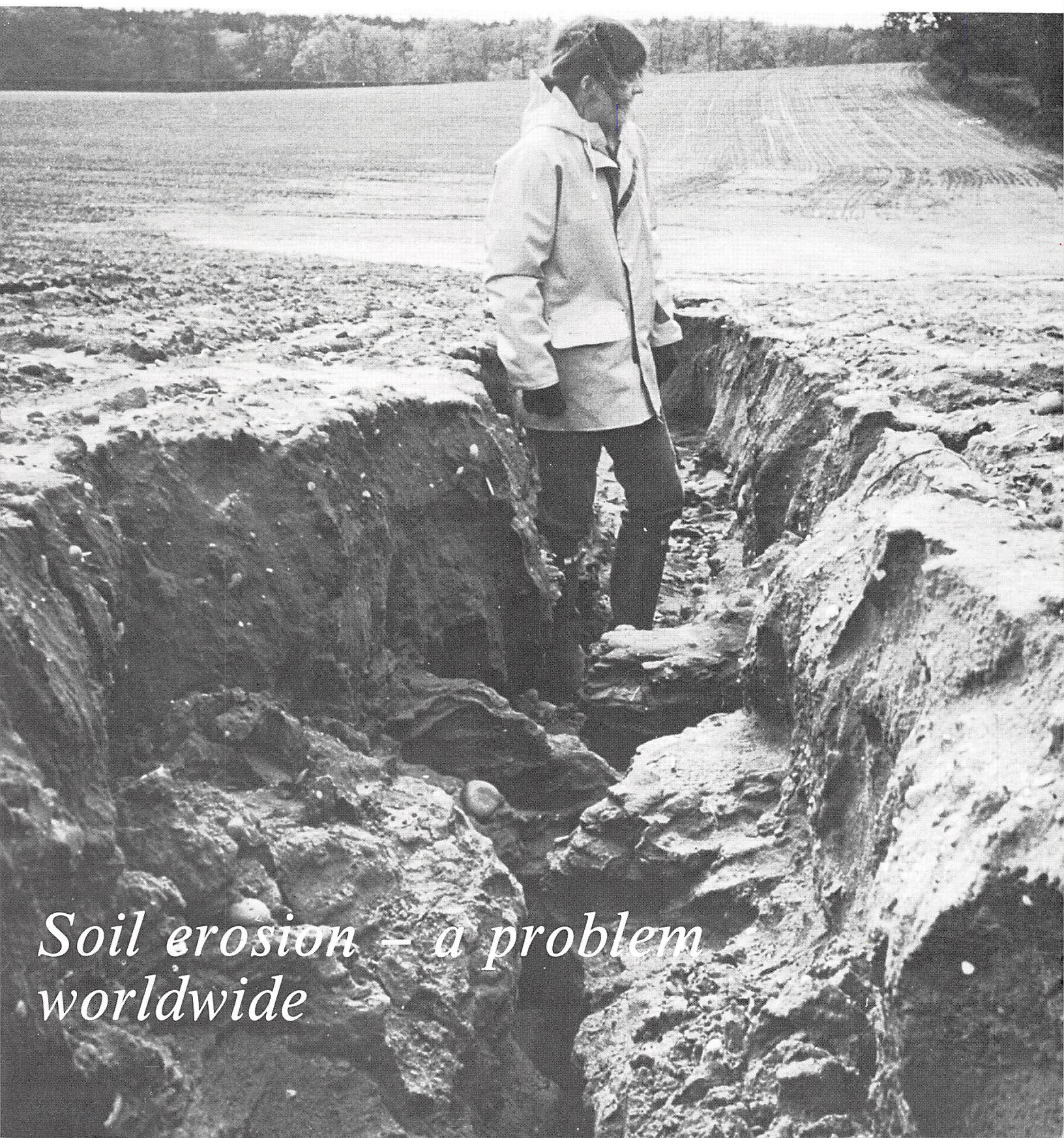
THE AGRICULTURAL ENGINEER

Volume 40, Number 4 WINTER 1985



The Institution of Agricultural Engineers

Journal and Proceedings

Front cover:
Soil erosion is not just a problem in developing countries (paper by Aneke) but in England as well. This gully erosion took place in Nottinghamshire on a sandy loam soil which had been ploughed and furrow pressed (Silsoe College photograph)

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Guest Editorial

IAgrE and Nomination by the Engineering Council

J A C Gibb

ON 22nd November 1985, the Engineering Council (EC) published its long-awaited Second List of Nominated Bodies. IAgrE is among some 50 other engineering Institutions listed and nomination by the EC confirms IAgrE's standing in the ranks of professional engineering Institutions, and its fitness to develop its activities under the Engineering Council's aegis.

The publication of the Second List marks the completion of the transfer of responsibility for engineering matters in the UK from the Council of Engineering Institutions (CEI) to the Engineering Council (EC), as a direct consequence of the publication in January 1980 of the Finniston Report "Engineering Our Future". As a necessary preliminary to nomination, all the Institutions listed were visited and assessed by panels representing the Engineering Council. Any shortcomings noted by the panels were reported back to the EC and Institutions were required to take remedial action before they were cleared for nomination.

The meaning of 'Nomination' of an Institution is that it is recognised by the EC as a body which EC has approved for the purposes of certifying the attainment by individuals of the requirements for engineering registration, in respect of academic qualifications, industrial training and responsible experience. In the case of IAgrE, nomination relates to the Technician Engineer (TEng) and Engineering Technician (EngTech) sections of the EC register, and full authority for these purposes is delegated by EC to IAgrE — subject only to provision for overriding monitoring and control, as for all Institutions, by the EC Board for Engineers' Registration.

Ian Gibb is Senior Lecturer in Agricultural Engineering at Reading University.

As well as being a Past President of the Institution of Agricultural Engineers, he is currently Chairman of the Membership Committee. He also holds personal appointments with Engineering Council as a member of the Nominations Committee and of the Technician Engineer & Engineering Technician Working Party.

J A C Gibb (photo: D Raby)

Certification of the attainment of individuals seeking entry to the Chartered Engineer (CEng) section of the register is directly available only to an engineering Institution holding its own Royal Charter, which IAgrE does not. For the benefit of non-Chartered bodies which seek to register as CEng those members who meet the relevant criteria, the EC has developed the system of 'Institution-affiliation', by which such bodies may be affiliated, *for this purpose only*, to an appropriate Chartered body.

Following agreement with the Institution of Civil Engineers (ICE), IAgrE is, therefore, included in the Second List as an 'Institution-affiliated' body, affiliated to ICE. Nomination of IAgrE thus means that, with the helpful co-operation of ICE's Affiliates' Sub-committee, IAgrE can put forward applications from eligible individual members for CEng registration, while for TEng and EngTech registration it can act in its own right.

The publication of the Second List of Nominated Bodies is thus the beginning of a new phase in the life of the engineering profession in the UK. The Engineering Council was set up with the primary object of enhancing the contribution of engineering to the life and economic wellbeing of the UK. To that end, the members of the EC are representative of industry, education, the trade unions and other official bodies.

During the early phase of its life, a good deal of the EC's attention has been given to the assessment of the capacity of this country's engineering Institutions to meet the EC's standards, and to the absorbtion of registrants under the Engineers' Registration Board on to the EC Register. Much other work has also been done and the framework has been laid for further development.

Among these activities are the establishment of a regional organisation to foster co-ordination of the many different branches of engineering on a local scale, and an annual Engineering Assembly to provide a forum at a national level. A further responsibility, inherited from CEI, is to maintain the status and position of British engineers in the international arena, by seeking continuing agreement of the mutual recognition of engineering qualifications.

The EC's programme of enhancement of professional engineering standards is outlined in the EC document 'Standards and Routes to Registration', or 'SARTOR' in short. This sets the threshold for CEng registration from 1992 onwards at the level of a BEng degree in engineering as defined by the EC, which is that of a current honours degree extended to incorporate integrated programmes of hands-on workshop training and project experience, and centred round design studies as a unifying concept.

The threshold level for TEng registration is set at the level of a Higher National Certificates of the Business and Technician Education Council (BTEC) and that for EngTech at (ordinary) National Certificate level of BTEC.

The implications for IAgrE of Nomination by the Engineering Council are quite far-reaching, and much preparatory work has been done. Changes have been made in the membership structure both in the Corporate and Non-corporate grades, which will facilitate the processing of applications for admission and transfer. They also establish clearly the relationship between members eligible for engineering registration — who must constitute not less than 60% of IAgrE Corporate membership — and those of equal educational standing, experience and responsibility in agricultural engineering, whose qualifications are in a relevant science rather than in engineering as such. The latter group, working in areas such as farm buildings, forestry, food processing or farm mechanisation, will not expect to qualify for registration with the EC, but can enjoy parity of esteem in the membership of IAgrE with those who are registrable.

To operate the new system, the working procedures of the Institution's Membership Committee have been revised and, for straightforward applications for admission to the Non-corporate grades, the turnround time should be quite short. However, the same can not be said for engineering registration, as distinct to admission to IAgrE membership, because the timetable is necessarily linked to the procedures of the EC itself. Particularly for CEng registration, long delays will inevitably occur, since the affiliation arrangement with the ICivilE provides for only two meetings a year to deal with applications.

As is to be hoped, Agricultural Engineering teaching departments and colleges have not been slow in meeting the new criteria established by the EC. A BEng course in Agricultural Engineering at Silsoe College, assessed and accredited by IAgrE in collaboration with ICE and the Joint Board of Moderators of which ICE is a member, accepted its first students in October 1985. Several HND and HNC and ND/NC courses under BTEC and SCOTVEC are also in the process of assessment.

The Coat of Arms for The Engineering Council portrays energy controlled and the universality and antiquity of engineering. The Arms depict suns representing energy duly chained and thus controlled, to the benefit of mankind. The Crest shows a male gryphon, which was anciently a creature associated with the sun. The gryphon emits sparks of fire from various parts of his body, fire again being another form of energy, and holds a wheel as an allusion to the antiquity of engineering. The Supporters with rayonny coronets about their necks are two pantheons. These heraldic beasts originated in the fifteenth century and were held to live among the stars as 'creatures of the universe', and thus symbolic of the universality of engineering and its dependence on energy. The Badge is based on the device hitherto adopted by the Council and represents earth, fire and water (Photograph courtesy Engineering Council)

To sum up, IAgrE's professional development over a long period had been confirmed in its Nomination by the Engineering Council. Quite apart from its pioneering work in establishing the National Diploma in Agricultural Engineering in 1950, IAgrE was a founder member in 1970 of the Engineers' Registration Board, in the TEng and Tech (CEI) sections, and in 1979 it became an Affiliate of CEI in the CEng section of the Board. Nomination thus constitutes further recognition of IAgrE's contribution to, and place in, the world of engineering at large, and provides continuing opportunities for appropriately-qualified members to align themselves with engineers in other disciplines. It also provides IAgrE with a voice in various committees of the Engineering Council.

Such privileges are not without obligations, however, and apart from not inconsiderable financial cost, largely borne by the processing and annual fees paid by members who are registrants, IAgrE has also undertaken to govern itself within the provisions of the EC Bye-laws and accept whatever restraints these imply. For example, professional interviews will eventually become a mandatory feature of the final stages of registration as CEng or TEng.

Looking to the future, it is greatly to be hoped that the Engineering Council will succeed in its objective of maintaining and upgrading engineering in Britain in all its forms. IAgrE, *through its Council,* has expressed it fullest support for the EC in a task which is of the highest importance not only for IAgrE members and other engineers and their employers, but for Britain as a whole.

Retractable lid attachment for box tipplers

D C McRae, O J Statham, J Fleming

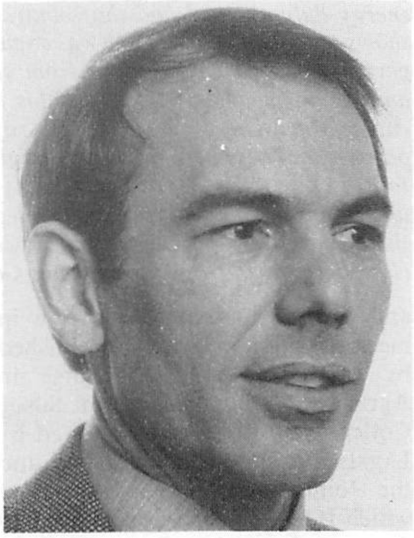
Summary

A RETRACTABLE lid to control the rate of discharge of potatoes from 1 tonne storage boxes in order to reduce damage was designed, constructed and the performance assessed. The lid replaces the box clamping arm fitted to a forward box tippler attachment used in conjunction with a fork lift truck.

Tests were carried out by discharging potatoes on to a bare trailer floor. The tests indicated that the lid effectively controlled the discharge rate and reduced external damage to tubers impacting directly on to the surface of the trailer floor by 75% and internal damage by 52%.

Some difficulties relating to the stability of the fork lift were experienced, but static stability measurements suggest that these could be avoided by additional ballast.

Top right: Douglas McRae



Oliver Statham

John Fleming

Introduction

Many thousands of tonnes of potatoes in UK are stored each year in boxes of which a majority have a capacity of 1 tonne, though some with capacities of 0.5 tonne and 2 tonnes or larger are also used. These boxes are emptied by either a static box tippler mounted over a storage hopper, or by a tippler unit mounted on an industrial or rough terrain fork lift truck.

The box tipplers available at present, whilst they succeed in completely emptying the box, allow the potatoes to escape in an uncontrolled manner. As they leave the box, they may impact against the top clamp of the tippler and often pour over the sharp edge of the angle iron clamping plate usually fitted to retain the box in position as it tips.

Depending on the type of tippler, the method of tipping the box may be by a forward movement or a lateral movement about the centre of the long axis of the box. In both cases, potatoes (or other produce) furthest from the front edge of the box avalanche rapidly out, combining their movement to the escape point with the drop thereafter. This can be damaging. In order to reduce the risk of damage to the potatoes, an attachment taking the form of a retractable lid for a box tippler was designed, constructed and tested.

Douglas McRae and John Fleming are in the Potato Crop Mechanisation Section of the Scottish Institute of Agricultural Engineering; Oliver Statham is Machinery Officer for the Potato Marketing Board.

Design considerations

Several factors had to be considered in the design. The lid had to replace the clamping arm used on a conventional tippler so its method of attachment had to be similar. This called for a lid which balanced fairly well about the attachement pivot. The overall dimensions were dictated by the size of box chosen, which was 1.83 m x 1.22 m and 0.91 m high. The absence of a universal standard for box size, means that boxes of a different shape may not be accommodated, unless the lid is specially tailored for them.

The need for simplicity in fabrication, to minimise production cost, suggested that a composite material for the lid rather than steel should be used. The lid dimensions of 1.83 m x 1.22 m gave sufficient span to produce considerable deflection after the box was inverted even though the 1 tonne load could be regarded as evenly distributed over the lid area. The material chosen was 25 mm thick exterior grade hardwood plywood. This combines strength, lightness and relatively low cost compared with fabricated steel, or a plastic laminate. Provision was made in the design for the deflection of the lid when the box was inverted, to be limited by the main cross member which connected the attachment to the clamping bar support.

Construction

Though there was no reason why the attachment could not be fitted to a rotary tippler, it was considered preferable to fit the first prototype on a forward tippler.

The main frame of the attachment comprises two channel section steel members (fig 1) attached to a box retaining flange, a cross beam and a rear angle iron member (not shown). A fixed lid occupies approximately half the width of the attachment and by spanning the two channel sections, lends rigidity to the structure and in conjunction with a sliding lid retains the potatoes.

The sliding lid with a round steel front edge, slides in the channels on rails. The underside of the lid carries two slide rails countersunk flush in the plywood, these slide on top of corresponding slide rails on the static lid. The four corners of the lid carry small nylon rollers to prevent the lid from jamming if it should skew slightly.

The channels are spanned by a deep rectangular hollow section cross beam bored to carry a double acting ram and strengthened in the region of the ram hole, this being the zone where the bending moment is high during the period when the box is inverted.

The lid control ram is mounted on trunnion plates and is free to pivot through a limited angle in a vertical plane. These plates also carry two sealed ball races which act as thrust rollers running on centre rails of the sliding lid.

The attachment is connected to the clamping bar by a clevis which may be fitted with stops to ensure that the lid adopts a substantially horizontal attitude when at rest.

A provisional patent for the attachment (McRae, 1983) has been assigned to the British Technology Group.

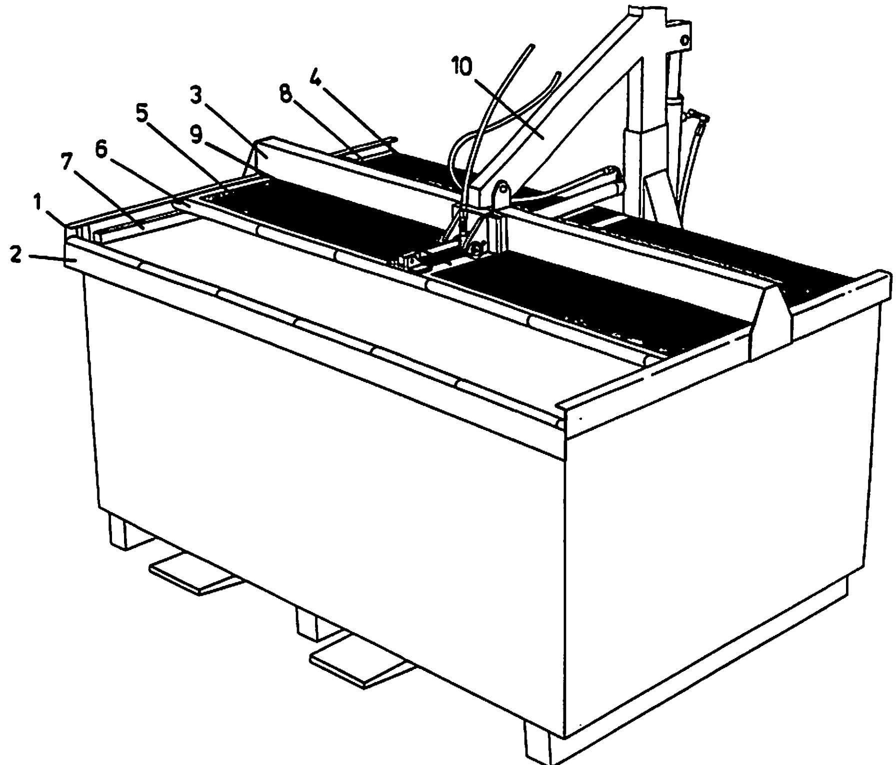


Fig 1 Diagram showing main components of box tipping attachment: 1) channel section steel member; 2) box retaining flange; 3) cross beam; 4) fixed lid; 5) sliding lid; 6) steel front edge; 7) slide rail; 8) static lid slide rail; 9) sliding lid centre rail; 10) clamping bar

Operation

The box filled with potatoes is lifted by the fork lift tippler unit in the normal way, after the clamping bar ram has lowered the attachment to grip the box. The operator now raises the box on the forks, inverts it over the hopper or container in which the potatoes will be tipped and operates a hydraulic control lever to retract the lid. The lid as it moves back slowly releases the load. The sequence of operation is shown in figures 2–7.

For safety reasons it is desirable that the hydraulic system operating the lid should operate in a set sequence, so that the lid is closed whilst the box is still over the hopper and before it is tipped back to the horizontal position. This arrangement should help to avoid the risk of a hand or limb being accidentally trapped between the lid and the box retaining flange and cross bar. An added safety feature comprising a 25 mm stop is fitted to prevent the lid from fully closing.

Test procedure

Tests were carried out to determine the damage done to potatoes when emptying one tonne boxes with or without the control lid attachment.

Samples of potatoes were taken from a full 1 tonne box prior to tipping in order to determine if the potatoes were bruise free — this they proved to be. The box was then partially tipped without having the attachment fitted and samples of 50 tubers were taken from the bare trailer floor on which tipping was carried out.

These samples were assessed for external damage using Catechol.

Further samples of 50 tubers were taken from the trailer floor and, after storage for 14 days, examined for bruising. After taking each sample, the floor was cleared to reduce the incidence of potatoes falling on each other rather than on the bare floor.

The procedure was repeated with the control lid attachment in place. In all 20 samples of 50 tubers were taken for external damage and a further 20 for bruising assessment for each treatment so that a total of 4000 tubers were examined.

Results

The results of the tests are shown in tables 1 and 2. In each case in which the lid was used, there is a very substantial reduction in damage to all samples. Even with the lid, the tuber damage level is high. This is attributable to the deliberate choice of a handling and pre-storage temperature of 4°C at which potatoes can be very vulnerable to damage. Damage could have been virtually eliminated if it had been possible to bring the box down to the trailer floor as illustrated in figure 6. During the tests, the height of the trailer side prevented the box from being brought nearer than 0.38 m from the trailer floor. It was beyond the scope of the test to determine the amount of bruising or even splitting which might occur when potatoes emptying from the box without a lid fell on

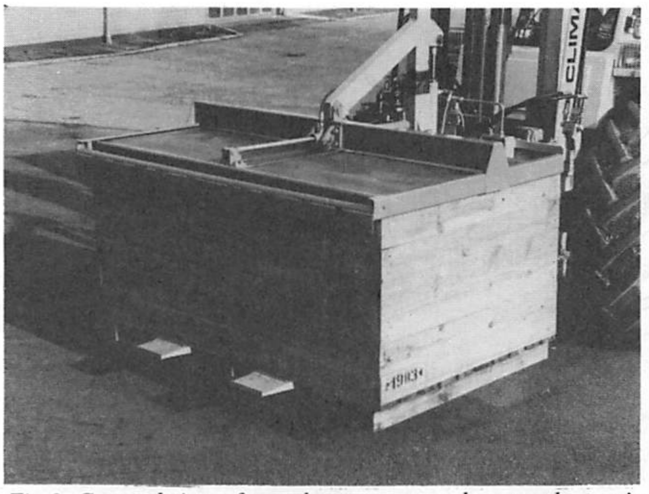


Fig 2 General view of attachment mounted on rough terrain fork-lift truck

Fig 3 Box being collected

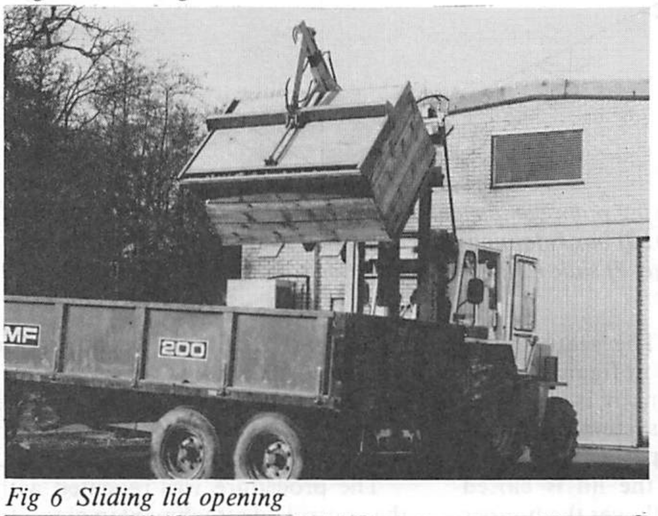


Fig 4 Box being lowered into trailer

Fig 5 Box fully tipped

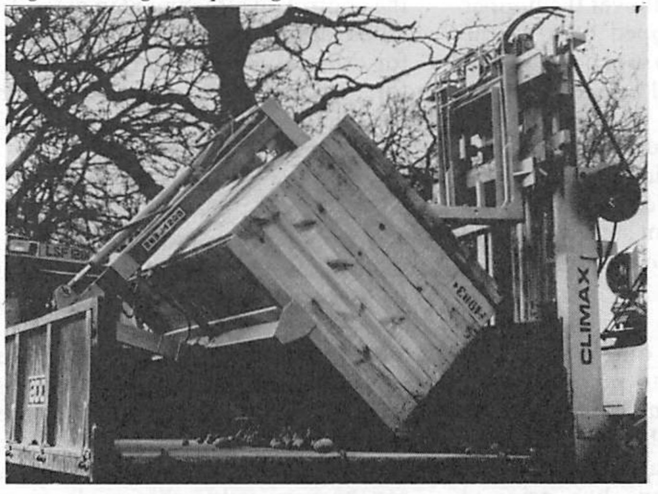


Fig 6 Sliding lid opening

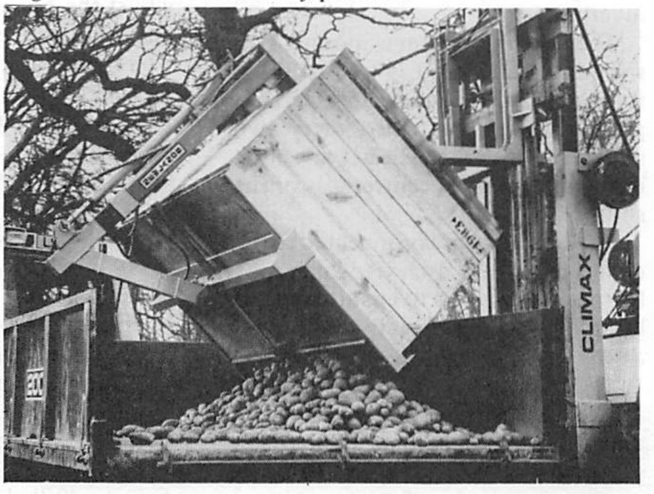


Fig 7 Controlled release of potatoes

layers of potatoes already lying on the trailer floor. Shimada (1980) has shown that damage will occur when large potatoes are dropped from a height of 1 m on to other potatoes.

Field testing

The attachment was fitted to an industrial fork lift truck tippler unit at Holbeach Marsh Co-operative Farm, Fleet, Holbeach Hurne. When the unit was operated, two problems became evident. Due to insufficient flow restriction in the hydraulic supply lines to the box tippler unit rams, the tipping rate proved excessive, resulting in the box accelerating forward until the lifting forks became bent. Since this test, suitable restrictors have been fitted in the ram supply lines to slow down the rate of tipping. It would be an advantage if slightly larger diameter rams could be inserted inside the forks to increase the control over tipping when the rams are near the limit of their stroke. The other problem arose with the weight distribution between the front and rear wheels of the industrial fork lift truck, resulting in it tipping forward against the side of the bulk lorry into which the box was being tipped.

The problem was referred to the Equipment Behaviour Section at the Scottish Institute of Agricultural

Table 1 Damage Index of tubers impacting on the trailer floor when emptying 1 tonne box with and without discharge control lid

Arrangement	*Damage index*			
	Range	*Mean*	*S D*	*Reduction in external damage, %*
Without lid	344–604	438.4	77.65	—
With lid	80–160	110.4	19.73	74.8

Table 2 Bruising when emptying 1 tonne box with and without discharge control lid

Arrangement	*Bruises/50 tubers*			
	Range	*Mean*	*S D*	*Reduction in bruises, %*
Without lid	6–15	9.95	2.93	—
With lid	2– 7	4.80	1.28	51.8

Engineering and a series of tests were carried out to investigate the stability of the box tippler and fork lift truck when emptying a 1 tonne box, with or without the retractable lid. The results of these tests will be reported in a Departmental Note.

Conclusions

1. The attachment enables 1 tonne capacity boxes to be tipped forward so that potatoes are released in a controlled manner without avalanching.
2. Substantial reductions in both external damage and bruising to that proportion of the load which directly impacts on the trailer or hopper floor, can be achieved by using the attachment.
3. A stability problem has become evident as a result of the restraint imposed on the free discharge of potatoes from the box. During the course of the inversion operation, the mass of the box and its contents acts beyond the rated load centre of the truck's fork carriage and this over-balancing force is not relieved until such time as the lid is retracted and a substantial part of the contents are discharged. From results of work to be reported in a SIAE Departmental Note, it would appear that added ballast is needed on all but the largest fork lift trucks when using the retractable lid. Though space is limited, an increase in diameter of the box tipping rams would improve control over the tipping operation.

Acknowledgements

The authors would like to acknowledge the contribution of the following:

E H Robertson, SIAE, for improvements to the basic design;

Holbeach Marsh Co-operative for their help and interest in testing the equipment;

G Owen, SIAE, for conducting stability tests on the fork lift truck when operated with and without the attachment.

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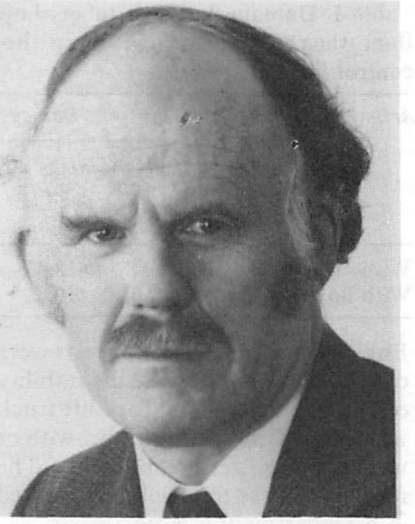
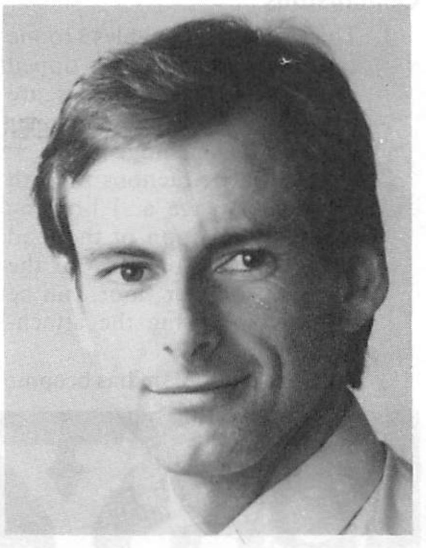
Self-choice feeding of battery hens

J A Pascal, A G Gray, J A Dean and R L Green





Jim Pascal
Alistair Gray

Summary

SELF-CHOICE feeding in deep litter houses has been proven, in biological terms, to be advantageous. The poultry are able to select, from a pair of feeds, a diet which relates to their individual nutrient requirements so that overall the birds in the flock utilise the ration better and hence food costs are reduced.

With the battery cage system, the problem lies with the mechanics of providing two feeds of equal availability in a single trough.

Development of a suitable automated feed mechanism was carried out by the Scottish Institute of Agricultural Engineering at the request of the Edinburgh School of Agriculture and installed at Easter Howgate Farm, Midlothian.

Some problems arose initially with the machine, mainly concerned with the method of feed level detection, feed delivery and injury to birds. Following suitable modifications, the feeder worked well.

Evaluation of the prototype in terms of egg production and feed utilisation is being undertaken by The Edinburgh School of Agriculture.

1 Introduction

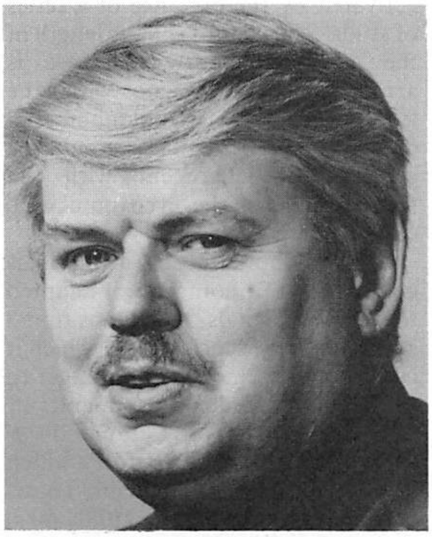
The value of self-choice feeding is established in biological terms. Poultry have the ability to select a diet from two feeds in such a manner that their nutrient needs are met in terms of maintenance and production, thus reducing food intake for the same level of productivity. The experiments carried out by Emmans (1975; 1977; 1978a; 1978b; 1981) on self-choice feeding during the previous decade indicated the benefits to be accrued by using the system. In practice, however, the system has only been demonstrated successfully in deep litter houses, particularly for growing birds, including turkeys. There is no problem in providing equal choice of two feeds in deep litter houses where bulk hoppers deliver feed to floor or near floor level troughs. In battery houses for laying hens, however, there are certain design difficulties in providing completely equal choice feeding for birds within the constraints of space and economy imposed by the battery cages themselves. Feeding systems employed for batteries at present do not permit self-choice feeding. One system consists of a large vee-shaped trough, placed along the front of the cages, which is filled with meal, pellets, etc, by means of travelling hoppers which straddle the cages and can be hand-pushed or driven electrically along each run of troughs. Other systems use a chain and flight conveyor which runs in the bottom of narrow troughs also placed in front of the cages, the conveyor being topped up with feed as it passes through the static hopper. The advantage of this latter system over the travelling hopper is that feed wastage is very low, as there is very little food in the bottom of the trough at any one time. Most new conveyor units are of this type, with more automatic control and monitoring fitted than is customary with travelling hoppers. In a bid to reduce the wastage from travelling hopper feeders, it is possible to fit wire grids over the troughs to prevent birds flicking out the food. The conventional travelling hopper system can be modified reasonably easily to provide two feeds side by side, whereas the chain and flight system is more difficult to modify for self-choice feeding. Nevertheless, self-choice feeding could still be incorporated by using an entirely different approach. The balancer and cereal grain could be mixed in a given proportion into the chain and flight conveyor and the return ratio of feeds monitored by a microprocessor which altered the input feed ratios to correct any imbalance.

The design of such a system is obviously more complicated than that for a travelling hopper so it was decided to design and build an automated unit for a travelling hopper feed system. It was realised that any such development would need to provide a feeder with a performance better than existing commercial feeding for the parameters of feed consumption, feed wastage and labour efficiency.

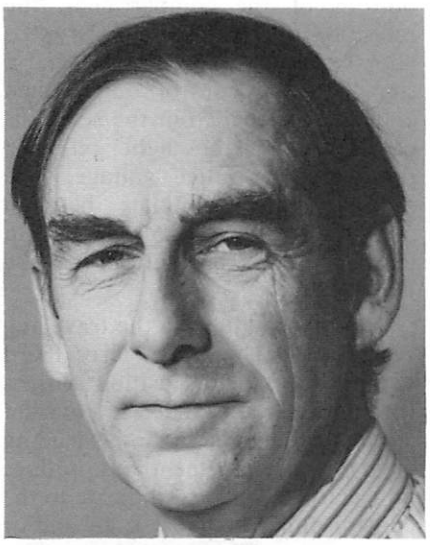
This article describes in detail, the design, construction, installation and subsequent operation of the feeder built at the Scottish Institute of Agricultural Engineering.

In order to assess the performance of the new self-choice feeder, it was installed in the Poultry Unit of the Edinburgh School of Agriculture at Easter Howgate.

Jim Pascal, Alistair Gray, Jim Dean and Roger Green are all from the Scottish Institute of Agricultural Engineering.



Jim Dean
Roger Green



2 Principle of self-choice feeding

Hens given free access to a large number of feed ingredients select a diet which allows good performance and shows a far from random choice between the ingredients (Banta, 1932). The hens can be seen as using a set of rules to select a diet. On the basis of evolution theory, Emmans (1975) suggested that the rules might well be:

(i) select a diet which allows potential output to be attained,
(ii) minimise excess nutrient intake,
(iii) rule (i) takes precedence over rule (ii).

Many experiments have given results which are consistent with the birds using these rules. Hens thus appear to apply the conditions of diet selection which are necessary for choice feeding to be successful.

A mature hen can be seen as having two purposes, maintenance of its state and production. Each purpose has a requirement for a particular group of energy and nutrients and the compositions of the groups by maintenance and production can be described. Within a flock, the production (maintenance and production) ratio varies between individuals, and with time from first egg. Any single feed will be, at best, the right feed for a small proportion of the individuals for a small proportion of the laying period. When given the most economic single feed, the consequences are that:

a) most birds will be over-supplied with nutrients,
b) some birds will over-eat, will attain their potential but get fat, and
c) a few birds while over-eating and getting fat, will still fail to attain their potential.

It happens that the composition of a cereal approximates to maintenance and a feed can be formulated to equate with production. Then if the hens are given equal access to grain and a feed equating with production, the disadvantages given above under (a), (b) and (c) of feeding one formulation will be avoided.

3 Development

3.1 Design and development strategy

A bird arriving at the trough to feed will be presented with equal access to each of two feeds by having them compartmentalised along the length of trough. Each compartment length is 100 mm with a depth of no more than 25 mm of feed to prevent wastage. The first compartment provides a particular bird with access to the first feed component and the second compartment with the second feed component, these compartments alternating along the length of the trough.

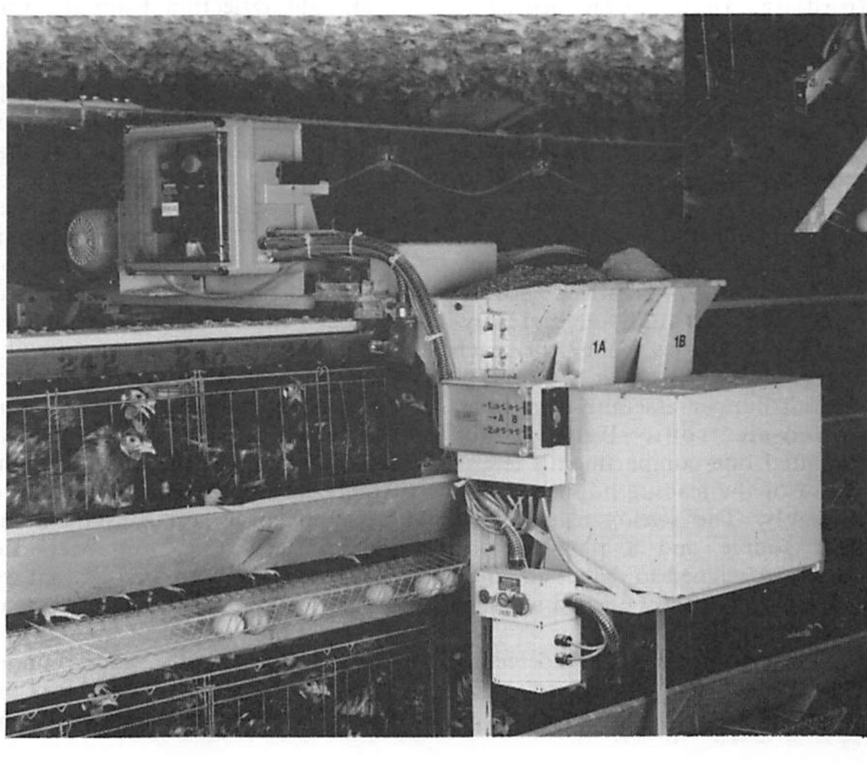
To provide two feeds for such a trough, a travelling hopper is used which carries both feeds and dispenses them to the appropriate compartments. The level of food in each compartment is detected and, if the volume present is below a pre-set quantity, the compartment is refilled automatically.

3.2 Details of initial design

An overall view of the feeder in operation is given (fig 1). For clarity of explanation a line drawing of battery cages with the choice feeding assembly is also given (fig 2), with numbered references for use in the following description.

The caged birds have access to one trough, 1, located in front of each row of cages and divided up into compartments 2, 3, 4, 5 etc, as shown. These compartments are filled from travelling hoppers 6 and 7, each hopper containing one of the two feeds. Thus hopper 6 contains grain

Fig 1 Self-choice feeder for battery hens



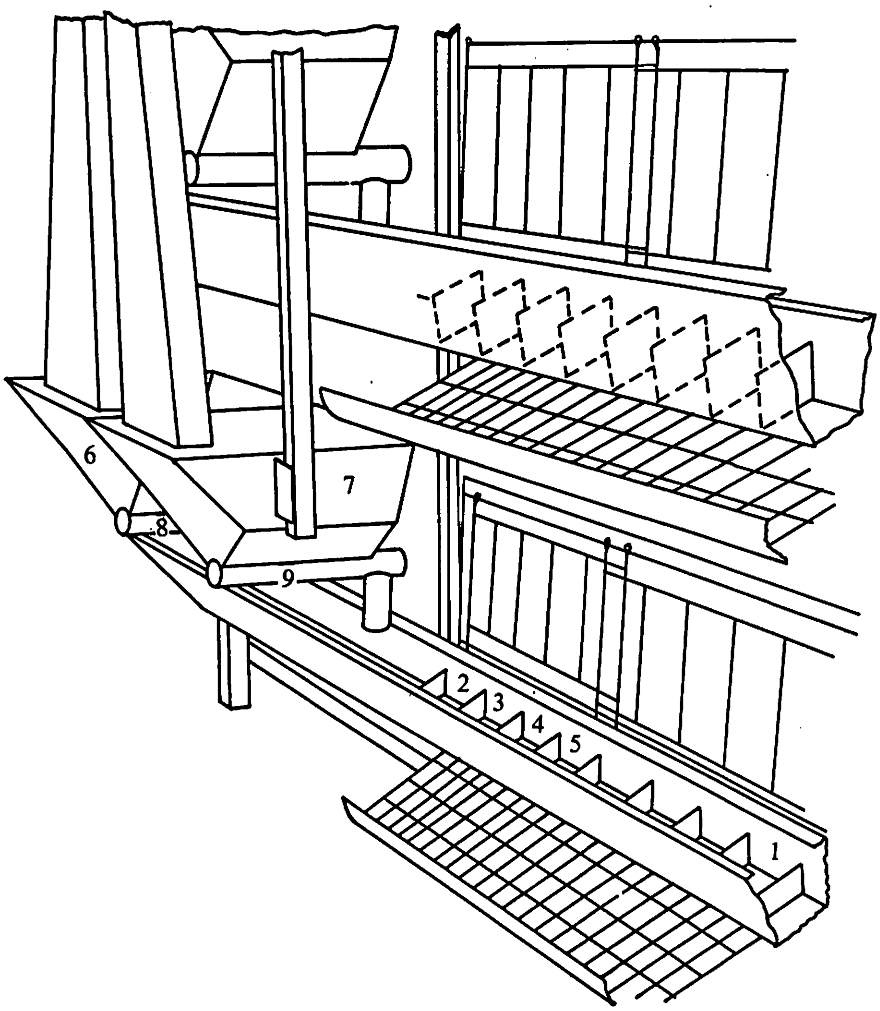


Fig 2 Diagrammatic view of self-choice feed assembly

for loading into the odd number compartments 3 and 5, while hopper 7 contains the protein balancer for loading into even number compartments 2 and 4, etc. In this manner, birds arriving at the troughs are presented with equal access to each of the two food components.

The hopper assembly incorporates feed delivery augers 8 and 9 to transfer feed to the appropriate compartment.

The augers are driven by a single continuously running motor operating through electrically-operated clutches, one for each auger.

Each hopper assembly carries an optico-electronic light sensor mounted one compartment's length ahead of the leading hopper in that assembly. The sensor comprises a light source and a photo-electric detector designed to detect any light reflected from the polished stainless steel compartment floor.

This method of feed level detection has been selected from the following choices:

a) acoustic (sonar),
b) light reflection from the feed surface (presence of feed),
c) light reflection from the tray bottom (absence of feed).

Experiments with acoustic transducers have shown an extremely confused mixture of standing waves and complex return echoes that would have been impossible to decode, so optical methods have been used. Since the design requirement is for a minimum of food to remain in the troughs before filling, method (c) has been chosen. This has the added advantages of avoiding the difficulty that different feeds do not produce the same reflectivities, and of needing no correction for the changes in distance between the bottom of the trough and the sensor, because this measurement is not constant along the run of cages. Moreover, the designers have been advised that the birds will comprehensively clean their trays between feed intervals.

Food delivery is dependent on an electronic proximity sensor on the travelling hopper assembly being activated by the presence of a series of studs. These studs run the length of the cages. One row of studs is arranged in alignment with the leading edge of the odd numbered compartments and the second row arranged in alignment with the leading edge of the even numbered compartments.

The self-choice feeding assembly is completed by a control unit adapted to receive signals from positional studs and light sensors from which it can actuate the appropriate auger to fill an empty feed compartment.

The hoppers are mounted as shown, on a travelling trolley which runs the length of the troughs. This is driven at a constant speed (0.03 m/s) and is controlled by a timer.

When feedstuff is present on the bottom of the compartment, the reflection of the beam is interrupted and the light sensor fails to send a signal to the control unit. When empty the signal from the sensor is constant and the light reflected produces an outlet voltage. The sensor can discriminate between areas of feed as small as 6 mm diameter and the bottom of the trough.

At the same time as the travelling trolley traverses the feed compartments, the position sensors (proximity switches) detect a marker stud in alignment with the leading edge of a compartment and produce an electrical signal to indicate to the control unit whether it is an odd or even number. The signal also enables an electronic clock to operate in conjunction with the output from the optical detector.

The optical detector arrives at the leading edge of the compartment at the same time as the position sensors and now scans the compartment. If feed is present and obscuring the reflective bottom, there will be no electrical output from the optical detector and the clock will continue to count. When the optical detector passes over a bare portion of the compartment floor, the electrical output produced stops the clock and holds the count until the sensor reaches a portion of the bottom obscured by feed whereupon the output will cease and the clock will continue its count.

As the optical detector is capable of discriminating small areas of feed, the magnitude of the count achieved by the time the optical detector has reached the end of the compartment will approximate to the proportion of feed covering the bottom of the compartment. Should this count be less than a preset small value, the information will be stored in the control unit until the appropriate auger is over the corresponding compartment, whereupon the electromagnetic clutch is engaged to drive the auger. This delivers a preset amount of feed by time duration previously determined by the forward speed of the trolley, length of compartment and diameter of the auger outlet.

This system operates along the length of the cages. At the far end of its travel, a limit control is actuated by an end stop which switches off the feed and drive motors and switches on a delay timer. After a five second delay, the reverse drive is operated to carry the assembly back to the start position where another limit control is actuated. These stop the motor and the equipment remains stationary until the time clock switches in the next feed cycle. During the reverse run, the feed motors and electronics are not operative.

3.3 Modifications to feed assembly

3.3.1 Feed compartment troughs

Experience showed that the birds did not clean the bottom of the feed compartments and a fine opaque covering was produced as a result of a mix of saliva with the finely ground feed. This inhibited the reflection from the stainless steel bottom, giving a negative response with no feed being delivered. Temporary improvement could be achieved by increasing the sensitivity of the optical sensor. This was self-defeating as feed was delivered sooner than required which resulted in high feed levels in the compartments with subsequent wastage and mixing through the birds flicking feed with their beaks.

The optical sensor gave better results if it was used to detect light reflected from the surface of the feed when the feed was within a fixed distance from the sensor, thus accepting the variations due to the different feed reflectivities and the fluctuating tray-to-sensor distance. This change required that the electrical signal from the sensor had to be inverted, ie to provide a signal when feed was present above the set level and not, as before, when no feed was present. A simple addition was made to the electronic circuitry to achieve this. The sensors used have a focusing arrangement to achieve the optical change.

Even at correct feed levels in the trough compartments, the problem of mixing remained when birds pecked from compartment to compartment and flicked food, thus mixing the two feeds. To reduce this, the height of the compartment dividers was increased from 50 mm to 60 mm.

3.3.2 Delivery auger spouts

Clearance between the end of the auger spouts and the frame of the cage was insufficient. After the birds became accustomed to the passage of the feed assembly they continued feeding as it passed causing a few neck and head injuries, some fatal.

Guards were initially fitted to the augers to deter the birds from feeding as the feed assembly passed but results were not entirely satisfactory. Therefore, the clearance between the ends of the augers and the cage bars was increased by fitting 36 mm spacers between the hopper mounting, motor mounting and the main frame. This allowed clear passage of the feed assembly and enabled the birds to feed at the same time without risk of injury.

3.3.3 Feed delivery

The feed hopper was originally designed for pelleted balancer meal. This increased the cost of feed to an unacceptable level, however, so ground meal was subsequently used. The moisture content and comminution of the meal led to "bridging" in the hopper. This difficulty was finally solved by fitting an electrically driven inertia vibrator on one side of each meal hopper. The noise of the vibrators was not sufficient to disturb the birds. Both the balancer meal and grain augers were blocked, on occasion, by foreign matter. Representations were made to the feed mill regarding the "dirty" grain and meal.

4 Future work

The prototype SIAE self-choice feeder will be evaluated in conjunction with three kinds of comparative control treatments:

(1) the same number of birds in the same type of cage, fed ad libitum on a good single feed (ie a mixture of the self-choice feeds although the grain will be ground);
(2) other like individually caged birds fed the same as in (1);
(3) other like individually caged birds fed the same as birds being fed by self-choice feeder.

As an alternative to the method of self-choice feeding, it is envisaged that feed could be presented to the birds by continuous, slow moving, open conveyor belt.

The two components of the feed would be placed on the belt by a mechanism capable of varying their proportions. The remains of the feed mixture at the other end of the belt would enter a device capable of measuring the proportions left after the poultry had taken their choice. The result of this measurement would be used to vary the proportions of feed being placed on the belt by the supply mechanisms. This closed loop would ensure that the supply matched the demand in terms of proportion of feed.

Acknowledgement

The assistance of the following is gratefully acknowledged: D Macdonald and staff, Edinburgh School of Agriculture, Easter Howgate Farm, Midlothian. N Turnbull and staff, SIAE Workshop, Bush Estate, Penicuik.

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Handling equipment to aid pregnancy testing of ewes

M J Sharp and E H Robertson

Introduction

The use of real-time ultrasonic scanning, a technique widely used in human obstetrics, can bring substantial benefits to the sheep industry if applied to the pregnant ewe.

The number of foetuses carried during late pregnancy has a considerable effect on the nutritional requirements of the ewe and without any reliable information on foetal numbers the feeding regime applied is often little more than a matter of guesswork. At best, it is a compromise, resulting in animals carrying single lambs being overfed and animals expecting multiple births being underfed. Both situations can be detrimental to production levels.

Lamb mortality is closely related to birth weight and overweight lambs often die as a result of prolonged and difficult births. Similarly, underweight lambs may die because of weakness and excessive heat loss. Ewes carrying a larger than average number of foetuses may also suffer from metabolic disorders, such as pregnancy toxaemia, if nutrient levels are insufficient.

Clearly the application of accurate pregnancy diagnostic techniques would be of considerable advantage to the flock manager, for the reasons given above. Moreover, some savings in feed cost may also be made, particularly with the identification of barren ewes. For the hill farmer the information is invaluable because he can separate ewes expecting multiple births prior to lambing and keep them on in-bye land thus achieving considerable savings in labour at lambing time.

Scanning

Real-time ultrasonic scanning of pregnant ewes was pioneered in

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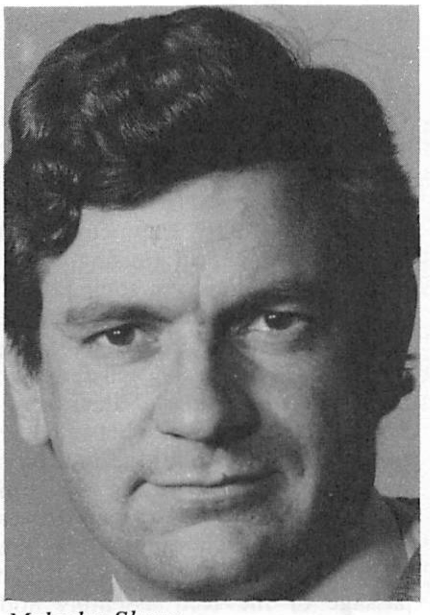

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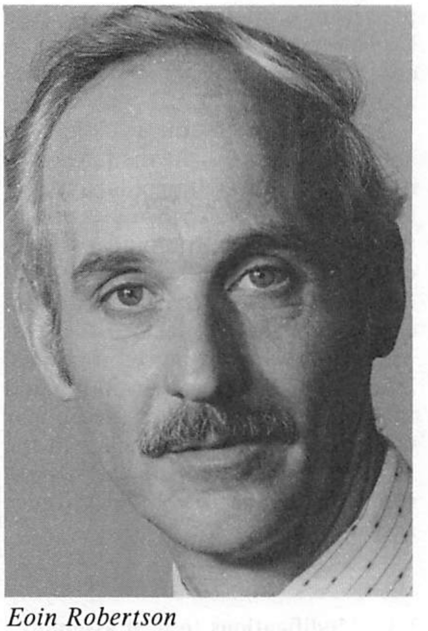


Eoin Robertson

Australia and subsequent research has been carried out in the United Kingdom by the Hill Farming Research Organisation (HFRO) at Bush Estate, Penicuik.

A short period of training for scanning operators is required and suitable courses are undertaken at the HFRO. Results have shown that with a little experience 99% accuracy of pregnancy diagnosis is obtainable when differentiating between barren, single and multiple bearing ewes. In commercial flocks, scanning should ideally be carried out after the last ewe mated is 45 days pregnant and before the first ewe mated is 105 days pregnant.

At the time of writing, contractors are charging approximately 45–50 pence per ewe for scanning using instrumentation costing in the region of £6000, hence a fairly large throughput of sheep is required to make the operation economical. The sequence of events entails catching the ewe, turning her manually and then sitting the animal in a small deck chair type frame where she has her belly clipped and an aqueous solution applied to act as an acoustic coupler; only after this procedure has been completed can the ewe be scanned. The scanning operator then waits until another animal is caught and prepared before he can proceed. This time consuming process requires a minimum of three people to perform, so obviously there is scope for an improved handling system.

With this objective in mind, the Scottish Institute of Agricultural Engineering (SIAE) embarked on a co-operative project with the HFRO to design and develop sheep handling equipment to make the scanning operation more efficient.

Two different designs have been produced at the Scottish Institute of Agricultural Engineering. The first is a large trailer giving all-weather protection and providing facilities required for research work at the Hill Farming Research Organisation. The second is a much smaller cheaper frame suitable for use by contractors on commercial farms.

Research type handling trailer

The Hill Farming Research Organisation required a purpose built trailer with all-weather protection which would incorporate a production line system (figures 1 and 2) whereby ewes would enter the trailer, be turned by some mechanical means into a cradle where they could be clipped in preparation for scanning. The cradle would be moved to a scanning station

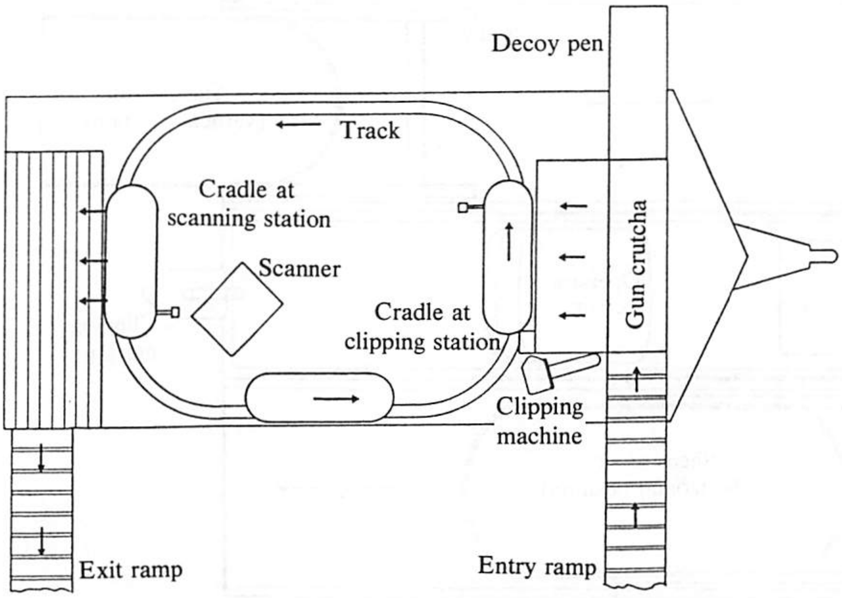


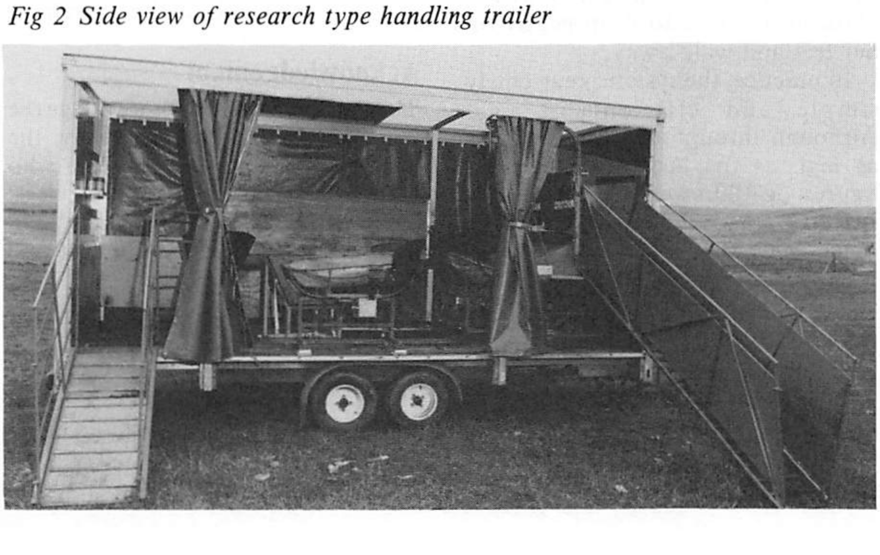
Fig 1 Layout of research type handling trailer

and the ewe subsequently released. Additional cradles in the circuit would allow for any time differences between scanning and clipping stations, thus ensuring that the scanning operator would not be delayed by waiting for sheep to be prepared.

The ewe turning machine preferred by the HFRO is an Australian machine known as the "Gun Crutcha", designed to invert sheep for tail clipping, foot trimming, etc. It consists of a compartment containing a tilting floor and side activated by a foot pedal, when the pedal is depressed sharply, the ewe is tipped out sideways on to a chute and into a cradle. Sheep enter the machine via a ramp, this being sufficiently long to ensure that the animals can see a decoy sheep standing in a pen attached to the other side of the unit.

The "Gun Crutcha" turning unit is mounted on the front of a 4.5 x 2.14 m aluminium platform of a specially designed trailer following modifications to lower the height of the machine and remove the fixed reception cradle. An oval shaped steel track is mounted on the platform floor immediately behind the turning unit. Running on, and attached to, the track are three trolleys each supporting a single cradle. The trolleys incorporate a spring damped, tipping mechanism to tilt the cradles, thus allowing the ewes to roll off on to their feet when released. A constant tension securing belt is fitted to restrain the more energetic animals across the chest while inverted. Two pedal operated stops are strategically placed at the clipping and scanning stations to hold the trolleys stationary. A non-slip rubber mat is fitted to the aluminium floor of the trailer where the ewes are released to prevent animals from slipping and damaging themselves.

Fig 2 Side view of research type handling trailer



Facilities are provided for the installation of an electric shearing machine and an ultrasonic scanner, and the trailer is equipped with a 13 A electrical system for connection to the mains supply or a generator.

All-weather protection is provided by means of sheet aluminium on the front and rear walls, and an opaque fibreglass roof. The front end of the trailer is wedge shaped to provide a more aerodynamic profile for towing. Heavy plastics curtains are fitted to the sides of the unit which can be tied back or closed in various ways to provide the degree of weather protection required.

In use

Once the trailer is in position, it is given a slight rearward tilt using the four corner jacks provided, to give the sheep laden cradles downhill travel. The exit and entry ramps are fitted at the front offside and rear offside of the trailer respectively. The decoy cage is attached to the turning unit at the front nearside of the trailer and is loaded with a decoy sheep. On seeing this decoy, the ewes run up the ramp and into the turning machine where a sharp depression of the pedal ensures that the animal will be turned upside down into a waiting cradle. She is secured in this position with the retaining belt and her belly is clipped by one of the two personnel on the trailer. The loaded cradle trolley is then released and pushed round the track to the scanning station. The ewe is scanned by the second man on the trailer and released by depressing the pedal which operates the cradle tilt mechanism. The ewe leaves the trailer via the exit ramp of her own accord.

Experience gained during the first season of use has shown that three cradles in the circuit is the optimum number, any more resulting in the working area being too crowded. Throughputs have been excellent with up to 150 ewes/h being achieved. Few problems have been experienced in getting the sheep up the ramp and into the turner but some dificulties have occurred in providing a cradle of an optimum size to suit all breeds of sheep.

Commercial type handling unit

While the ewe pregnancy testing

trailer is ideally suited to the specialist requirements of a research institute, it is probably too costly for a comercial contractor to purchase purely for sheep scanning. There is, therefore, a requirement for a more simple and less expensive piece of equipment to replace the somewhat crude "deckchair" fabrications currently in use on farms. Ideally, any new equipment should provide a system of operation whereby sheep can be placed into a cradle in order to be prepared for scanning whilst another ewe is in the process of being scanned, to maintain a high throughput. A simple method of obtaining this is to place a device capable of holding an inverted sheep on either side of the scanner operator. It is desirable that the loading and clipping operation takes place slightly behind the scanner operator to ensure that he, or the expensive equipment, does not get damaged. This requires the use of a trolley system to allow the sheep cradles to be moved backwards and forwards slightly.

The adoption of such a system requires the operator to scan sheep using both his right and left hands and, in practice this has been something that operators have been quick to learn, however care must be taken, when using the less dominant hand, to ensure that the transducer is held correctly to avoid images that mirror those normally examined.

The problem of finding a suitable cradle for holding sheep was solved by the introduction through the Scottish Farm Machinery Working Group of a sheep chair invented by W Hiddleston, a Scottish hill sheep farmer. The chair consists of a tubular frame holding a rubber stretcher and has six legs allowing it to sit in two positions, upright and horizontal. The transition from the upright to the horizontal position is achieved by rocking the chair back as it pivots on the central legs.

The basic framework of the handling unit consists of three rectangular frames constructed from hollow section mild steel. The central frame is fitted with a wooden platform and sides to support and protect the scanning instrument and operator, a chair for the operator, and a pole to carry the shearing machine. The other two frames are located by pins on either side of the central frame to act as tracks for small trolleys carrying the sheep chairs (fig 3). The whole unit is easily transportable by trailer or pick-up truck.

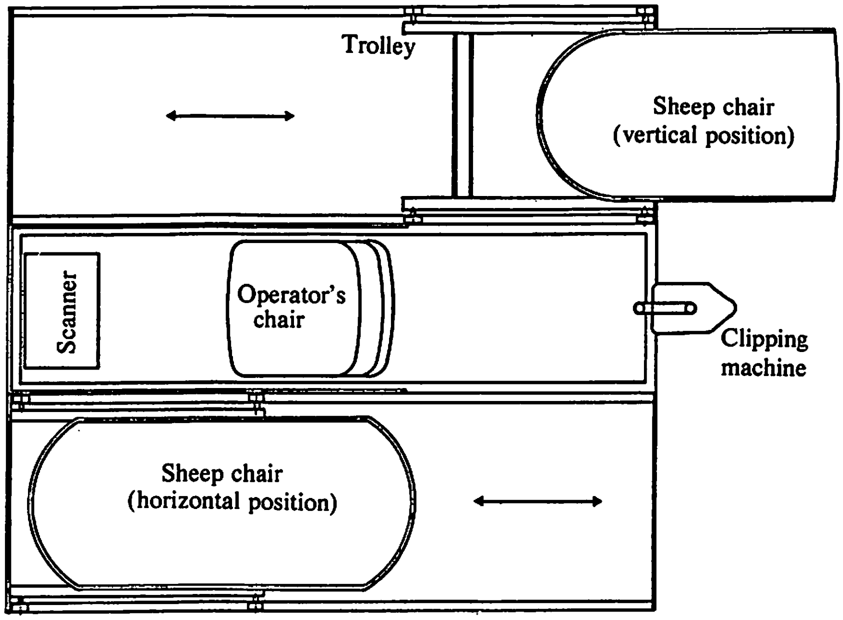


Fig 3 Layout of commercial type handling unit

In use

The unit is set up in close proximity to a small pen from which sheep can easily be caught. Individual sheep are caught, reversed back into the sheep chair and the chair set in the horizontal position, after which the animal is clipped. A small foot pedal is depressed to release the trolley to allow the cradle to be moved forward for scanning. While the animal is being scanned, the chair at the other side is loaded and the sheep prepared. To release the sheep, each chair is pulled to the back of the unit and tipped into the upright position allowing the ewe to drop gently on her feet and walk away.

In practice, the system is extremely simple and efficient in use. Although throughputs are not quite as high as the large sheep trailer, figures of 100 ewes/h are possible. An advantage of the system is the quiet and efficient way it works resulting in a minimum amount of stress on the pregnant animals as they lie very quietly in the sheep chairs. The system works with only three people, one scanning, and two catching and preparing the ewes.

Future developments

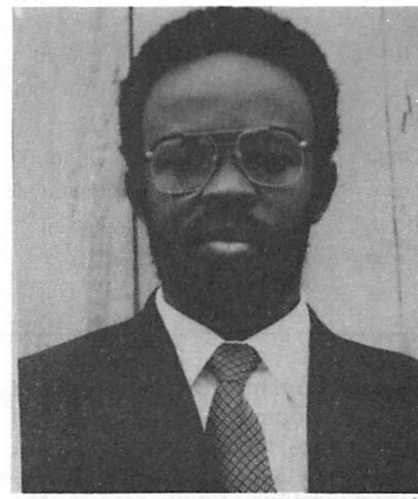
While the two machines described greatly speed up the operation of scanning ewes, there still remains the labour-demanding tasks of turning the ewe, clipping her belly and applying an acoustic coupling fluid. These procedures are necessary due to the design constraints of present day linear scanners, but research in scanner design has now proceeded to a point where a new sector scanner will shortly be available. This will allow scanning of ewes to take place without the need to clip the belly, therefore scanning can be carried out with the ewe standing up, perhaps in a specially designed race. This will greatly alleviate the handling problem and speed up the operation.

Acknowledgement

The authors wish to acknowledge the help and assistance given by the farmers and scanner operators who used the two handling devices; particularly Angus Russel and Ian White of HFRO, John Burnett and George Wilson of Broughton, Biggar.

The effect of changes in catchment characteristics on soil erosion in developing countries (Nigeria)

D O Aneke



Summary

RECENTLY, soil erosion has progressed at a sporadic but alarming rate almost throughout the country. In order to find the causes of and remedy for this problem, a team of experts was assembled to undertake a survey of erosion status of the country. The team noted a rapid infrastructural and industrial development in the country between 1971 to 1981.

Numerous roads, industrial establishments, public and private buildings, academic institutions, stadia, airports etc were developed on a massive scale all over the country within this period. The characteristics of the water-shed were significantly affected.

The basic equation in flood control is:

$$Q = CIA/360$$

where: Q = rate of runoff in m^3/s
C = coefficient of runoff
I = intensity of rainfall in mm/h for storms of 2 h duration
A = area in hectares between 100–200

Since the coefficient of runoff is the variable in this type of situation where the annual rainfall intensity, area and soil of the country are constant, the responsibility for the increased runoff and so increased erosion must be largely borne by the changes in the catchment characteristics.

Introduction

The cause of the recent occurrence of sporadic soil erosion in Nigeria could be traced to inadequate planning in the rapid project developments brought about by the increased revenue earning power between 1971 and 1981. There has always been soil erosion processes but, since 1971, the country has witnessed unprecedented gully and sheet erosion of soil by water. Under natural conditions, soil erosion always takes place at a rate not in excess of geologic. The control of accelerated erosion is, therefore, the concern of all soil conservationists. Accelerated erosion is caused by activities of man in the environment in which he lives. The objective of these activities have always been to improve man's standard of living and create better facilities and environment for better living. The activities include massive bush clearing for agricultural and industrial purposes, building of better and larger houses, stadia, airports, roads (rural and expressways), numerous academic institutions, more and larger village squares, club houses, etc. These developments were carried out with little or no planning, resulting in radical changes in the natural topography and slopes. As a result, large areas were exposed, more runoff was generated and soils were detached by the runoff and eventually moved into the drainage system by the uncontrolled runoff. Until about 1974, many people were not aware of the need to provide soil

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Fig 1 Slope stabilisation of gully endangering nearby houses

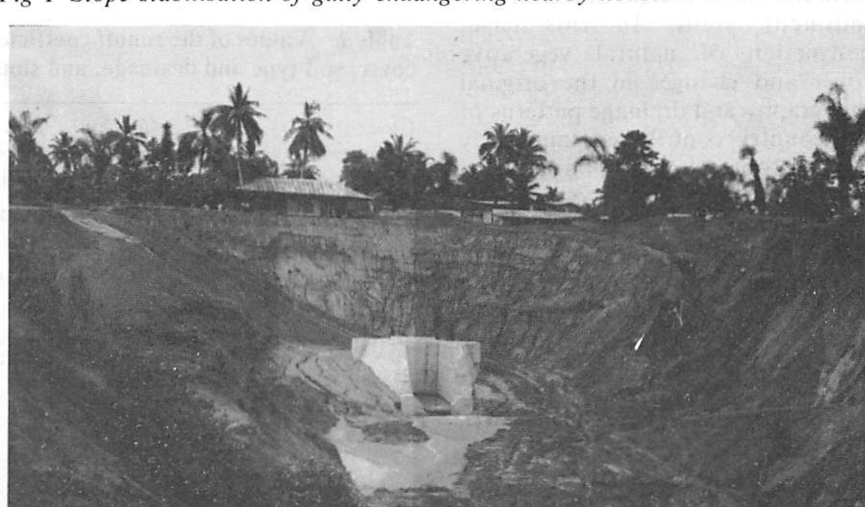

Table 1 Technical data and estimated costs of the proposed protective measures in ten selected gully areas (One gully area in each State) 1981

State	*Visited towns*	*Local Government authority*	*Affected area, km²*	*Max length, km*	*Max width, m*	*Max depth m*	*Max slope, %*	*Average slope, %*	*Estimated cost,(N)M*	*Remarks*
Kano	Walawa	Gwarzo	1.4	3	1000	30	3	2	0.185	Very active
Niger	at 16 km, Minna-Tigina Dukku village	Chanchaga	10	9	4	5	5	3	0.038	Very active
Sokoto	Birni-Kebbi	Birni-Kebbi	50	15	1500	12	20	10	1.21	Serious destruction in the area
Gongola	Panti Sawa	Jalingo	100	5	6	8	25	10	0.10	Very active
Plateau	Mangu	Pankshin	25	1.5	35	4	5	1.5	0.078	Very active
Kwara	Egbe	Oyi	1.2	0.6	8	6	10	9	0.060	Very active
Ondo	Idanre	Ondo	0.6	1.1	1.5	4	10	9	0.081	Moderately active
Ogun	Yey-Erumon	Ijebu-Ode	0.7	1.2	90	8	5	4	0.10	Very active
Bendel	Auchi	Estsaji	0.5	1.5	5	6	14	13	0.040	Very active
Cross River	Uyo	Uyo	8.5	1.2	100	45	37	21	0.750	Very active
								Total estimated cost	*= N2.642M*	

conservation measures in land and road developments. It was not until large houses, industrial sites, schools, roads, stadia and whole villages became victims of gully erosion that the attention of both the Federal and State governments were drawn to this problem. Now Nigeria spends an average of thirty-five million Naira every year in the control of gully and sheet erosions in the country. Table 1 shows a typical survey and the cost estimate for ten gullies in the country selected for remedial measures. Most of the literature reviewed (Aneke 1982, Aneke *et al* 1982, Fidelis and Foragate 1973, Harold 1957, Melvin 1971) show that, for a given catchment, the togography (slope), soil vegetative cover and rainfall form the major factors in runoff and sediment yield. In this case, destruction of natural vegetative cover and changes in the original togography and drainage patterns of the country contributed immensely to the problems of erosion hazards. The problem is likely to continue until a more serious effort is directed towards effective and economic soil erosion control measures by trained soil conservationists and engineers.

2 Catchment characteristics as an index in predicting runoff and erosion

By using the catchment characteristics as an index, it is possible to predict the runoff in the given catchment area. The runoff coefficient is a fraction of the rainfall in a catchment area. This is determined by factors such as drainage pattern, vegetation, soil characteristics, topography, etc (table 2). This can be evaluated from the rational formula:

$$Q = CIA/360$$

where: Q = rate of runoff in m³/sec;
C = dimensionless coefficient of runoff;
I = rainfall intensity in mm/h for storms of 2 h duration;
A = catchment area in hectares between 100–200.

It is the change or alteration of one or more of the catchment characteristics that have triggered a whole series of soil erosion problems which always end up in gullies. For any particular location, the rainfall intensities, soil and the area are constant. Therefore, it is the massive and unprecedented changes (without adequate planning) in the catchment characteristics that would account for the phenomenal rate of soil erosion in Nigeria in recent times. These changes have been summarised below.

2.1 Rainfall interception

The amount of rainfall or precipitation reaching the ground surface is dependent upon the nature and density of vegetation and ground cover, including roofing materials. In recent years, roofing materials have been revolutionised in Nigeria.

Table 2 Values of the runoff coefficients, C, for the three additive components of cover, soil type and drainage, and slope for Africa — S Rhodesia (Hudson 1973)

Cover	*C*	*Soil type and drainage*	*C*	*Slope*	*C*
Heavy grass	10	Deep well drained soils	10	Very flat to gentle	5
Scrub or medium grass	15	Deep moderately previous soils	20	Moderate	10
Cultivated lands	20	Soils of fair permeability and depth	25	Rolling	15
Bare or eroded	25	Shallow soils with impeded drainage	30	Hilly or steep	20
		Medium heavy clays or rocky surfaces	40	Mountainous	25
		Impervious surfaces and water logged soils (add 5 for t_1 and 15 for t_2 where soils have a factor of 30 or less	50		

Fig 2 Interceptor drain for runoff

Numerous thatched houses were replaced with more solid houses of corrugated iron sheets, asbestos materials, etc. Deforestation of large areas were carried out for industrial and agricultural purposes. More runoff was then generated due to the decrease in vegetation cover. Since no adequate planning was made to take care of the increased runoff, erosion problems were created and multiplied to become a real threat to many communities.

2.2 Infrastructural development

There were massive developments in Nigeria's infrastructure. Residential and commercial buildings, expressways, markets, airports, schools, stadia, quarry and mining grounds, borrow pits, parks, etc, were liberally established without adequate provisions for erosion control. The values of the coefficient of runoff consequently increased and so the erosion rate.

2.3 Farming activities

Under the Federal Government Land Clearing Programme for the "Green Revolution", it was estimated that over 150,000 hectares of arable land were cleared between 1971–1981. The State Governments were also known to have cleared more than this figure (Federal Dept of Agric 1978).

The problems of land clearing is compounded by the use of wrong equipment for the clearance work. Soil structure was destroyed and, in some cases, the top soil was entirely removed and dumped at the edge of the farm. These activities and processes create favourable conditions for erosion on the farms.

2.4 Changes in drainage pattern

It is a common sight in the villages to observe many roads that have turned into gullies. These rural roads were built without any regard to the original existing drainage pattern. This often results in the sudden appearance of rills on the roads which eventually become gullies. Some of the main roads were built without a proper drainage system, thereby creating erosion problems.

2.5 Play-grounds and parks

Recently, Nigeria was split into numerous Local Government Areas. Each of these Local Government Areas has at least one stadium, numerous play-grounds and motor parks. Nigeria's "Social Clubs" are almost innumerable and they all have developed headquarters and play-grounds in the villages. Natural drainage patterns were changed and sometimes entirely blocked. The brown or muddy streams and rivers that are seen all over the country are clear evidence of the erosion and sedimentation which has occurred in recent times.

3 Case studies

3.1 Uyo gully erosion (Cross River State)

Uyo is a fast growing town in the Cross River State of Nigeria. Not very long ago, this town was provided with Colleges of Education, two Sports Stadia, many new residential areas and expanded motor parks. The commercial activities in the town prompted river sand and laterite removal within and around critically stabilised watersheds. Sewage and waste water were disposed of carelessly. These activities drastically changed the catchment characteristics. The value of the runoff coefficient was increased and so also the soil erosion rate. Today, some of the structures, such as sports stadia, residential houses and roads, are now right inside the gullies.

3.2 Aba Township gully erosion

The case of Aba in Imo State is similar to that of Uyo. This is a very fast developing commercial and industrial town in Imo State. Recently, many industrial sites have been cleared and built up. Many residential houses have been built without a proper drainage system. Ground has been cleared and converted into markets. The natural drainage pattern and vegetative cover has been tampered with, resulting in drastic changes in the catchment. More runoff was consequently generated, causing soil erosion.

3.3 Agulu/Nanka/Alor erosion complex

It is believed that this gully complex developed about 200 years ago. Many reasons have been deduced as causes of this problem. Most reasons point to the destabilisation of the ecological equilibrium. At one stage, the gullies were almost stabilised by applying conservation measures to the complex. Recently, the problem became very acute once more, due to very rapid changes in the physical development of the area. Many houses, schools, roads and farms fell into the fast expanding gullies. This is particularly alarming at Alor where the rate of gully advance has been recorded at 96 metres in one rainy season of six months. Within this catchment area, drastic changes have occurred, exposing the soil and changing the drainage pattern.

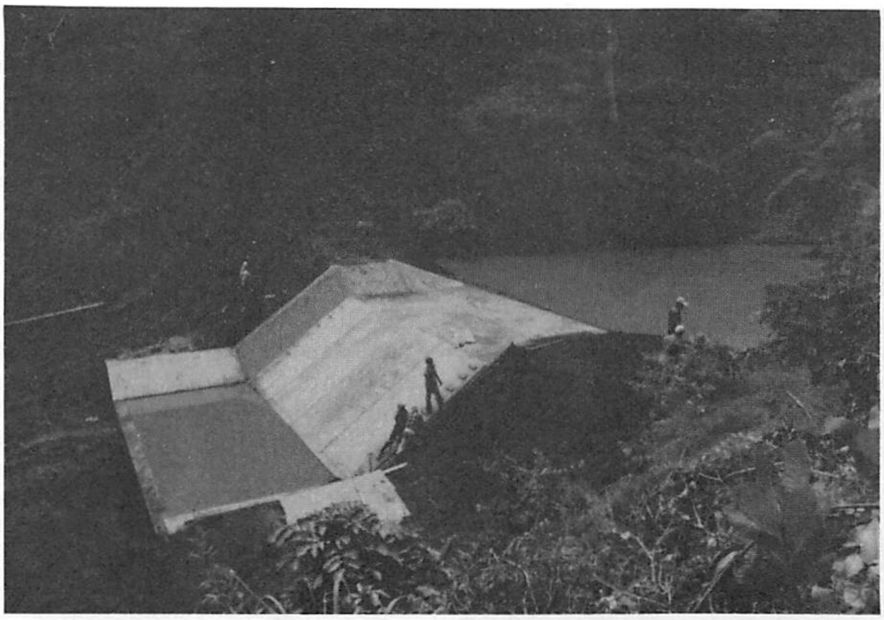

Fig 3 A check mixed dam to detain runoff

3.4 Amucha gully erosion problems

Amucha is one of the recent gully erosion problem areas in the East of Nigeria. The main causes are the changes within and around Njaba River catchment. Very close to the gully sites are two big secondary schools recently built. Many local roads have been constructed without adequate drainage systems. Markets and village squares have been surfaced quite recently. The rate of gully advance here has been recorded at 152 metres within five months of rainfall — May to September 1982.

3.5 Ankpa gully erosion

Ankpa is a fast developing town in Benue State. One of the main gully units developed as a result of large runoff generated from the developing town. Police Barracks have been established and expanded. The other two gullies are located very close to the expanding Government Teachers' College. In general, large areas have been cleared at Ankpa for one kind of development project or another. The original drainage pattern and topography of the town were seriously affected, leading to increased runoff and therefore increased erosion rate.

3.6 Gombe gully erosion

The Gombe gully erosion in Bauchi State is a typical example of erosion problems arising from mining and quarrying activities. The ancient clay mines were not properly reclaimed before human settlement took place around the mines. The hitherto rural hydrology quickly transformed into urban hydrology. This change was responsible for the urban gully erosion.

3.7 Jos/Hiepang/Bukuru erosion problem

This complex is yet another example of erosion caused by mining and quarrying activities. The topography, drainage pattern, and natural vegetation have been greatly tampered with. Indiscriminate digging and excavation activities ended up creating big gullies. The soils which were greatly disturbed and exposed were easily picked up by the runoff, and eventually big gullies and numerous rills were made.

4 Land use patterns

Table 3 represents the dominant land use pattern of Eastern Nigeria before the massive civil and industrial developments reached their height in 1982. In this survey, a total of 4743km^2 were covered in Anambra and Imo States. Only about 17% of the total area surveyed were either effectively cropped or urbanised. On commencement of the physical changes, the ecosystem was significantly destabilised and the physical characteristics of the catchments disorganised, resulting in unprecedented and uncontrolled runoff.

5 Conclusion

The nation's wealth increased remarkably between 1971–1982. As a result of this, many agricultural and industrial developments were undertaken without proper planning, especially as they affect the land. Numerous new roads, land clearing, industrial developments and the like which were undertaken throughout the country significantly affected river catchment characteristics. Much more runoff was generated from the catchment areas and the resulting flood created complicated erosion problems almost throughout the country. Losses and damage caused by erosion can be measured in terms of lives, properties and fertile agricultural land which have been claimed by erosion phenomena.

In order to check or control this disaster, systematic planning has to be adopted, for example:

Table 3 Representative land use patterns of Southern Nigeria (Niger Techno Ltd *et al* 1978)

Land use	*Anambra State* Area, km^2	*Anambra State* %	*Imo State* Area, km^2	*Imo State* %
Cropped areas (grass crops)	445.81	24.5	244.97	8.1
Abandoned areas	307.15	16.9	574.62	18.9
Abandoned areas except 15% to 20% cropped surface	26.20	1.4	447.91	14.7
Oil palm grove in association with other tree crops	523.85	29.3	1,376.22	45.0
Oil palm grove in association with herbaceous crops	232.44	12.8	—	—
Savannah and/or uncultivated land	112.25	6.2	206.24	6.8
Forest	34.93	1.9	176.76	4.8
Gully areas	21.83	1.2	1.68	0.1
Areas subject to flooding	16.30	0.9	—	—
Thickets along river banks	68.52	3.8	42.65	1.4
Urban areas	20.02	1.1	565	0.2
Total area covered by survey	1,696,30	100	3,046.70	100

1 by-laws on land use and development should be enacted at the Federal, State and Local Government levels to control abuse of land;
2 all road contracts should provide for erosion control measures;
3 before any massive land clearing is carried out, adequate soil conservation measures should be made;
4 efficient drainage systems should be provided in all the urban and semi-urban developments, especially in new settlements;
5 scientific farming system is necessary to cut down on soil losses on crop lands;
6 integrated watershed development is essential to control erosion from uncultivated and barren land;
7 critical catchment areas should be reserved and human settlements avoided near gully and mining areas.

Since soil erosion is an interdisciplinary affair, combined efforts of engineers, soil scientists, foresters, geographers and even sociologists are needed to effectively control it.

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Some design and operational aspects of 3-link implement attachment systems

F M Inns

1 General

THE 3-link implement attachment system as we know it today originated with Harry Ferguson. He extended the functions and versatility of all previous mounted implement attachment systems by incorporating a hydraulic system to provide for implement lift and also, most profoundly, to allow automatic control of implement working depth. Although elegantly simple in concept the 3-link system has to fulfil many requirements, sometimes conflicting, for a wide variety of implements. Some major functional requirements are to:

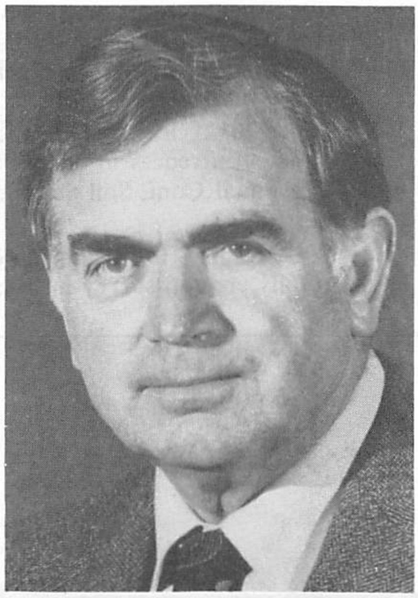
- lift the implement for field manoeuvrability and road transport and lower it into work,
- provide adjustments to allow correct alignment of the implement when in work,
- match implement and tractor forces for optimum operational efficiency (steerability, traction, etc.),
- provide stability and control of the implement when in work,
- provide operator convenience and safety.

This paper will review briefly some of the principles involved in the design of the 3-link attachment system. The intention has been to choose aspects which may be of interest and relevance to the operator of tractors and machinery.

2 Basic concepts

Linkage geometry

Linkage "geometry" is defined by the



length of the top and lower links and the spatial relationship between the attachment points at the implement and tractor ends. At the implement end, this relationship is governed by standards (eg BS 1841: part 2, 1973) which are generally accepted and observed by implement manufacturers. Alternative top and lower link attachment points may be provided on some implements. At the tractor end, the positions of the attachment points are the responsibility of the tractor designer, as are the lengths of top and lower links. He has to design for a workable combination of tractor and implement, taking into account the standardised 3-point hitch dimensions of the implement according to the power output of the tractors with which it is intended that the implement should be used (table 1). Some manufacturers provide alternative linkage attachment points on the tractor, usually for the top link in order to give varying sensitivity to the draught control mechanism. Alternative lower link attachment points are provided on a few tractors — eg Marshall 302 — particularly when no draught-sensing control mechanism is fitted.

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Table 1 3-link attachment systems: recommended size categories according to tractor power (BS 1841: part 2, 1973)

Category	*Maximum drawbar power, kW*
1	up to 33
2	30 to 75
3	more than 60

BS 1744 gives details of test procedure for assessing drawbar power.

Point of convergence

The performance of soil engaging implements is very strongly influenced by the point of convergence (PoC) of the attachment links. The point of convergence in the

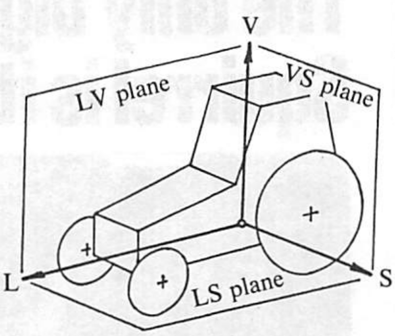


Fig 1 Definition of longitudinal, vertical and side directions, VS, LS and VS planes

LV plane (side view — see fig 1) determines the kinematics of implement lift and lower movements, influences the capacity of the implement to penetrate to working depth, has a significant effect on depth control and governs the amount of weight transfer and weight addition generated in free-link conditions. The point of convergence in the LS plane (plan view) may assist the implement in maintaining a stable working position in straight-ahead movement (lateral stability), influences the motion of the

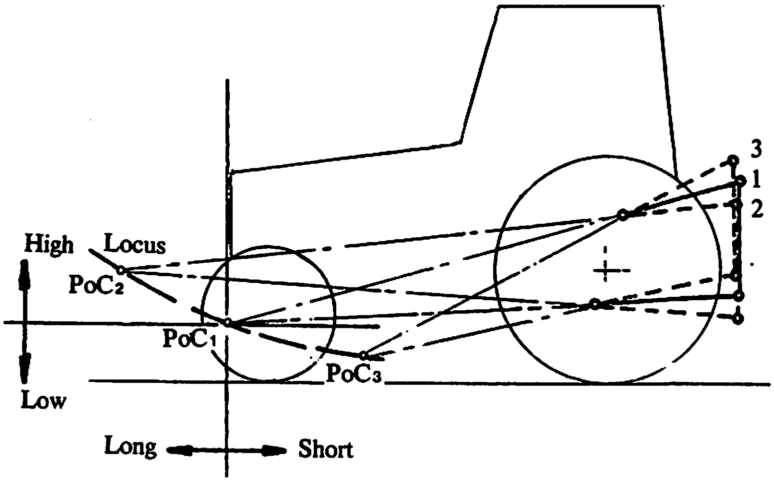


Fig 2 Locus of the point of convergence of linkage as the implement lifts (LV plane)

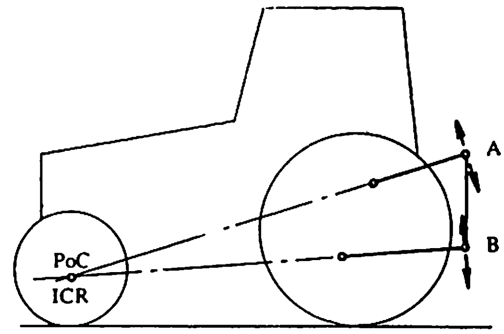


Fig 3 Illustrating instantaneous centre of rotation. Movement of the implement is governed by movements at attachment points A and B. These movements have a common centre at the point of convergence of upper and lower links. The point of convergence is also the instantaneous centre of rotation for small movements and when link lengths are fixed.

implement when working on a curve (eg contour ploughing) and affects the forces necessary to steer the tractor.

The tractor designer sets the point of convergence by deciding the lengths of the links and their points of attachment at the tractor end. In the LV plane, vertical movement of the links, as when lifting or lowering, causes the point of convergence to move, tracing out a line (locus) as shown in figure 2. Typically, the point of convergence occurs somewhere close to the front wheel centres as shown and other positions of the point of convergence may be described relatively as short or long, high or low, as indicated in the figure. It is possible for the operator to vary the point of convergence if alternative attachment points are available either at tractor or implement ends — a judicious variation can sometimes produce useful results.

Instantaneous centre of rotation

When the lengths of the links and the positions of attachment are fixed — as they almost invariably are in present-day use — a vertical movement of the implement is associated with a change in the implement's attitude, ie a slight rotation of the implement. For small "instantaneous" movements, the rotation is apparently centred at the point of convergence which, in the circumstances stated, is also the instantaneous centre of rotation (ICR) of the implement — see figure 3. In other circumstances, the instantaneous centre of rotation will not necessarily coincide with the point of convergence, eg if the link length (top link or lower links) is varying (with or without angular movement of the links).

Free and restrained links

Upper and lower links have a ball joint at each end which transmits forces between the link and the relevant attachment pin, and also permits the link to rotate freely about the pin. When the link is subjected to forces applied only at the two ends it is a condition for equilibrium that the two forces must act along the axis of the link as a tensile or compressive pair. In the case of the lower links, a downward rotation of the links may be prevented, ie the links may be restrained — by applying a transverse (lifting) force from the lift rods, which is additional to the forces at the ball ends. This has the effect of changing the force at the link ends from a purely axial direction as shown in figure 4. The lower links may ,be free (lift rod force = O and ball end forces are purely axial) or restrained (ball end forces make an

Fig 4 Equilibrium of a lower link subjected to lifting force L. Transverse components T_t and T_i of attachment forces increases with L. For given axial load ($A_t = A_i$) the angle θ of resultants R_t and R_i relative to link axis will increase with L.

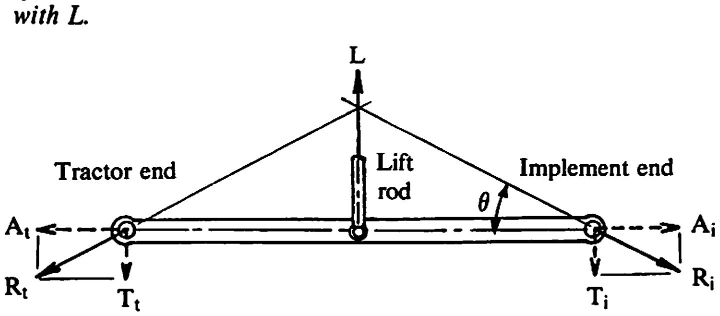
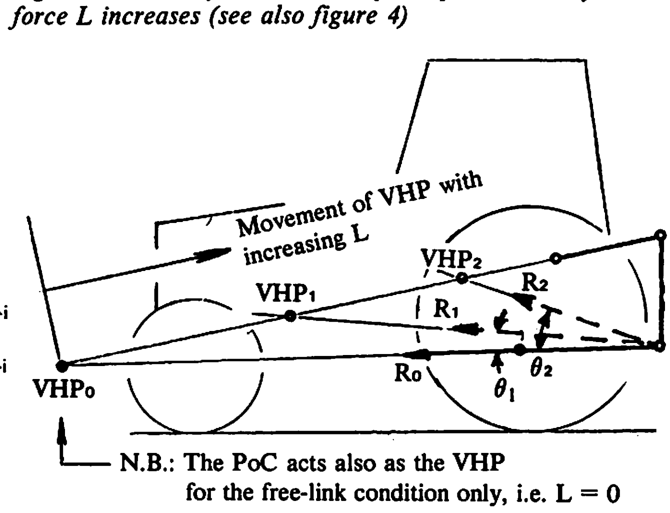


Fig 5 Variation of virtual hitch point position as lift rod force L increases (see also figure 4)



angle θ to the link axis, depending on the magnitude of lift rod forces).

Virtual hitch point
A trailed implement attached to a tractor by a single drawbar pin is obviously pulled by a force from the pin, which represents a real hitch point. In the case of an implement attached by a 3-link system, the force which pulls it is the resultant of the forces from each of the attachment pins. The resultant force does not act from any physically identifiable point on the tractor but appears to come from a "virtual hitch point" (VHP) which can be identified as the common point at which the lines of action of the attachment pin forces meet, which is therefore the point at which the single resultant force acts. In the LV plane, the virtual hitch point may thus be identified.

- *For a free link system*, since attachment forces must act axially along the links, the virtual hitch point coincides with the point of convergence.
- *For a restrained link system*, the virtual hitch point is at the point of intersection of the line of the free top link (for which attachment forces are axial) and the lower link implement pin forces (which make an angle θ to the line of the lower links, depending on the magnitude of the life rod forces — see figures 4 and 5).

Figure 5 illustrates variations in the virtual hitch point.

3 Kinematics of implement attachment

Change of attitude of the implement
When lifted out of work, it is desirable that the implement should permit a good ground clearance or "angle of departure" for the tractor/implement combination as shown in figure 6. A short point of convergence, and hence short radius of rotation of the implement, results in a large change of attitude of the implement for a given lift and hence a good angle of departure.

Influence on work required to lift the implement
For a given height of lift (ie height above the ground of the lower link implement ball ends when the implement is lifted) a large change in attitude results in increased height of the implement centre of gravity (dimension h in figure 6). A large change of attitude is a consequence of a short point of convergence so that, compared with a long point of convergence, more work must be done in lifting the implement to the fully raised position. Since the work available is limited by the pressure and stroke of the hydraulic power lift cylinder, it follows that for a heavy implement (particularly with long overhang to its centre of gravity, such as a disc harrow) a long point of convergence is desirable to limit the height through which the centre of gravity must be lifted. A long point of convergence requires a near parallel linkage which may sometimes be achieved by attaching the top link to a lower position on the implement mast when alternative attachment points are available.

Influence on implement operation

When the implement is lowered into work, high initial penetration is needed to encourage it to reach its working depth quickly. For a mouldboard plough, it is desirable that the implement is pitched into the ground when the front point meets the soil surface and then levels off rapidly as it reaches its working depth. A short point of convergence is desirable for this purpose and it should also be low to encourage penetration to a good depth of work. A tined implement such as a chisel plough acts in a contrary manner — "pitching in" discourages penetration so that a long and low point of convergence is desirable. Penetration of disced implements such as disc harrows is relatively unaffected by pitch but they best maintain evenness of work at varying depths when the point of convergence is long (near-parallel links).

Stable operation of the implement is encouraged when the virtual hitch point of the implement coincides with the point of convergence. This matter is further referred to under the heading "Equilibrium of the implement: restrained linkage draught control system".

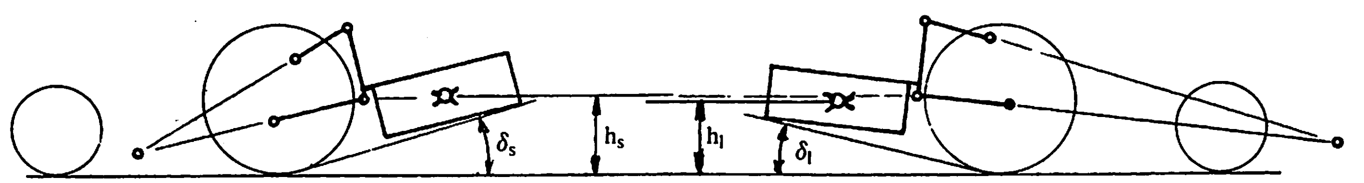
4 Adjustments to the implement in work

In three-dimensional space, the implement has six possible components of movement relative to the tractor. These can be defined according to the L, V and S axes shown in figure 1 as three translational movements in the longitudinal, vertical and side (L, V and S) directions and three rotational movements — pitch, roll and yaw — in the LV, VS and LS planes, respectively. The three-link attachment holds the implement in a fixed position relative to the tractor in the longitudinal direction whilst allowing adjustment and control of movement in each of the other five modes, as shown in table 2.

5 Implement operation and depth control on a plane surface

When the tractor and implement are moving across a plane surface, the depth of work of the whole implement will be maintained constant along the length of the implement, provided that the implement is set level (parallel to the surface) and one reference point on

Fig 6 Angle of departure δ and height of lift of implement centre of gravity h – variation with linkage convergence.

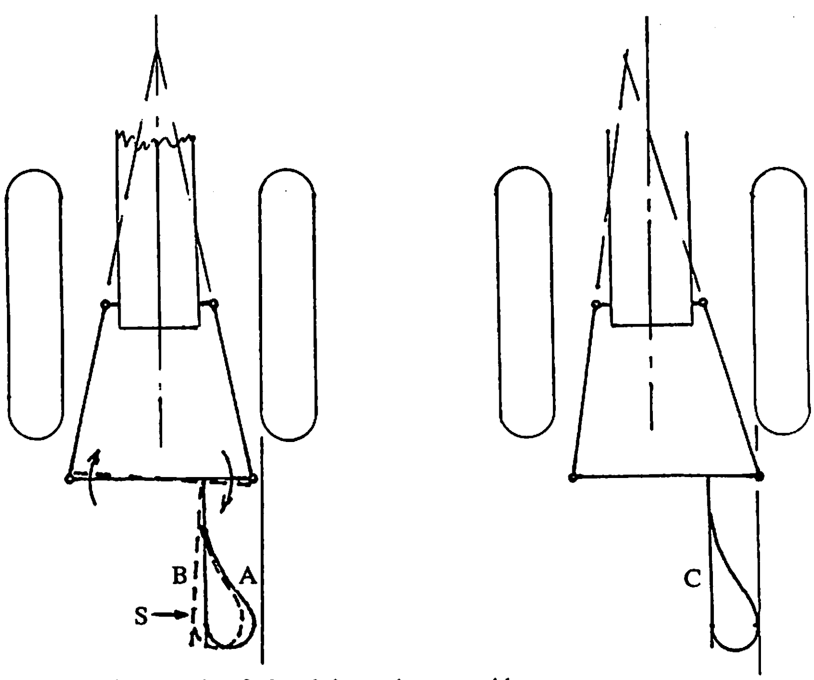


a) Short convergence;
— good angle of departure δ_s
— high lift h_s

b) Long convergence;
— poor angle of departure δ_l
— low lift h_l

Table 2 Adjustments to provide relative movement between the tractor and its implement

Mode of movement	*Purpose of adjustment*	*Method of adjustment*
Translation:		
In L direction	No adjustment: the implement moves forward with the tractor when coupled	None
In V direction	1 To raise the implement for transport and manoeuvrability	Operate implement lift lever
	2 To control implement depth in work	Operate depth or position control lever
	3 To allow the implement to ride over an obstruction	The linkage is free to move upwards from its restrained position
In S direction	1 To adjust width of cut of leading body when ploughing	i) Reposition implement on cross-shaft ii) Rotate cranked cross-shaft Note: correct wheel track settings must be used
	2 To eliminate side-sway of implement when raised for transport	Check chains fitted inside the lower links tighten automatically when the implement is raised
	3 To restrict or eliminate side-sway of the implement (mower, sprayer, etc) when in work	Fit and/or adjust stabiliser link(s) or chains at outside of the lower links
Rotation:		
In LV plane (pitch)	To ensure that the implement runs level (beam or frame parallel to the ground) when viewed from the side Note: pitch may need correction when the working depth is changed	Use the turnbuckle adjuster in the top link to change its length
In VS plane (roll)	1 To ensure that the implement runs level (cross-shaft or frame parallel to the ground) when viewed from the rear	Use the levelling box in the right hand lift rod to change its length
	2 To change the implement from its level setting, eg when making opening and finishing runs when ploughing	As above
	3 To allow the implement to roll in order to follow the ground surface or ride over an obstruction on one side (particularly necessary for wide implements)	The lift rods may have an adjustment which allows them to telescope independently
In LS plane (yaw)	To correct the width of cut of the leading plough body whilst in work Note: this is an indirect method of causing translation of the plough in the S direction (see figure 7)	Rotate cranked cross-shaft



A: Front body of plough is cutting too wide
B: Rotation of cross-shaft mis-aligns the plough deliberately causing additional side force S on landside
C: Side force pushes plough to right until alignment is restored at reduced width of cut or vice versa

Fig 7 (left) Adjustment of front furrow working width by rotation of a cranked implement cross-shaft

the implement is maintained at a set depth. Various methods of implement depth control aim at achieving this desirable state, eg:

- free linkage, variable geometry control,
- free linkage, gauge (depth) wheel control,
- restrained linkage, draught control.

The force systems associated with these major methods of control are examined below.

Equilibrium of a pulled implement

An implement when used with a tractor must form a stable controllable combination when in work and also in the transport position. Forces acting on the implement when in work are:

- gravity (weight);

— soil forces: *fundamental*, eg forces to cut and turn the soil when ploughing;
parasitic - frictional and support forces derived from the soil as necessary to maintain stability of operation) eg soil forces on the landside of a plough and/or support forces on a depth wheel or skid;

— hitch forces transmitted to the implement from the three ball-ends of the linkage.

For equilibrium (steady work at uniform speed), the resultant of the hitch forces must exactly balance the resultant of the gravity and soil forces, ie the magnitude and line of action of the two resultant forces must be the same whilst their directions are opposed.

Figure 8 shows how the resultant of the fundamental soil and weight forces acting on the implement varies with depth of work and consequent variation of draught. In the case of two of the control systems mentioned above, ie:

— free linkage variable geometry control,

— restrained linkage, draught control,

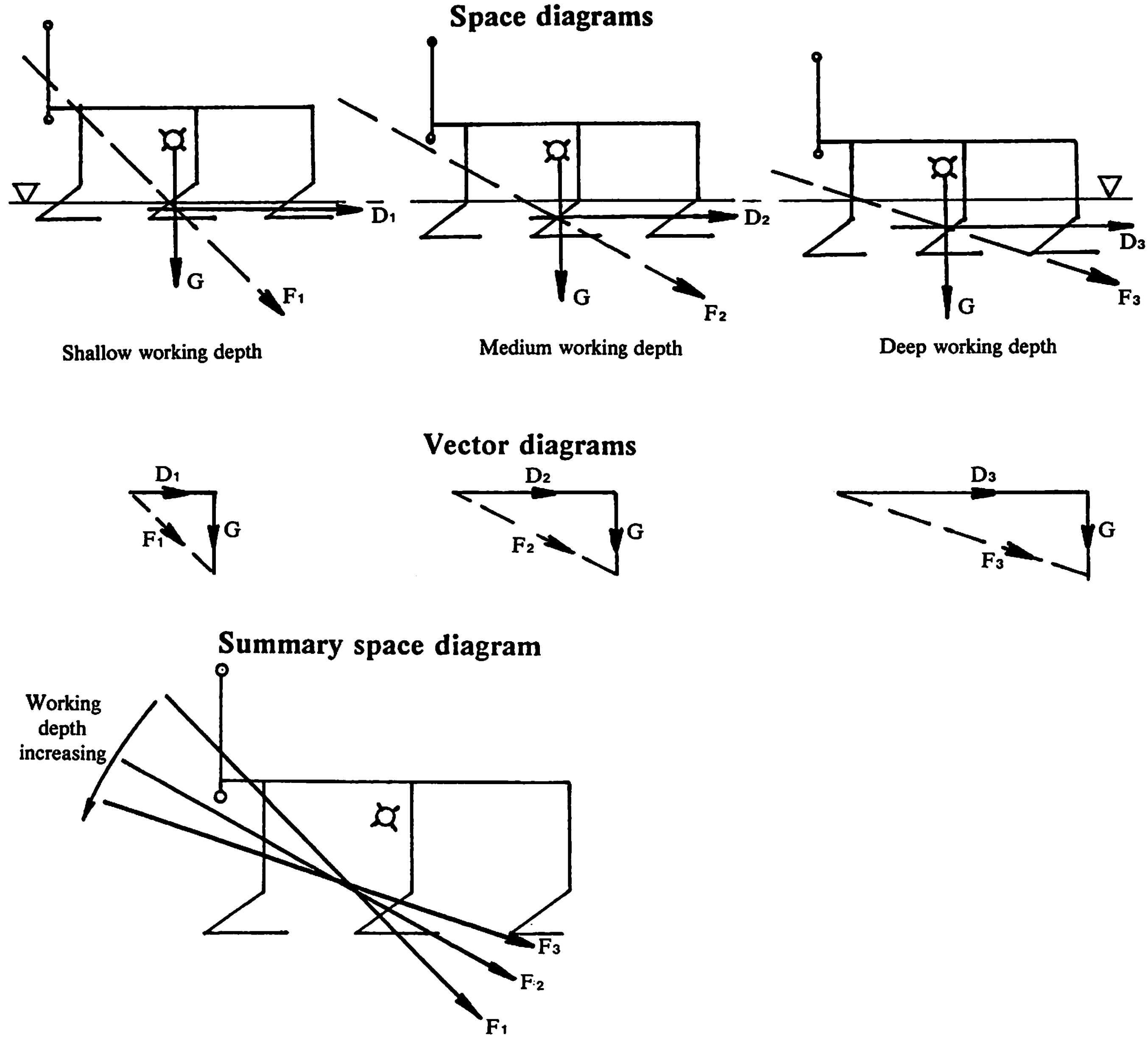
it is a resultant force of this nature which the implement applies to the tractor and which is balanced by the resultant force arising from the component forces at the linkage ball-ends.

In the third system of attachment — free linkage with gauge wheel control — the resultant of soil and weight forces is modified by addition of the support force at the depth wheel as shown in fig 9. This gives a new resultant force with a shallow line of action which depends on the magnitude of the support force.

Weight addition and weight transfer

When it acts on the tractor the resultant of the implement soil and weight forces (and the depth wheel support force if any) causes weight addition (WA) and weight transfer (WT) effects as shown in figure 10. The load on the rear wheels is increased by weight addition and weight transfer, which improves the tractive ability of these driven wheels. The load on the front axle is decreased by the weight transfer effect, which can result in loss of steerability — it may be necessary to add front end weights in compensation.

Fig 8 How the resultant of soil and weight forces varies with depth of work. It is assumed that the soil force is horizontal (no vertical component) - nearly true for a mouldboard plough in most conditions.



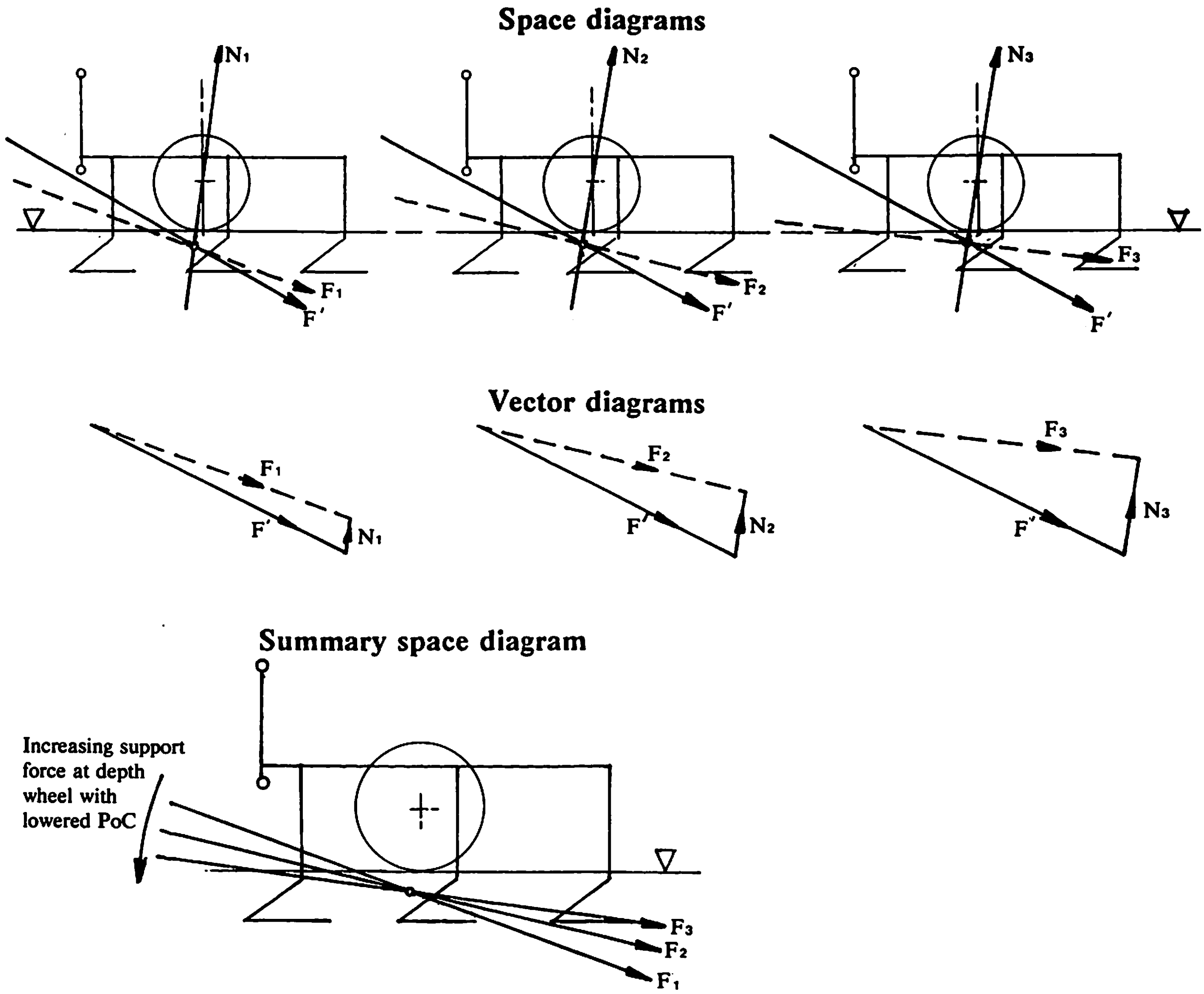
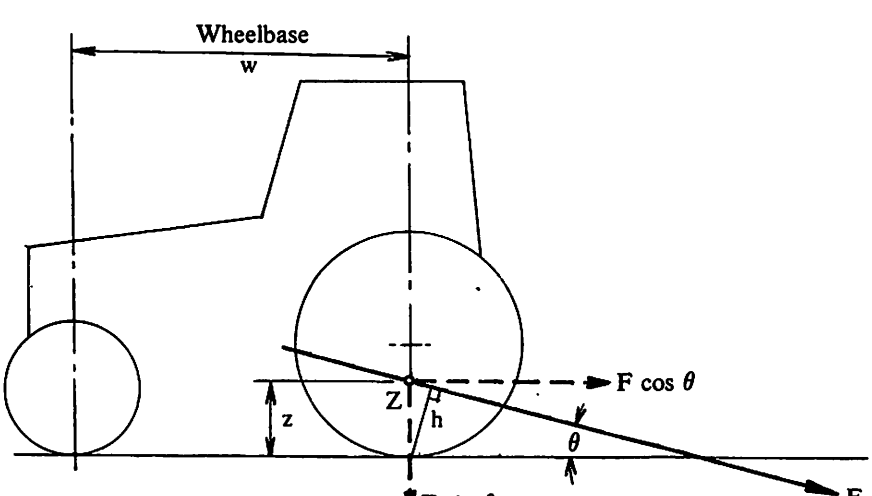


Fig 9 How the resultant force acting on a depth-wheel controlled implement varies with the magnitude of the depth wheel support force, (resultant force is the vector sum of soil, weight and depth wheel support forces)

Fig 10 Weight addition and weight transfer. The force F from the implement is resolved into components at the point Z where its line of action intersects the vertical through the rear wheel centre. Its effect is to increase the load on the rear wheels by:
$F \sin \theta$ — weight addition
$F \cos \theta \; z/w$ — weight transfer ($= Fh/w$)
Load on the front wheels is reduced by $F \cos \theta \; z/w$.



The overall effect of weight addition and weight transfer is sometimes called dynamic weight transfer. Compared to the initial static rear axle load of the tractor (as give in the manufacturer's specification, ie with no implement attached) dynamic weight transfer typically adds about 65% when the implement is mounted (free linkage variable geometry and restrained linkage draught control systems) and 45% when the implement is semi-mounted (free linkage depth wheel control).

Equilibrium of the implement: free linkage variable geometry system

This mounted implement system is used on some small tractors. The Marshall 302 provides five alternative attachment points for the lower link pins at the tractor end (fig 11, resulting in five alternative virtual hitch points. Figure 12 shows how pin positions may be chosen to

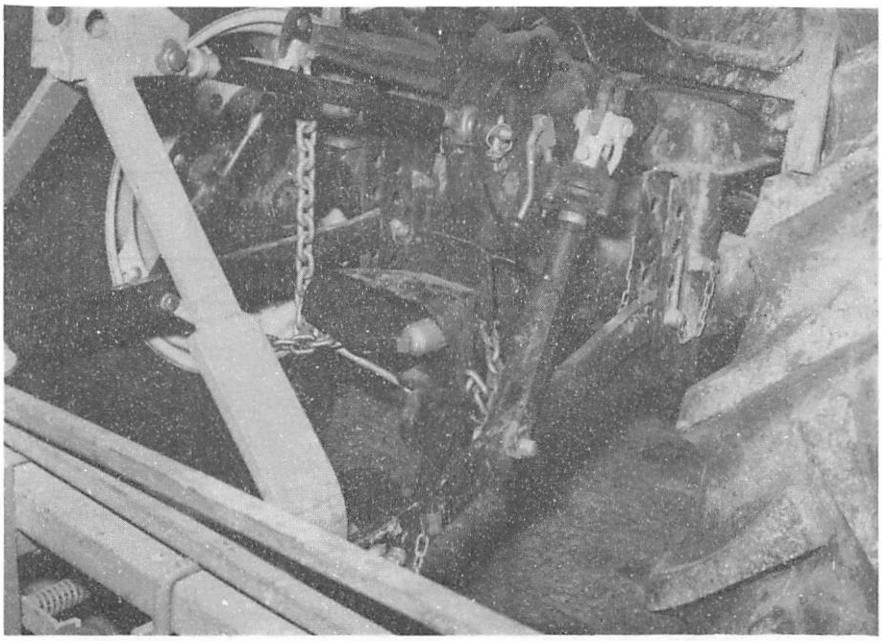


Fig 11 Free linkage variable geometry control. Details of the 3-link attachment system (Marshall 302). The lower link may be attached to the brackets in any one of five positions.

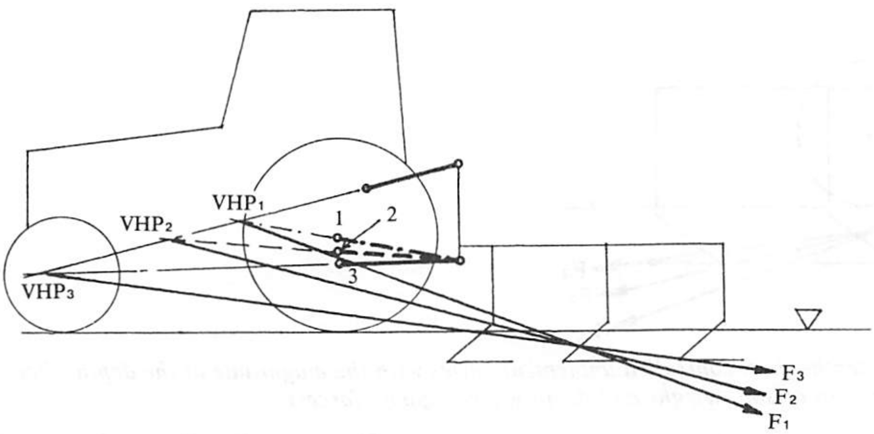
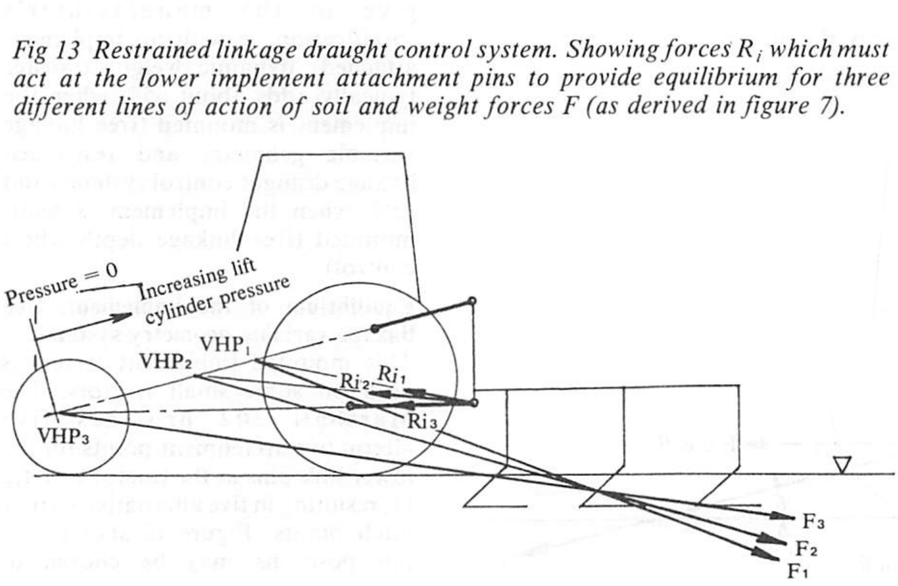


Fig 12 Free linkage variable geometry control showing positions of the lower links to provide equilibrium for three different lines of action of soil and weight forces F (as derived in figure 7)

Fig 13 Restrained linkage draught control system. Showing forces R_i which must act at the lower implement attachment pins to provide equilibrium for three different lines of action of soil and weight forces F (as derived in figure 7).



provide equilibrium at particular depths of work corresponding to F_1, F_2 and F_3 (compare figure 8). Each pin position corresponds, for a particular implement in a particular soil, to a particular depth of work. With a mouldboard plough and other implements which are directionally stable at working depth, it is possible to achieve depths intermediate to the five nominal depths of work by adjusting the pitch of the implement slightly (by varying the length of the top link), causing the implement to move slightly deeper or more shallow.

The free link variable geometry system provides maximum available weight addition and weight transfer with good implement stability at working depth. The point of convergence is different at each link setting, causing variation of the kinematics of the implement when lifting, with undesirable characteristics possible at some settings.

Equilibrium of the implement: restrained linkage draught control system

Essentially the method of control is the same as in the free linkage variable geometry system but the direction of the attachment forces at the lower link ball ends is adjusted to the required direction by applying a force to the lift rod — see figure 4 — instead of by physically adjusting the direction of the lower links. By varying the lift rod pull (which depends upon lift cylinder pressure), the virtual hitch point can be moved from the point of convergence (lift rod pull is zero at this point) upwards along the line of the top link as shown in fig 13.

Lift cylinder pressure and hence lift rod pull is regulated by an automatic control mechanism to maintain the implement at a depth corresponding to a set value of draught force. The consequence of a "reduce cylinder pressure" signal is to move the virtual hitch point back towards the point of convergence position. If this is done too rapidly, the line of pull which the linkage is applying to the implement is reduced to a shallow angle, passing through the point of convergence in the case when cylinder pressure has been reduced to zero. Weight addition and weight transfer may be greatly reduced and implement control may become erratic. These effects can be reduced by including a "response control" restrictor in the hydraulic circuit so that cylinder pressure is leaked away gradually. Alternatively, it is theoretically possible to arrange for a high point of convergence close to the virtual hitch point position needed to give equilibrium according to the line of action of the resultant implement force. A reduced pressure in the lift cylinder can then provide the virtual hitch point at the same required point along the line of the top link, leading to more stable operation of the implement. From this point of view, best performance is likely when the point of convergence and virtual hitch point coincide but penetration of the implement to working depth might be impaired.

The restrained link draught control system provides maximum available weight addition and weight transfer, except when the automatic control mechanism sends a "lower" signal to the lift cylinder. The linkage then approaches a free link condition. The effectiveness of automatic control systems may be questionable — refinement of linkage geometry may contribute to improvement in some cases. Because the linkage geometry is fixed, its kinematics can be designed to give good implement lift characteristics.

Equilibrium of the implement: free linkage depth wheel control system

This is the type of control system provided for implements which are semi-mounted in work. If equilibrium of the implement is not provided by varying the linkage geometry or restraining the links as in the systems above, the implement will tend to rotate about its instantaneous centre of rotation. The magnitude and direction of the couple causing rotation will depend upon the magnitude of the resultant of the implement soil and weight forces and its moment arm about the virtual hitch point, which coincides with the point of convergence and the instantaneous centre of rotation in this case. If the resultant passes above the point of convergence, it will have a clockwise moment (in the view shown in fig 14) about the point of convergence/virtual hitch point which will cause the implement to move deeper into the ground. This movement will be resisted by a support force at the depth wheel which will build up until it reaches the required level so that, when combined with the soil and weight forces, it provides a new resultant which passes through the point of convergence/virtual hitch point — reference may be made to figure 9.

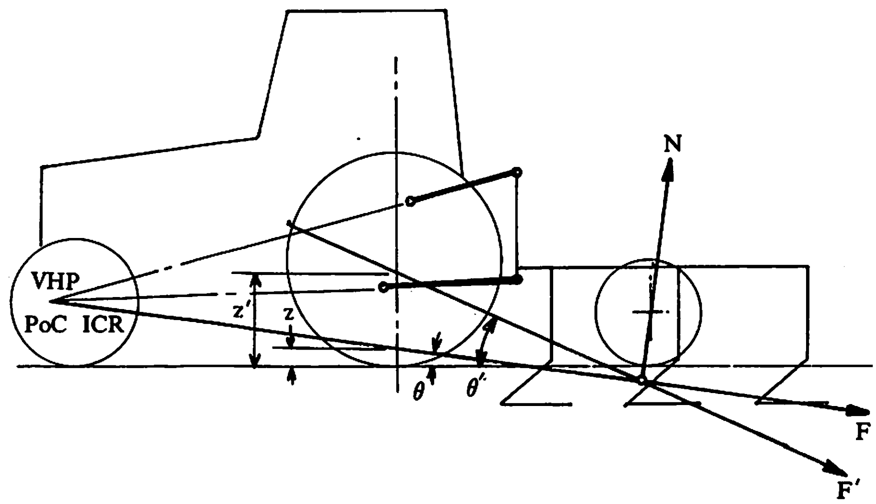


Fig 14 Free linkage depth wheel control. F' is the resultant of soil and weight forces before combining with depth wheel force N to give new resultant F, which must pass through the virtual hitch point for equilibrium. Note that $\theta < \theta'$ and $z < z'$, ie weight addition and weight transfer are reduced in a system with depth wheel control.

The effect of the depth wheel support force is to reduce the weight addition and weight transfer acting on the tractor from that which would have been provided by F^1 to that provided by F (see fig 14). The new resultant, F, has a reduced vertical component, F sin θ, and a reduced intercept, z. (refer to fig 10). Therefore to maximise the weight addition and weight transfer, the point of convergence/virtual hitch point should (in theory) be adjusted to the highest feasible position, by using any suitable alternative link attachment points which may be available at tractor or implement ends, so as to reduce the depth wheel support force to zero. In practice a small residual load on the depth wheel is necessary otherwise a slight increase in soil resistance would cause the implement to lift and find its equilibrium at a shallower working depth, acting in these circumstances as a free linkage system without depth wheel control.

6 Implement operation and depth control on a non-planar surface

General

To maintain an even depth of work on a planar surface it is sufficient to:

- set a fixed depth of work using depth wheel control
  or, assuming uniform soil conditions, by maintaining constant draught,
- set the pitch of the implement so that it has an even depth of work from front to rear.

In these circumstances, the implement in work maintains a fixed position relative to the tractor without any movement of the linkage.

The surface on which the tractor and implement are required to operate may not be planar due to surface disturbances which may be abrupt, such as mounds and furrows, or attenuated such as surface undulations. The latter type of disturbance poses the more significant problem from an operational viewpoint. Undulations of seemingly long wavelength and low amplitude are sufficient to cause unacceptable variations of working depth, particularly at higher working speeds.

When working on an undulating surface it is necessary to provide for two components of relative movement between the tractor and the implement:

- vertical movement to allow the implement to maintain a constant average depth of work,
- pitching movement (rotation in the LV plane) which enables the implement to achieve the optimum evenness of working depth along its length.

With a conventional three link attachment system pitching movement is a defined function of vertical movement and of the position of the point of convergence/instantaneous centre of rotation (disregarding the manual pitch adjustment by variation of top link length which is not intended, and is quite unsuitable, for continuous pitch control). It is necessary to relieve this constraint in order to provide freedom for the plough to achieve correct pitch and correct working depth independently. This may be done by breaking the common identity of the point of convergence and the instantaneous centre of rotation which exists in conventional systems, eg by varying top link length continuously (see the paragraph on "... Instantaneous centre of rotation" above). The position of the instantaneous centre of rotation is then no longer dictated by the position of the point of convergence and the way is open to achieve automatic pitch control by means of a continuously varying geometry (CVG) linkage, in addition to automatic draught control.

Linkages with continuously varying geometry

A single depth wheel or a draught control system cannot detect the change of pitch necessary to maintain evenness of working depth along the length of the implement. It is necessary to specify the depth of work at two reference points (probably near the front and rear of the implement), detect the actual depth of work at these points and use the error signals to operate an automatic pitch control mechanism. Automatically controlled adjustment of the top link length is an obvious way of providing the implement with a continuously controlled variation of pitch although a similar effect could be obtained in other ways such as changing the position of the link attachment points at either tractor or implement ends. The extent to which conventional automatic draught control can be, or needs to be, incorporated together with automatic pitch control into a continuously varying geometry linkage system would be an interesting matter for discussion. Probably a less conventional depth control system, eg achieved by monitoring load on feeler wheels, would be more appropriate or feasible.

A continuously varying geometry linkage system may be the next step in the development of Harry Ferguson's original linkage concepts. Tractor and farm size and working speeds have increased markedly in the 50 years since the original Ferguson system was marketed and the farming environment — technical, economic, social and managerial — has changed enormously in that time. It is a tribute to Harry Ferguson's inventive genius that his basic concepts have been capable of development in response to these changing circumstances and that further development remains as a challenge for the future.

Footnote

It should be noted that the diagrams in this paper are presented to illustrate the main effects discussed and some simplifications have been made to aid clarity for this purpose. Accurate space and vector diagrams are necessary to investigate any particular case in detail.

Related reading

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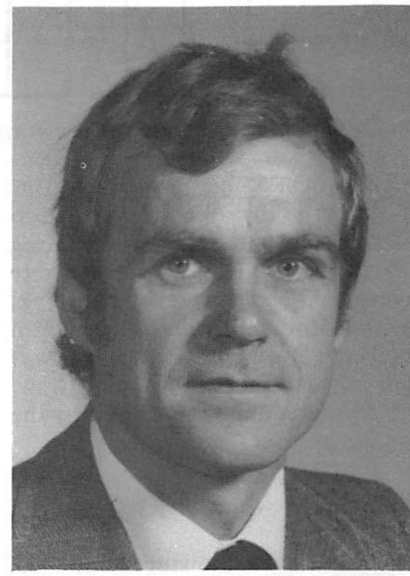
Control of high temperature continuous flow grain driers

J A Marchant



Summary

THIS paper examines the mode of action of various established methods of controlling high temperature, continuous flow grain driers. A simple computer model is used to illustrate the behaviour of proportional, proportional plus integral, and also no control at all with various disturbances to the moisture content of the incoming grain.

Four requirements of a control system are specified. These are: accuracy in meeting the correct output moisture content; freedom from continued oscillations; fast recovery from input moisture changes; successful operation over a range of input and target output moisture contents.

It is shown that simple controllers, where the feedback signal is proportional to the output moisture content and the throughput is adjusted in proportion to the error, are unlikely to meet all of these requirements. A new type of controller is proposed which performs well in the simulation. It is planned to test the controller in the near future with a full scale drying rig presently being constructed at the National Institute of Agricultural Engineering.

The need for automatic control

In order to establish the need for automatic control it is necessary to examine the alternative, that is manual control. When controlling manually, the operator measures or estimates the output moisture content, compares this with the moisture content he hopes to achieve, and adjusts the throughput of the drier accordingly. He may also judge the moisture content of the incoming grain to give him advance warning of any changes that need to be made. A manual control sequence may be specified as follows:

a) turn on the drier;
b) set the initial grain throughput;
c) measure the output moisture content and change the throughput until correct;
d) leave at that throughput.

In the initial phases (a) to (c), the grain will probably be re-circulated to avoid discharging too much wet grain.

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The problems with manual control include the time and effort needed to stabilise the drier (ie to get to stage(d)) and the need to reset if the input moisture content changes. Such a scheme needs frequent checking and adjustment by a skilled operator.

A simple on-off automatic system

The above manual sequence could be automated after reaching stage c) by using the exhaust air temperature as a measure of the output moisture content as follows:

e) after stabilising, record the exhaust air temperature;
f) record the throughput rate;
g) control by stopping the grain outflow if the exhaust air temperature is lower than (e) (ie the output grain is too wet) or running at a rate slightly higher than (f) if the temperature is higher than (e) (ie the grain is too dry).

The scheme obviously relies on a fixed relationship between the exhaust air temperature and the output moisture content.

Step (g) is the rule under which the control system operates, usually called the "control algorithm". This simple on-off algorithm is easy to design and will work over a wide range of operating conditions. However, it may be preferable to have an algorithm that gives a steady throughput rather than an intermittent one. One reason for this is to avoid the need for buffers in the grain handling system. Another reason is to avoid grain damage by keeping the grain face exposed to the hot air continually moving. The last point is especially relevant when using very high temperatures to increase efficiency.

Systems for producing a steady throughput

Requirements

The technical requirements of any control system are:

a) accuracy — the output moisture content must be close to the desired value;
b) stability — the system must not oscillate wildly, otherwise large fluctuations in output moisture content would occur;
c) speed of response — it must recover from disturbances (eg changes in input moisture content) quickly;
d) robustness — it must operate successfully over a wide range of conditions.

In order to discuss the performance of various types of control algorithm in the light of these requirements, their behaviour will be illustrated with a simple mathematical model.

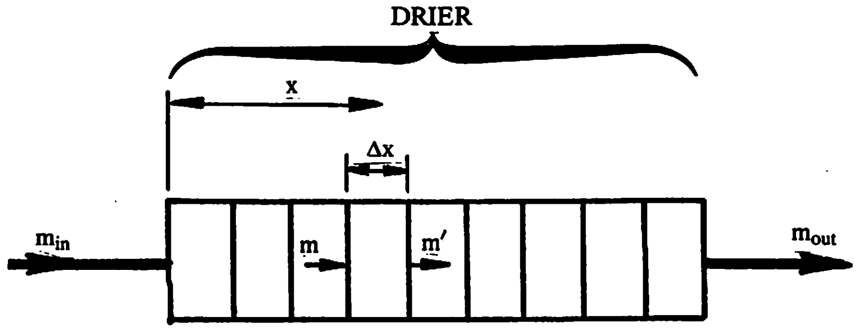


Fig 1 Simple model used for illustrating controller performance

The model simulates the behaviour of the drier by dividing time into discrete steps,Δt. The distance along the drier is divided into discrete layers,Δx (fig 1). At any distance, x, the moisture content of the grain entering a layer is m. If the layer was thin in the direction of the air flow, the drying could be described by the equation:

$$\frac{m' - m_e}{m - m_e} = \exp(-t/\tau) \quad (1)$$

where m' is the moisture content of the grain leaving the layer, m_e is the equilibrium moisture content, and τ is a constant for the particular grain (Simmonds *et al*, 1953). At each time step, the computer calculates m' for each layer given m. From the throughput rate it calculates the distance travelled through the drier (ie the number of layers) in that time step and moves the grain through the drier accordingly. In this way, the moisture profile throughout the drier is continuously calculated.

The model is obviously a simplified one. For example, in a cross flow drier the grain depth in the direction of the air flow cannot be regarded as thin. In a concurrent or counterflow drier, the equilibrium moisture content, m_e is not constant but depends on how much drying is done before the air reaches the layer concerned. However, the model does have two of the primary features of concern to the control engineer — firstly there is a considerable time delay between grain entering the drier and the same grain leaving it, and secondly the amount of drying depends on the time in the drier where the drying rate slows as the grain dries.

System behaviour

The following examples have been calculated assuming a drier of total length 2.5 m filled with grain having a drying time constant, τ, of 100 mins. The equilibrium moisture content varies along the length of the drier from 5% at the inlet to 12% at the outlet. This variation is a simplified representation of a concurrent flow drier where the air passing along the drier gradually picks up moisture giving a higher equilibrium moisture content at the outlet. All moisture contents are in dry basis.

No Control

Figure 2 includes a block diagram for the no-control situation. The operator sets a constant throughput to dry from an input moisture content of 25% to a target output moisture content of 17%. In this case, the throughput, V_{set}, is 0.04 m/min. The calculated behaviour is shown in figure 3. After some time, the input moisture content is suddenly changed to 20% and after this drier grain passes through, the output moisture content drops to below 15%. Because there is no control, the throughput is too slow for the new input moisture content and the grain is overdried.

Proportional control

The situation can be improved by using a proportional control loop (fig 2). In this case, the output moisture content is compared with the target value, m_d, to form an error, E. The set throughput is then modified by an amount proportional to the error, KE, where K is the proportional gain. Figure 3 shows the behaviour for various values of K. It can be seen that the higher the gain, the closer is the output moisture content to the target. This happens because a smaller error is necessary to give the required throughput modification. Two points are apparent. Firstly,

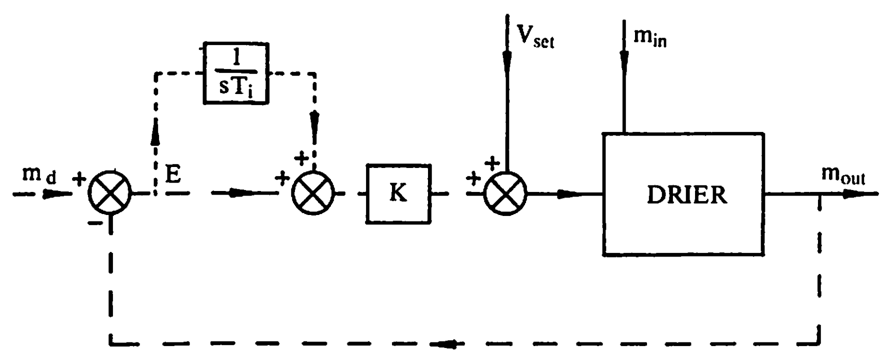
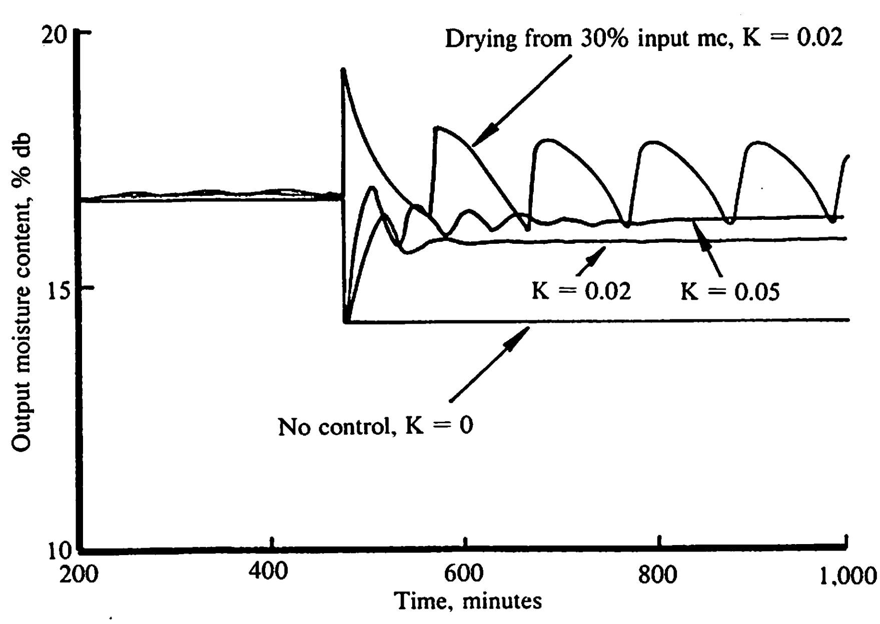


Fig 2 Block diagrams of possible control schemes

Fig 3 Behaviour of model drier with various proportional control gains drying from 25% with a step to 20% input moisture content except where shown



there is always some steady-state error. Secondly, at the highest value of gain, the system is showing signs of instability. There is a conflict between two of the control system requirements in that gains which give a more accurate response also give a less stable one. The response for K = 0.02 may give an acceptable balance between the two requirements for the conditions chosen. However, if the input moisture content is increased to 30% rather than decreased to 20% with K = 0.02, the response is very different (fig 3). The system is now unstable, resulting in an oscillating output moisture content and a correspondingly variable throughput. There is evidently another problem in that the last requirement of robustness has not been met.

Proportional and integral control

A proportional and integral control scheme is also shown in figure 2. In addition to the proportional term, the throughput is also modified by adding a proportion of the integral of the error. In this scheme, a steady positive error, for example, results in the integral term gradually increasing. A new steady-state is only achieved when the error is returned to zero. In this case, the integral term gives exactly the correct throughput to suit the input and target moisture contents. The proportional and integral scheme thus always satisfies the first requirement in that the steady-state error is zero in response to a step change in input moisture content.

Figure 4 shows the response for three values of the integral time, T_i, with K = 0.005. The disturbance in the output moisture content after the input changes from 25% to 20% can again be seen. Eventually the output moisture content returns to the target value of 17%, but for the high value of T_i the rate of recovery is slow. A value of T_i = 15 mins may give an acceptable response but, once again, an increase in input moisture content to 30% renders the control system highly unstable. The requirements of accuracy and speed of response may have been met but the algorithm is still not robust.

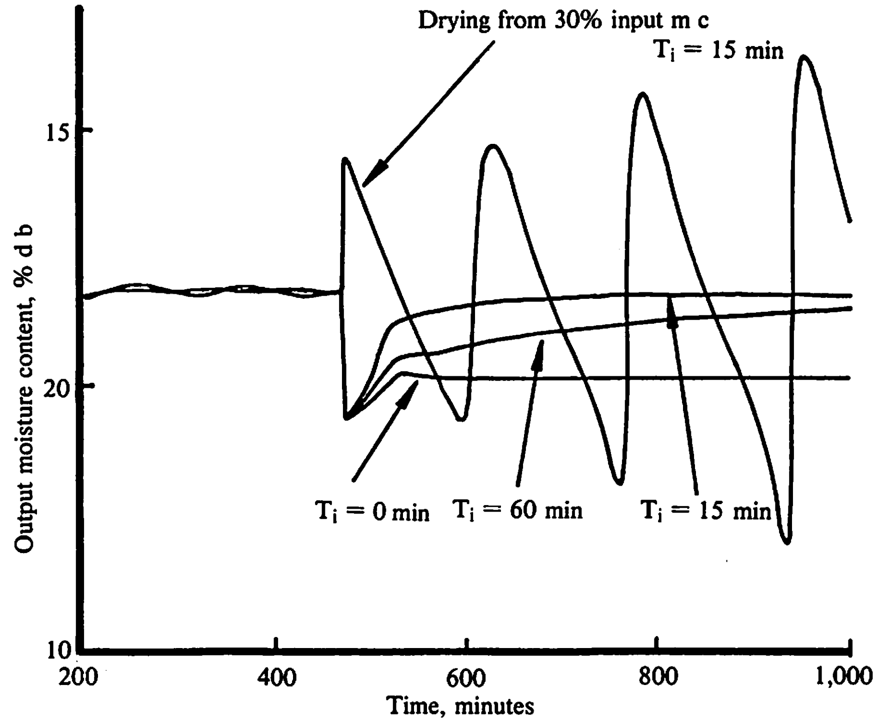
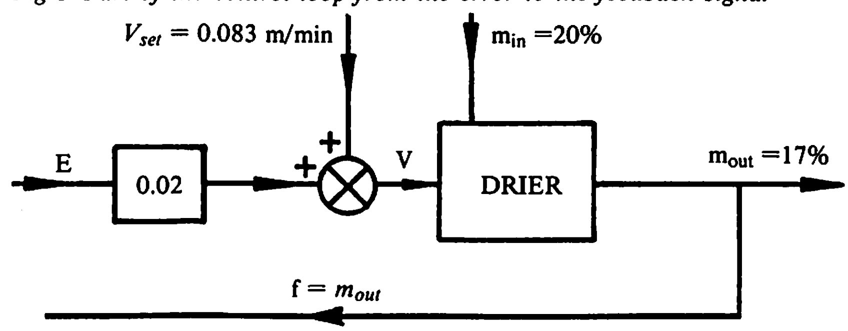


Fig 4 Behaviour of model drier under proportional and integral control – with K = 0.005 and various values of T_i, drying from 25% with a step to 20% input content except where shown

Fig 5 Part of the control loop from the error to the feedback signal



A new type of algorithm

The problem of robustness could be solved (and often is in practice) by the operator adjusting the control system throughout the course of drying. However, it is not obvious what to adjust and the effect of any adjustments will not be seen for a hour or two. A truly automatic system should relieve the operator of this duty and the following suggests how this may be achieved.

The cause of the problem

To simplify the argument, assume that the behaviour of the concurrent flow drier previously simulated can be further approximated. Rather than m_e varying from 5% at the inlet to 12% at the outlet, it will be assumed that m_e is constant at the mean of the two values, ie 8.5%. The residence time, T, to dry from the input moisture content, m_{in}, to the output moisture content, m_{out}, can now be calculated by modifying eqn 1 to give:

$$\frac{m_{out} - m_e}{m_{in} - m_e} = \exp(-T/\tau)$$
$$= \exp(-X/V\tau) \quad ...... (2)$$

where V is the throughput. Figure 5 shows part of the control loop from the error E round to the feedback term, f, which in this case equals m_{out}. When drying from 20% input to 17% output, the control system will be aiming at a throughput of 0.083 m/min (eqn 2). (Note that the throughput in tonnes per minute can be obtained by multiplying by the cross sectional area of the drier and by the density of the grain). If the error changes to 1% moisture content m_{out} and hence f will change by 0.52% moisture content. The sensitivity of the control loop (ie change in f ÷ change in E) is thus 0.52. If the calculations are repeated for a 30% input moisture content, the sensitivity is 4.13 — about eight times the previous value. It is therefore not surprising that the control system behaves differently with different operating conditions.

The solution

The previous section shows that the cause of the lack of robustness is the varying sensitivity of the control loop. The solution therefore lies in deriving a loop with constant sensitivity.

Equation 2 can be re-written as:

$$\log (m_{in} - m_e) - \log (m_{out} - m_e) = \frac{X}{V\tau}$$

Define: $n_{in} = \log(m_{in} - m_e)$;

$n_{out} = \log(m_{out} - m_e)$;

$B = \frac{1}{V}$

The equation now becomes:

$$n_{in} - n_{out} = BX/\tau \text{...... (3)}$$

A control loop based on eqn 3 is shown in figure 6. The error is now the difference between n_{out} and n_d where $n_d = \log(m_d - m_e)$. B is derived by multiplying E by the gain K and a calculation performed to derive V. A calculation is also performed on the output moisture content to derive the logarithmic moisture content, n_{out}, which is used as a feedback signal. The system thus operates by measuring the logarithmic moisture content and controlling the inverse velocity to suit. Because of the linear form of equation 3, a given change in error results in a constant change in the feedback signal for all values of input moisture content. The control sensitivity is thus constant which should result in a robust controller.

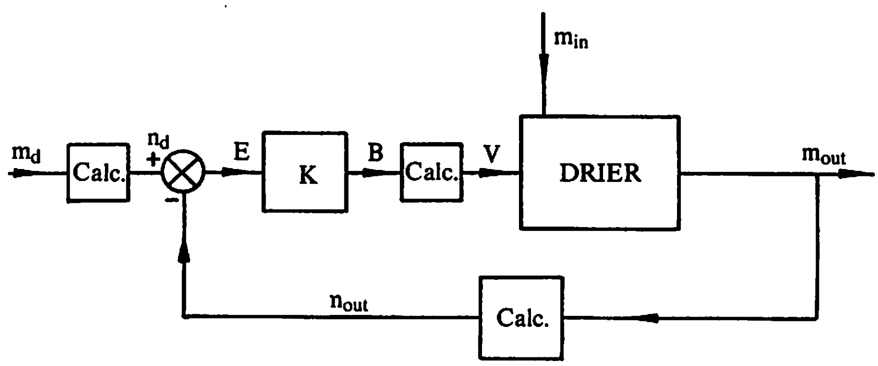
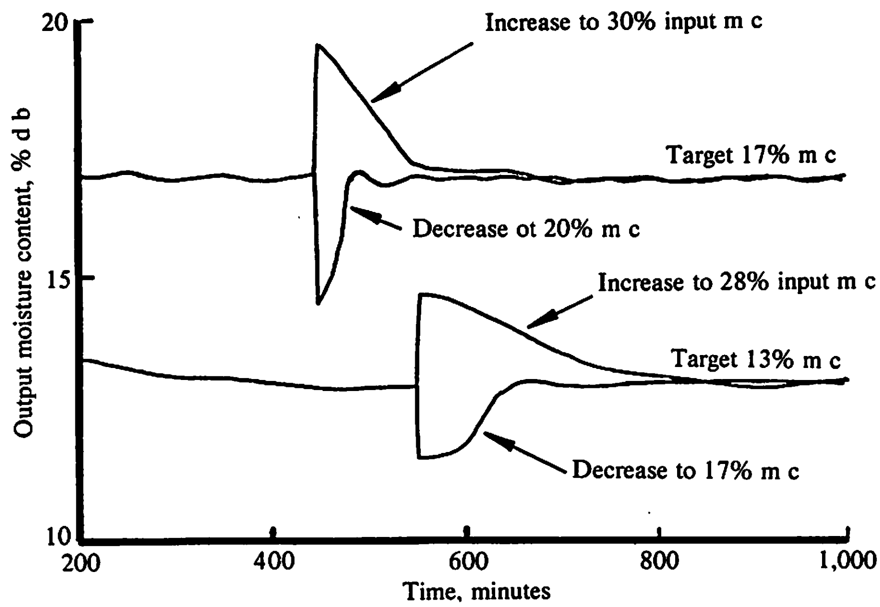


Fig 6 Control loop based on equation[3]

Fig 7 Performance of robust control loop: upper, 25% initial moisture content followed by a step change to 20% or 30%, lower, 22% initial input moisture content followed by a step change to 17% or 20%



Designing the control algorithm

The other system requirements, accuracy, stability, and speed of response, can be met by using fairly standard control system design techniques. These techniques are not covered in detail here, but the author has used such techniques to design a controller based on eqn 3. The method uses frequency domain compensation using a describing function to derive the frequency response of the drier (see for example Shinners, 1964). In order to use these methods, a quantitative description of the drier dynamics is required. This is best derived using mathematical models of the heat and mass transfer, such as have been in use at the NIAE for a number of years (eg Bruce, in press; Nellist, 1974).

As a result of using these techniques, a control algorithm for the simulated drier has been derived as:

$$B = B_{-1} + 23E - 19E_{-1} \text{...... (4)}$$

The output moisture content is sampled every 5 minutes and the current value of E calculated from the logarithmic moisture content. A value of B and hence the throughput rate is calculated from eqn 4 where B_{-1} is the value of B at the last sampling time and E_{-1} is the corresponding previous value of E. This algorithm is only suitable for the particular drier simulated and the reason for quoting it is merely to show that neither the form of the algorithm nor the numbers contained in it are obvious. In order to derive an algorithm it is essential that proper design techniques be used.

Performance of the controller

Figure 7 shows the calculated performance. Four operating conditions are shown. In the first two, the drier is stabilised for an input moisture content of 25% and a target of 17%. The input grain then changes to either 20% or 30%. In the second two conditions, the initial input moisture content is 22% followed by changes to either 17% or 28% with a target output moisture content of 13%. It can be seen that a good balance between stability and speed of response is obtained. Also the output moisture content returns to the target value after the input disturbance. The algorithm is also robust in that the performance is preserved over a wide operating range. Note that the time taken to recover from an increased input moisture content is longer than that for a decreased one. There is also a longer recovery time for the 13% target moisture content. This is because the throughput is lower in these cases, and although the recovery time is longer, the amount of grain discharged at the wrong moisture content is about the same in all cases.

Controller hardware

The suggested controller needs to perform arithmetic calculations which requires some form of computer. The data handling and control requirements are easily within the capability of a single board microcomputer which would cost a few hundred pounds. It is also possible to use a single chip microcomputer to do the job. In this case the computer chip would cost only a few pounds. However, added to this must be the cost of program development, the cost of packaging the device in a form suitable for an agricultural environment, and the cost of sensors, motor drive circuitry, wiring, etc.

Once a computer is used as the basis of a controller, it can also be used to perform other tasks, for example:

- start up conveyors, burner, etc, in the correct sequence;
- automatically perform the stabilisation phase;
- handle alarm and emergency shut-down procedures;
- provide information and records for the operator.

The controller could also be changed or extended by re-programming.

Conclusions

Controllers for high temperature, continuous flow driers should satisfy the requirements of accuracy, stability, speed of response and robustness. It should be possible to apply design techniques to achieve a reasonable balance between the requirements. However, using proper design techniques requires a quantitative description of the drier dynamics. A simple description has been used here for the purposes of illustration but a serious study requires the use of heat and mass transfer models.

A new type of control algorithm has been described which requires a microcomputer for its implemention. If a computer is used it can perform many other functions in addition to moisture content control and should result in a cost-effective and flexible solution to the problem.

Although this work has been based on scientific principles, the conclusions are, at present, speculative. However, it will soon be possible to make firmer conclusions. A high temperature drying rig is being commissioned at the National Institute of Agricultural Engineering. This rig will be used to test the ideas contained in this paper and hopefully it will then be possible to report the development and testing of a computer controller.

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Performance characteristics and criteria of some types of cleaner

by J J Lenehan

Introduction

Grain as harvested is accompanied by various contaminants, eg chaff, straw, weed seeds, dust and sand which reduce the value of the product. By cleaning grain it is possible to reduce the levels of these contaminants and increase its specific weight. In general, cleaning operations fall into three main categories.

1. *Pre-cleaning*
   This rudimentary process is aimed at removing straw, chaff, plant fragments, small seeds, dust and sand. It is the minimum treatment recommended before all forms of continuous drying and bulk storage.
2. *Commercial cleaning*
   This is a more intensive operation than pre-cleaning and results in the production of samples for sale capable of meeting market standards.
3. *Cleaning of seed samples*
   The aim here is to clean and grade to a degree which ensures that a potential seed sample is not rejected or lowered in value because of impurity or non-uniformity.

In practice, it is extremely difficult and usually unnecessary to obtain a sample of grain totally free of contaminants. The admissible level of contaminants is defined by appropriate published standards depending on the intended use for the grain.

Performance of cleaning equipment

Reducing the level of contaminants by pre-cleaning will result in an increase in the overall specific weight as the specific densities of the impurities are less than that of grain. In addition, these contaminants affect the packing efficiency of the bulk sample. To further increase the specific weight of samples

requires the removal of poorly filled grains. In order to assess the extent to which this occurs in practice, the specific weights and impurity levels (in accordance with Intervention Test Procedure) of samples were measured before and after cleaning on farms and at merchants' premises.

The results in table 1 show that increases in specific weight of 2kg/hl were readily obtainable by 'pre-cleaning'. More intensive cleaning/grading resulted in increases in specific weight of up to 6.75 kg/hl.

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Laboratory procedure

Samples of grain were passed through the Rober-Mini-Petkus 2-sieve aspirated cleaner in the ADAS Agronomy Department Laboratory at Cambridge and the component parts were remixed to simulate the effect of using 1-sieve and 2-sieve aspirated and unaspirated cleaners. The impurity level was assessed in accordance with Intervention Test Procedure. Specific weight was measured using a Glasblaserei laboratory chondrometer and/or a Digi-Sampler. Results of the test are presented in tables 2a and 2b.

The specific densities of different size fractions of the grain were measured using a Vector Voidmeter. This apparatus measures the void content of a fixed volume (3.5 litres) of a granular material on the basis of Boyles Law — the product of the pressure and the volume of a given mass of gas is constant at a given temperature. Knowing the void content and weight of the sample, it was possible to calculate the specific density of the grain.

Slotted screens were used to separate the previously cleaned grain into fractions. The specific weights, percentage voidage and specific density of these sub-samples are presented in tables 3a and 3b.

Table 2b Effects of laboratory simulation of cleaning equipment on barley samples

	Sample 1 (mc = 15.1%)		*Sample 2 (mc = 16.1%)*	
	Total impurities	*Specific weight, kg/h (Digi-Sampler)*	*Total impurities*	*Specific weight, kg/hl (Digi-Sampler)*
Uncleaned	5.34	67.6	9.94	64.9
2 sieve* aspiration	3.78	70.6	8.81	68.1
1 sieve** aspiration	3.93	70.0	8.39	66.9
2 sieve, no aspiration	4.04	70.6	8.83	68.1
1 sieve, no aspiration	3.65	70.0	9.47	67.7
Aspiration only	3.71	70.0	9.06	65.7

**Top sieve 3.0 mm, bottom sieve 1.0 mm   **Top sieve only*

Interpretation of the results

The laboratory cleaner was fitted with slotted top and bottom sieves for the initial test and the level of aspiration set to simulate a typical pre-cleaning operation. The results in tables 2a and 2b show that although the original samples were of relatively high quality, the cleaning operation increased specific weight and decreased the level of impurities. When the cleaner was used as a simple aspirator, the increases in specific weight values were approximately the same as when the cleaner was used as a 2-sieve aspirated machine. This would appear to be because the original samples did not contain high levels of 'large' trash which would be removed by the top screen, where the aspiration section effectively removed light trash and light, shrivelled grains.

Tables 3a and 3b reflect the observation that as the size of grains increase, the specific weight increases. It can also be seen that very small differences were found between the specific densities of different size

Table 1 Performance of grain cleaning equipment

Machine	*Throughput, t/h*	*Grain quality* — *Specific weight, kg/hl* — *Before*	*After*	±	*Impurities, %* — *Before*	*After*	±
DAMAS SIGMA 754	60	75.76	77.80	+ 2.04	3.3	2.0	- 1.3
		76.00	76.90	+ 0.90	4.3	3.8	- 0.5
(Duty — Precleaning wheat)							
(Design — This machine has four pairs of vertical screen drums arranged in a planetary system rotating around the vertical centre line of the machine. The individual pairs of drums rotate around their own axes, light impurities are removed by aspirator).							
DAMAS SIGMA 1004	88	70.17	71.11	+ 0.94	6.8	5.5	- 1.3
		73.96	74.79	+ 0.83	5.3	4.2	- 1.1
		71.18	72.78	+ 1.60	7.9	7.3	- 0.6
(Duty — Precleaning wheat)		73.14	74.10	+ 0.96	5.6	4.5	- 1.1
		75.74	77.73	+ 1.99	6.7	3.5	- 3.2
		73.62	75.68	+ 2.06	9.7	8.1	- 1.6
(Design — As above)							
KAMAS SI 70	8	62.36	68.33	+ 5.97	10.9	2.3	- 8.6
		64.35	67.48	+ 3.31	9.7	3.3	- 6.4
(Duty — Cleaning malting barley)							
(Design — Three screen machine with double screen boats and integral head and tail aspiration)							
LAW-DENIS EA0600	N/A	66.25	68.65	+ 2.40	7.5	3.8	- 3.7
		66.90	69.75	+ 2.85	8.7	3.5	- 5.2
(Duty — Cleaning barley)							
(Design — Rotary drum cleaner with 3 screens and integral aspirator)							
LAW-DENIS D200	N/A	70.65	77.40	+ 6.75	9.8	3.3	- 6.5
(Duty — Cleaning wheat)							
(Design — Two screen machine with double screen boats and integral head and tail aspiration)							
TRIPP BATT 40/60	50	70.70	72.18	+ 1.48	7.4	4.7	- 2.5
		70.12	72.56	+ 2.44	7.5	4.2	- 3.3
(Duty — Precleaning wheat)							
(Design — Rotary drum precleaner with integral aspirator)							
TRIPP BATT 40/60	20	72.00	76.50	+ 4.50	8.2	3.1	- 5.1
		76.00	78.50	+ 2.50	7.4	4.5	- 2.9
(Duty — Precleaning wheat)		72.90	78.20	+ 5.30	9.3	2.9	- 5.3
(Design — As above)							
TURNER 6 x 4	15	72.78	77.10	+ 4.32	7.6	4.8	- 2.8
		72.34	76.48	+ 4.14	8.5	4.7	- 3.8
(Duty — Precleaning wheat)							
(Design — Two screen precleaner with aspirated feed spout)							
KIPP KELLY SY300	N/A	(Reduced levels of ergot by approximately 75%)					
(Duty — Removal of ergot from wheat)							
(Design — Specific gravity separator)							

N/A = Not applicable

Table 2a Effects of laboratory simulation of cleaning equipment on wheat samples

	Sample 1 (mc = 14.4%)			*Sample 2 (mc = 13.8%)*			*Sample 3 (mc = 14.2%)*			*Sample 4 (mc = 14.0%)*		
	Total impurities	*Specific weight, kg/hl*		*Total impurities*	*Specific weight, kg/hl*		*Total impurities*	*Specific weight, kg/hl*		*Total impurities*	*Specific weight, kg/hl*	
		Glasblaserei	*Digi-Sampler*		*Glasblaserei*	*Digi-Sampler*		*Glasblaserei*	*Digi-Sampler*		*Glasblaserei*	*Digi-Sampler*
Uncleaned	8.82	79.48	79.2	5.92	73.23	72.9	6.64	71.74	71.7	6.50	79.25	79.1
2 sieve* aspiration	5.67	81.34	81.4	1.39	74.44	74.6	2.25	73.29	73.2	1.98	81.42	81.3
1 sieve** aspiration	5.83	80.97	81.0	1.75	73.38	73.3	2.55	73.01	73.0	2.20	81.02	81.3
2 sieve, no aspiration	6.63	80.98	81.4	4.72	73.64	72.5	4.11	72.03	71.7	3.91	79.20	79.5
1 sieve, no aspiration	6.34	79.48	80.6	5.23	73.62	72.5	4.23	71.65	71.5	3.75	79.05	79.5
Aspiration only	6.70	81.07	81.0	2.60	74.78	74.6	2.82	73.11	73.0	2.14	81.33	81.3

**Top sieve 3.5 mm, bottom sieve 1.0 mm **Top sieve only* fractions. When this factor is compared with the recorded voidage values, it is apparent that variations in specific weight is a function of the 'packing efficiency' of different sized fractions.

The highest values of specific weight are consistently found to be for the grains held on the top screen. However, experiments show that this fraction did not necessarily have the highest specific density (note the samples were of relatively high quality). The percentage of voids for the particular size fraction increased as the size of the fraction (on a thickness basis) decreased. This suggests that the smaller grains do not pack together as efficiently as the larger 'plump' grains, leaving a larger amount of free space in a given volume of grain. Thus, the specific weight of the fraction is reduced. However, as specific weight of a sample depends on grain size, shape, surface texture, specific density and also moisture content, it is difficult to draw any general conclusions from the above results.

Table 3a Specific weight, specific density and per cent voids of different size fractions of wheat*

		% in category	*Specific weight, kg/hl*	*Specific density, kg/hl*	*Voids, %*
SAMPLE 1	Cleaned grain	100	81.34	149	43
	Grain over 3.00 mm	45.6	82.00	151	44
	Grain held on 2.75 mm	28.2	80.98	151	46
	Grain through 2.75 mm	26.2	78.36	152	49
SAMPLE 2	Cleaned grain	100	74.44	138	45
	Grain over 3.00 mm	36.2	75.21	135	44
	Grain held on 2.75 mm	42.1	73.90	136	44
	Grain through 2.75 mm	21.7	66.90	135	50
SAMPLE 3	Cleaned grain	100	73.29	142	47
	Grain over 3.00 mm	48.4	75.46	141	47
	Grain held on 2.75 mm	20.0	73.35	141	48
	Grain through 2.75 mm	31.6	65.52	142	54
SAMPLE 4	Cleaned grain	100	80.71	148	44
	Grain over 3.00 mm	51.1	81.57	150	44
	Grain held on 2.75 mm	30.3	79.33	152	43
	Grain through 2.75 mm	18.6	77.21	151	50

**Grain subdivided on slotted sieves.*

Table 3b Specific weight, specific density and per cent voids of different size fractions of barley*

		% in category	*Specific weight, kg/hl*	*Specific density, kg/hl*	*Voids, %*
SAMPLE 1	Cleaned grain	100	70.6	140	47
	Grain over 2.75 mm	34.1	70.6	141	48
	Grain through 2.75 mm	65.9	69.4	143	50
SAMPLE 2	Cleaned grain	100	68.1	140	50
	Grain over 2.75 mm	40.4	68.5	143	52
	Grain through 2.75 mm	59.6	63.7	145	54

**Grain subdivided on slotted sieves*

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