "WHIP1"

8. <u>Subroutine "WHIP1"</u>

- This subroutine calculates the X-Y position of the tip of the stem with or without the whiplash effect given by the rotor, X-Y position of the tangential point and the wrapping angle around the rotor and ground displacement.

- If the tip of the stem is in contact with the setting of either the keyhole radius (RKEY) or tip radius (RDIA) then go to subroutine "TIP".

14. Subroutine "MOV3"

Case 3. Stem length < the tangential line and above the vertical hood height.

- Calculate X-Y position of tip of the rotor and ground displacement until tip of the stem Y position = vertical hood height (SDIF3), then go to subroutine "ROT3".

- If the distance between the rotor centre and the tangential point XDIS(J) = the keyhole radius (RKEY) and the ground displacement (X-POSITION) < XR, then go to subroutine "WHIPP3".

- If the distance XDIS = RKEY and X.POSITION > XR, then go to subroutine "WIPE3".

15. Subroutine "ROT3"

- Calculate the X-Y position of the tip of the stem with or without the stem recovery effect deflected by the hood inlet edge ground displacement until the distance between rotor centre and tangential point XDIS(K) = the key radius. Then got to subroutine "CHECKPOINT".

16. Subroutine "CHECKPOINT"

This subroutine compares the ground displacement X(K) and the rotor centre position (XR)

- If X(K) ≥ XR then go to subroutine "WHIPY3"

- If X(K) < XR then go to subroutine "WHIP3"

17. Subroutine "WHIPY3"

Calculate X-Y position of the tip of the stem with or without the whiplash effect given by the rotor, wrapping angle around the rotor and ground displacement until the tip of stem is in contact with the setting of either the keyhole radius or tip radius, then go to subroutine "TIP3".

24. Subroutine "ROT5"

Calculate X-Y co-ordination until the tip of the stem reaches the setting of either keyhole radius or tip radius, then go to subroutine "WHIP5".

25. Subroutine "WHIP4"

Calculate the stripping angle based on data from subroutine "ROT4".

26. Subroutine "WHIP5"

Calculate the stripping angle based on data from subroutine "ROT5".

27. Subroutine "DISP"

Displays the result.

28. Subroutine "GRAPH"

Plots the graph.