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Mechanisation of forestry operations
Subject Index & Author Index

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Front cover:

Prototype forestry plough designed by SIAE and built by the Forestry Commission for an overall ploughing system in which the indurated layer is broken and soil from the lower horizons is mixed with the surface layers.

[SIAE photograph]

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Contents

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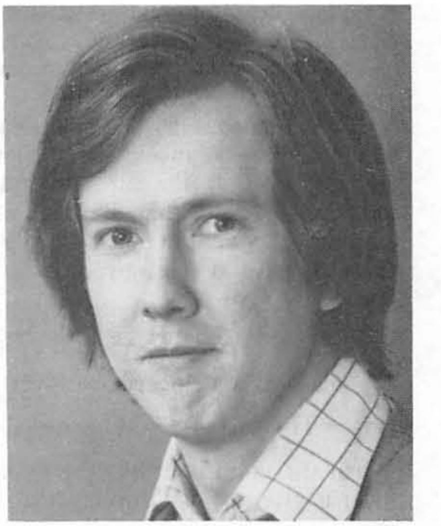
Maximum safe depth for barley in near-ambient temperature grain driers

E A Smith



Summary

COMPUTER modelling is used to consider the near ambient drying of very wet barley in the relatively cool climate of the upland areas of Britain. Grain with a moisture content above 22% wet basis (0.28 dry basis) is normally dried in beds less than 2.4 m deep when air of near-ambient temperature is used. Using mould growth as the criterion of unacceptable damage, this paper examines how the depth of the grain bed should be reduced in relation to the grain moisture content for safe drying. It has been suggested elsewhere that supplementary heat should not be used when drying very wet grain because of the risk of increasing the surface moisture content. This paper demonstrates that supplementary heat can be valuable in near-ambient drying once the problem of condensation is dealt with. Ways of preventing an increase in surface moisture content due to condensation are suggested.

1 Introduction

In near-ambient drying systems such as on-floor or in-bin driers, it has been suggested (MAFF 1982a) that the maximum moisture content should be 0.27 dry basis (21% wb) and that above that level it is better to use high temperature systems. This is because with a typical airflow of 432 kg h^{-1} m^{-2} and a depth of 3 m, the grain will be mouldy when its initial moisture content is above 0.27 dry basis. However, there are many farmers who are faced with the problem of drying grain with a moisture content above 0.27, using a near-ambient drying system.

A fairly large percentage of grain harvested in Britain has a moisture content of 0.28 dry basis or above; in the eastern counties of England (MAFF 1966) in 1948, 17½% of the grain was at or above this level and, in 1960, it was 17%. These were considered to be average years. In a survey of high temperature driers (Bartlett 1981) in southern Britain in 1980, 22% of the grain measured had a moisture content of 0.28 dry basis (22% wb) or above. These figures are from the southern parts of Britain, so the upland areas are likely to have a larger percentage of wet grain. Many people in these upland areas use low temperature systems; in 1975–76, 75% of Scottish farmers with driers used the low temperature system (MAFF, DAFS and DANI 1980). The present recommendation (MAFF 1982b) for such farmers is to reduce the bed depth below 2.4 m when the grain moisture content is above 0.28 dry basis, and to blow the grain continuously but without heat; the depth to be used for each initial moisture content is not given.

A relationship between safe depth and initial moisture content for various seeds was calculated by Nellist and Dumont (1978). The depths for drying several types of seed were calculated for various initial moisture contents, in grain beds through which an airflow of 217 m^3 h^{-1} t^{-1} could be maintained. As part of this work they assumed a plenum pressure of 500 N/m^2 and calculated the safe depth of seed bed for various moisture contents. For cereals with a moisture content of 0.22 dry basis (18% wb) or less, the calculated maximum safe depth was 3 m and, at 0.28 dry basis (22% wb) or less, the maximum depth was 1.8 m.

In this paper, the maximum depth at which barley can be dried without mould growth is calculated for various initial moisture contents and airflows. The relationship is calculated between the bed depth and the grain moisture content for the safe drying of grain when one fan, with a typical characteristic curve, is used. This approach is different from the previous one (Nellist and Dumont 1978) in that the drying process is modelled more accurately and deterioration in grain quality due to mould growth is calculated. Also, the calculated depths are the upper limits for safe drying and not the values recommended for drying practice. It would be better to dry at a depth less than the maximum safe value. For this reason the depths in this work are larger than those calculated by Nellist and Dumont (1978) but are close to the upper limit recommended by ADAS (MAFF 1982b).

The effect on the safe drying depth of using a larger fan is considered as well as the effect of increasing the air temperature by 5°C.

This paper considers the maximum depth which can be safely dried and is not concerned with controlling a drier to achieve a given final moisture content in the most economic way. Work on this has been undertaken by Smith and Bailey (1983).

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2 Mathematical models

2.1 Drying

The model used to calculate the grain temperature and moisture content throughout the grain bed assumes that the grain and air are in thermal equilibrium. Also, it assumes that the grain dries according to a commonly used simple, empirical formula called the thin layer drying equation (Boyce 1965). This approach attempts to combine the speed of computing associated with a model where the air and grain are in thermal and moisture equilibrium, with the accuracy achieved when the complete heat and mass transfer process is modelled (Sharp 1982, Sharp *et al* 1982). This is an approach which has been shown to be fast and accurate (Bowden *et al* 1983).

The grain bed is divided up into a number of layers and heat and mass balances are considered over each layer. It is assumed that the air and grain are at the same temperature and that the air maintains a constant enthalpy throughout the drying process. Consequently the exhaust and inlet air conditions for each layer are related by:

$$c_a T_x + (\lambda + c_v T_x) H_x = c_a T_i + (\lambda + c_v T_i) H_i \qquad (1)$$

The mass balance over each layer is represented by:

$$(H_x - H_i) = (M_o - M)\, \rho\, \Delta x / (G\, \Delta t) \qquad (2)$$

When the grain is drying, the moisture content in each layer is given by the thin layer drying equation:

$$M = (M_o - M_e) \exp(-k\, \Delta t) + M_e \qquad (3)$$

where the equilibrium moisture content is given by:

$$M_e = 0.1431 - 0.01577\, \ell n\, \theta - 0.07949\, \ell n\, (1 - \phi) \qquad (4)$$

as proposed by Nellist and Dumont (1979) and modified by Bowden *et al* (1983). Also in equation (3), the drying rate coefficient, k, is given by Bowden *et al* (1983) as:

$$\ell n\, k = 20.95 - \frac{6942}{\theta + 273.15}$$

The method of solving these equations is to start at the air inlet where the absolute humidity, H_i, and the temperature, T_i, are known. Then in the first layer with its initial moisture content of M_o, the values M, H_x and T_x at the end of the first time step of length Δt can be calculated using equations (1) to (4). Then H_x and T_x for the first layer become the inlet conditions H_i and T_i for the second layer and the process is repeated to calculate the moisture content in each layer at the end of the first time step. The calculation is then repeated for the second time step and so on.

Equation (4) was used during drying but, during rewetting, it was assumed that the air left the layer in equilibrium with the grain moisture content. The value of the time step used in this paper was $\Delta t = 12$ hours and the width of each layer was such that the bed was divided into 60 layers.

2.2 Grain quality

Reduction in grain quality during storage is caused by a number of agents such as rodents, insects, mites, mould and ageing leading to a reduction in germination. The effects of rodents and mites are related to the hygiene of the store and it was assumed that precautions were taken to ensure that these effects were negligible. Insects can be controlled (Howe 1965) by storing the grain at temperatures below 15°C. Loss of viability due to ageing has been modelled previously (Bowden *et al* 1983) but with limited success so was not used in this paper. The main problem with the model was that small changes in the initial value of viability led to large changes in the rate of deterioration. The grain quality model used in this paper is based on the time taken for mould to grow (Kreyger 1972).

The time before the appearance of mould has been related to the grain temperature and moisture content by the formula (Bowden *et al* 1983):

$$t_m = 67 + \exp\{5.124 + (39.6 - 0.8107\, \theta)\,[1/(W - 12) - 0.0315 \exp 0.0579\, \theta]\} \qquad (5)$$

In each layer of the grain bed the time to the appearance of mould at the j^th^ time step is defined as t_{mj}. The storage time ratio in the j^th^ time step of length Δt is defined as $\Delta t / t_{mj}$. This measures the amount of progress towards the growth of mould during each time step. The grain temperature and moisture content will change with time, so that t_{mj} will also vary. By adding together the storage time ratios for each time step, the total progress towards mould growth is measured. This leads to the accumulated storage time ratio:

$$\Sigma STR = \sum_{j=1}^{limit} (\Delta t / t_{mj})$$

When $\Sigma\, STR = 1.0$ then mould growth has occurred.

2.3 Fan power and temperature rise

Energy supplied to drive a fan also heats the moving air. The temperature rise and associated reduction in relative humidity are useful in low temperature drying. If the air is ducted over the fan motor, it is heated directly by the motor losses. In addition, it has been shown (Lamond 1982) that all the work done by a fan in friction and in adiabatically increasing the air pressure appears as an increase in temperature above ambient at entry to the grain as a result of a rise in enthalpy (assuming no energy loss through the duct walls). Thus all power supplied to a fan is ultimately available as heat for drying.

The power supplied to the fan per unit air inlet area, assuming 50% efficiency, is:

$$Q = 2\, \Delta p\, V$$

where the pressure head Δp can be calculated from the grain resistance (Spencer 1969):

$$\Delta p = \frac{x\, a\, V^2}{\ell n\, (1 + bV)} \qquad (6)$$

and where $a = 2.10 \times 10^{-3}$ and $b = 3.72 \times 10^{-3}$ for Midas barley. The resulting temperature rise is given by:

$$\Delta T = \frac{Q}{(c_a + c_v H) G}$$

3 Comparison of model predictions with experiment

To test the drying model, an experiment was conducted (Bowden *et al* 1983) in which barley with a moisture content of 0.348 dry basis (25.8% wb) was dried with air at 24.2°C and a relative humidity of 70.2% using an airflow of 443 kg h^{-1} m^{-2}. The depth of the grain bed was initially 2.3 m and during drying it was reduced to 2.0 m. This was modelled by relating the width of each layer, Δx, to the moisture content in that layer, M_ℓ, using the equation:

$$\Delta x = x\, \rho (d_1 M_\ell + d_2)/n \qquad (7)$$

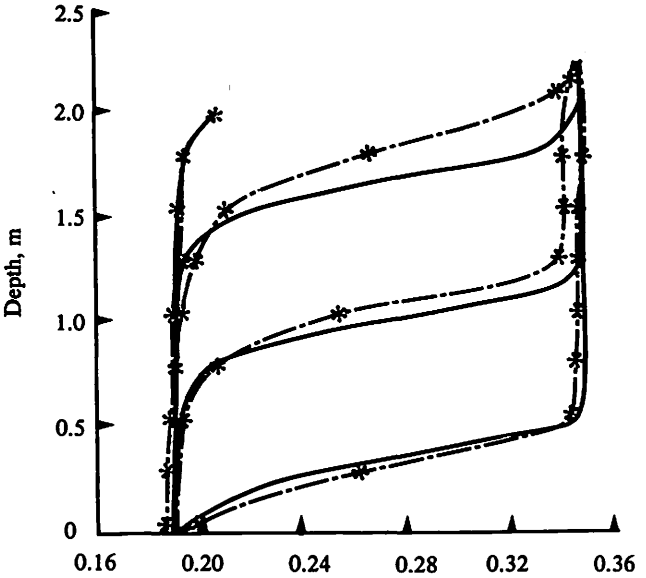

Fig 1 Experimental (·—·—·) and calculated (—) values of moisture content (dry basis) with depth

where $d_1 = 8.979 \times 10^{-4}$ and $d_2 = 1.563 \times 10^{-3}$ were obtained from the experiment, $\rho = 533$ kg/m³ was the initial bulk density of dry matter, $x = 2.3$ m was the initial depth and $n = 60$ was the number of layers.

The experimental and calculated values of moisture content and temperature throughout the grain bed are shown in figures 1 and 2. The calculated drying front moved more slowly through the bed than the measured one, taking about one day longer. The shape of the observed drying zone is very close to the observed one. The results are in reasonable agreement so that the model can be used for predicting drying behaviour.

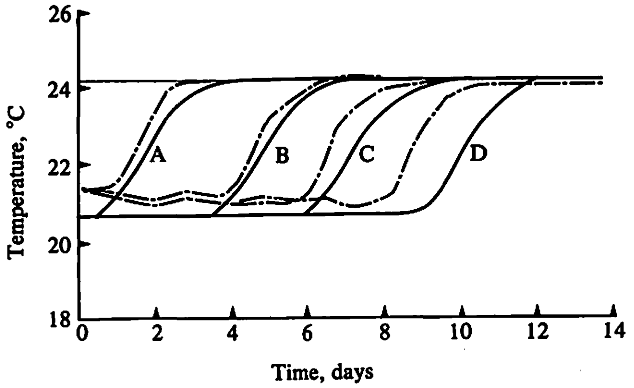

Fig 2 Experimental (–·–·–) and calculated (—) values of temperature with time for the depths A, 0.29 m above bin floor; B, 0.79 m; C, 1.29 m and D. 1.79 m

It may be noted that the observed and calculated values of surface moisture content remained fairly constant at 0.35 dry basis, despite the use of warm air to dry very wet grain.

Mould growth on the surface layers was noticed on day 6 which agrees with the value calculated by the mould growth model; using the observed values of surface temperature = 21°C and moisture content = 0.35 dry basis in equation (5), the value of $t_m = 6.01$ days.

4 Simulation

The model described in section 2 was used to investigate the safe limit for grain drying. Weather data from northern Britain was used to calculate the maximum safe depth of grain bed which can safely be dried with various airflows and heat inputs.

The weather data used to represent a major grain growing area of northern Britain were from Turnhouse

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Notation

a, b	constants in equation (6)
c_a	specific heat of dry air, J kg⁻¹ °C⁻¹
c_v	specific heat of water vapour, J kg⁻¹ °C⁻¹
d_1, d_2	constants in equation (7)
G	mass airflow, kg h⁻¹ m⁻²
H_i	absolute humidity of air at inlet to a layer, kg water/kg air
H_x	absolute humidity of air at exhaust from a layer, kg water/kg air
k	drying rate coefficient, h⁻¹
M	moisture content at end of time step, decimal dry basis
M_o	initial moisture content, decimal dry basis
M_ℓ	moisture content in a layer, decimal dry basis
M_e	equilibrium moisture content, decimal dry basis
n	number of layers in grain bed
p	static air pressure, N/m²
p_m	maximum p produced by fan, N/m²
Δp	static pressure drop over grain bed, N/m²
Q	fan power per unit air inlet area, J h⁻¹ m⁻²
t_m	time for mould to appear, h
t_{mj}	time for mould to appear at the jth time step, h
Δt	time step of 12 h
T_i	air temperature at inlet to a layer, °C
T_x	air temperature at exhaust from a layer, °C
ΔT	temperature rise over fan, °C
V	air velocity, m/h
V_m	maximum V produced by fan, m/h
W	moisture content, percentage wet basis
x	depth of grain bed, m
Δx	thickness of layer, m
θ	grain temperature, °C
λ	latent heat of evaporation of water, J/kg
ρ	dry grain bulk density, kg/m³
ΣSTR	accumulated storage time ratio
ϕ	air relative humidity, decimal

on the Lothian coastal plain. The data were hourly records of temperature and relative humidity from the 15th August to 31st December for the years 1969–1978. On average, the daily temperature range is 11°C to 16.5°C in August and 4.3°C to 6.7°C in November. The relative humidity range is 69% to 91% in August and 80% to 88% in November. Since the program used 12 hour time steps, the data were averaged over the periods 2100 to 0800 hours and 0900 to 2000 hours.

The question of the best size of time step has been considered by several authors, in relation to the simulation of grain drying and dry matter decomposition (Bakker-Arkema *et al* 1977 and Morey *et al* 1979). They have concluded that with $\Delta t = 24h$, the errors are small. However, it would be better to use $\Delta t = 12h$, since the increase in computing time is small.

The effect of the size of the time step on the maximum safe bed depth is of more direct relevance to this paper. The average value over the years 1968 to 1972, of the maximum safe depth was calculated for grain with an initial moisture content of 0.32 and 0.26, dried both with and without supplementary heat. The values when $\Delta t = 1h$ were compared with those when $\Delta t = 12h$. In all cases the difference was small and very much less than the range of values over the five years considered. The worst case was when the initial moisture content was 0.32 and no supplementary heat was used; here the average value of the maximum safe depth was 1.25 m when $\Delta t = 1h$ and 1.18 m when $\Delta t = 12h$; a difference of 6%. However, in this case, the values of the maximum depth went from 0.92 m to 1.64 m over the five years considered. In the other cases, the difference in depth between using $\Delta t = 1h$ and $\Delta t = 12h$ was about 2%.

It was assumed that the grain bed shrank during drying according to equation (7) derived from the experiment described in section 3. To obtain the maximum safe depth, it was necessary to use an iterative technique in which the depth was systematically altered, using the secant method, until the value of ΣSTR obtained for a particular depth was less than 1.0 but greater than 0.99.

The simulation was stopped when the drying front had passed through the top of the grain bed. This event was calculated using the drying rate of the grain on the top surface. This drying rate rose to a peak value and the simulation was stopped when the rate had fallen to half the peak value.

At this point the grain may or may not be suitable for sale or storage; it may require mixing or further drying. However, the main purpose of this paper, to calculate the maximum depth of grain which can be safely dried, will have been satisfied. Any further operation, such as drying with humidity control, can be carried out without the risk of mould growth.

5 Results

5.1 Maximum depth

The main risk of mould growth occurs at the surface of the grain bed furthest from the air inlet since the grain there is at the high initial moisture content for the longest period. This period and the risk of mould growth increase as the bed depth increases.

The values of the maximum safe depth are plotted in fig 3 as a function of the airflow for several values of the initial moisture content. This shows the expected trend of decreasing maximum depth with lower airflows and larger initial moisture content. It also shows an effect noted previously (Nellist and Dumont 1978) that larger depths can be safely dried by increasing the airflow when the initial moisture content is low but for wet grain an increase in airflow is less effective.

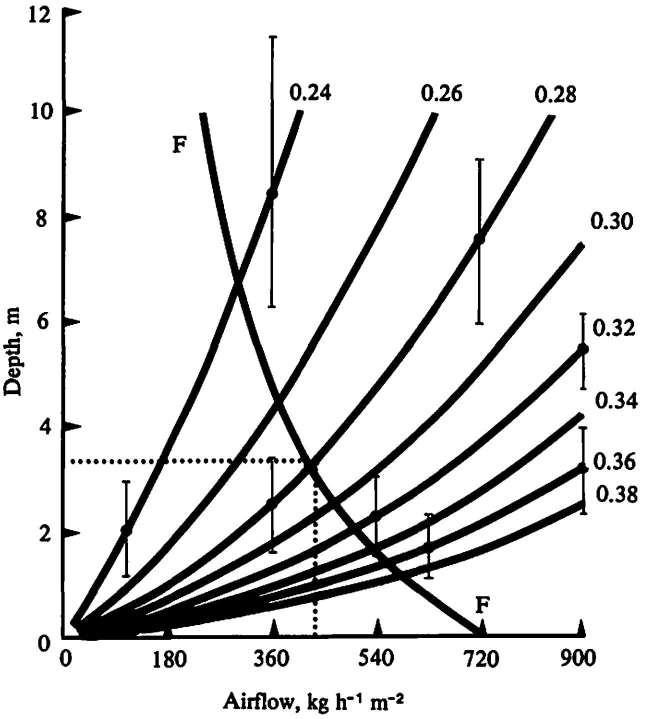

Fig 3 Maximum safe depth as a function of airflow for several initial moisture contents (dry basis). The curves are the average values and the vertical lines the ranges of values over ten years. The curve marked F is the airflow through different bed depths produced by a standard fan. The airflow, 432 kg h- m-2; and the depth 3.3 m are marked (......)

Each curve represents the average value of maximum depth obtained when the simulation was made for the years 1969 to 1978 and the vertical bars indicate the range of values for these 10 years. The range of values decreased with the average value of maximum depth.

There is a range of recommended airflows (MAFF 1982b) and the maximum, used for the wettest grain in upland areas, is 432 kg h^{-1} m^{-2}. With this value in fig 3, grain with an initial moisture content less than 0.28 dry basis (22% wb) can, on average, be safely dried at 3.3 m with continuous ventilation. But in the worst year considered, the maximum safe depth was 2.3 m.

When grain is at 0.27 (21% wb) or above, one method of safely drying the grain is to reduce the bed depth which increases the airflow and reduces the distance to be travelled by the drying zone. To model the effect of reducing the bed depth, it is necessary to know the fan characteristic curve, which relates the fan static pressure to the volume of air blown through it. This was obtained from the fan characteristic curve given in a manufacturer's catalogue for a high efficiency centrifugal fan (Muir *et al* 1983):

$$p = p_m \ell n\,(3.47 - 2.47\, V/V_m) \qquad \text{when } V/V_m \geq 0.31$$

and

$$p = p_m \{\ell n\,(3.47 - 2.47\, V/V_m) - (0.31 - V/V_m)\}$$

when $V/V_m < 0.31$.

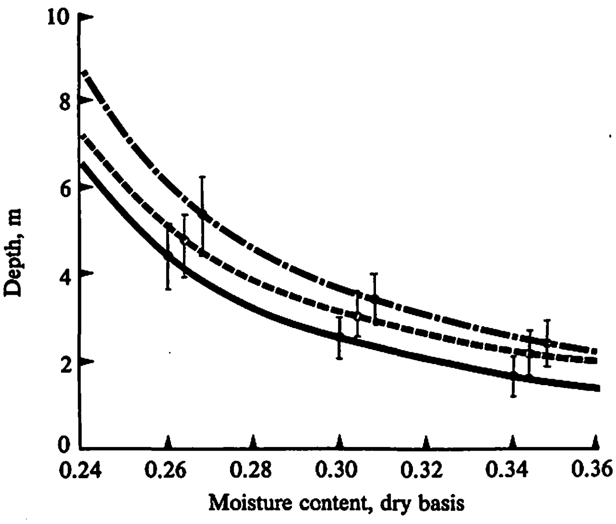

Fig 4 Maximum safe depth as a function of initial moisture content. Each curve is for one fan; the standard fan (–), the standard fan with a 5°C rise (----) and a fan producing 1.5 times the standard airflow through a 3 m bed depth. (·——·——) The curves are the average values and the vertical lines the ranges of values over ten years

The values of p_m and V_m determine the fan size which is set by defining the airflow produced by the fan through a given depth. The standard fan in this paper produces air with a velocity of 360 m/h through 3 m of grain with, from equation (6), a static pressure of 321 N/m^2 when the fan is operating at maximum efficiency. At this point the airflow is 60% of V_m and the static pressure is 66% of p_m, so that V_m = 600 m/h and p_m = 486 N/m^2.

A curve showing the airflow produced through different bed depths by the standard fan is drawn in fig 3 crossing the constant initial moisture content curves. The intersection of the curves gives the maximum depth which can be dried for each initial moisture content. The curve showing how the maximum safe depth varies with the initial moisture content is plotted in fig 4. One curve is drawn for the standard fan which produces an airflow of 432 kg h $^{-1}$ m $^{-2}$ through 3 m of grain, another curve is drawn for a fan producing 1.5 times that airflow and a third curve is drawn for the standard fan with a heater which produces a 5°C temperature rise. Each curve represents the average value over ten years and the vertical bars indicate the range of values in these years.

5.2 Final moisture content

For safe storage over a long period, and occasionally in order to sell the grain, it is necessary to reduce the moisture content below 0.176 dry basis (15% wet basis).

The values of final moisture content achieved when grain was dried at the maximum safe depth for different values of the initial moisture content are shown in fig 5 for the two fan sizes and the standard fan with the heater. The final moisture contents were on average above the 0.176 level when no heat was used. The range of values of the final moisture content over the 10 years studied was quite large. With the standard fan and an initial moisture content of 0.26 (20.6% wb), the range was from 0.176 to 0.216 and, with an initial moisture content of 0.36 (26.5% wb), the range was from 0.194 to 0.248.

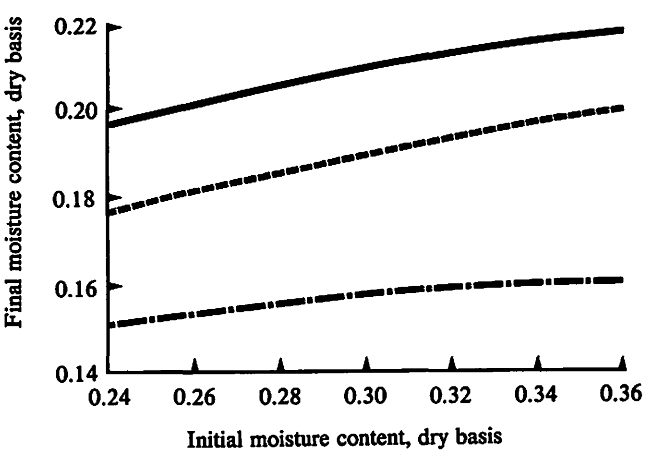

Fig 5 Final moisture content (dry basis) for different initial moisture contents. Each curve is for one fan; the standard fan (—), the standard fan with a 5°C rise (----) and a fan producing 1.5 times the standard airflow through a 3 m bed depth. (·——·——). The curves are the average values over ten years

The range of values of final moisture contents throughout the bed in each year was also quite large. With a standard fan and an initial moisture content of 0.26, in the year with the largest range, the average final moisture content was 0.204 and the range was 0.195 to 0.229. When the initial moisture content was 0.36, the average final moisture content was 0.239 in the year with the largest range through the grain bed, and the range of values was 0.226 to 0.281.

The final moisture content never went below 0.176 and on some occasions it would require further drying for safe storage even for short periods. This problem has been noted previously (Smith and Bailey 1983) where it was suggested that for grain with an initial moisture content of 0.25 dry basis (20% wb) supplementary heat is required to achieve final moisture contents below 0.17 dry basis (15% wb) in northern Britain.

The reason that the final moisture content varies with the initial value is that the heat supplied by the fan is lower when the bed depth is lower, so the wetter grain was dried with cooler air.

With the larger fan the final moisture content was about 0.02 less than the value obtained with the standard fan. The range of values was from 0.16 to 0.20 when the initial moisture content was 0.26 and when it was 0.36 the range of final moisture contents was 0.17 to 0.23.

When the heater was added to the standard fan to give the air a 5°C temperature rise, the final moisture content was always below 0.176.

This shows that a heater is required to reduce the moisture content below 0.176, even when fairly large fans are used to dry grain using continuous ventilation.

5.3 Energy consumption

The energy required to drive the fan, or fan plus heater, and dry the grain at the maximum safe storage depth increased with lower values of initial moisture content. When the standard fan was used to dry grain with an initial moisture content of 0.24 dry basis (19% wb), the energy consumption per unit air inlet area was on average 740 MJ/m^2; and for grain at 0.36 dry basis (26% wb), the energy used was 180 MJ/m^2 on average. This is because the safe depth was lower for wetter grain. For a given fan size or heater, the energy consumption per tonne of grain varied very little with the initial moisture content. This is because both the maximum safe depth and the energy consumption per unit air inlet area fall at the same rate when the grain initial moisture content is increased. The energy consumption per tonne increases as the fan size is increased. For the standard fan the value was on average 154 MJ/t; for the larger fan it was 250 MJ/t and for the standard fan with the heater it was 407 MJ/t.

6 Discussion

When drying very wet grain with a near-ambient air drying system, there are a number of options. Those considered here are a reduction in the bed depth below the normal 3 m level, using a larger fan and finally using a heater.

If the bed depth is reduced, then less grain can be safely stored, so this method is used only when there is no other option. The final moisture content is likely to be above a level for sale to intervention or even for safe storage for short periods, so that further drying would be required.

Increasing the airflow allows wetter grain to be dried with the same depth of grain bed. With an airflow of 648 kg h^{-1} m^{-2}, then grain with a moisture content up to 0.30 dry basis (23% wb) was always safely dried. But the larger fan uses more energy and this cost will occur each year whether the initial moisture content requires a large airflow or not. Also, on average, the final moisture content will be above 0.176 dry basis (15% wb).

The standard fan with a heater supplying a 5°C temperature rise always safely dried grain with a moisture content less than 0.30 dry basis (23% wb) in a grain bed 3 m deep. The maximum safe depth was about 0.5 m higher when the standard fan was used with a heater compared with the value when no heater was used. Using a heater provides a more flexible approach than using a larger fan, since the heat need only be used in years when the grain is wet. In addition, the final moisture content was always much less than when only a fan was used and, in the example here, the final moisture content was always below 0.176 dry basis (15% wb) so further drying was not required.

The risk in using a heater is that grain near the surface will become dangerously wet from re-adsorption of moisture removed from lower down in the bed, and from condensation. Also, the grain will be warmer so that mould growth is more likely. Because of this risk, it has been suggested (MAFF 1982b) that heat should not be used when drying wet grain in low temperature driers.

The grain drying model described in section 2 takes into account the increase in grain temperature when a heater is used; also, it accounts for the re-adsorption of moisture due to the high relative humidity of the air and the cooler grain temperature near the air exhaust from the bed. But the model does not account for condensation because this is mainly controlled by the building in which the grain is dried and can be prevented. If condensation is prevented there is little risk in using heat to dry wet grain.

The surface moisture content does not change much when wet grain is dried with warm air unless it is possible for water to condense on surfaces outside the grain bed, such as the roof, and drip back onto it. The experiment described in section 3 shows that this is the case. With an initial moisture content of 0.348 dry basis (25.8% wb) and an inlet air temperature of 24.2°C, the maximum observed surface moisture content was 0.36 (26.5% wb). However, within the grain drying building, metal surfaces were coated with water and overnight the concrete floor was covered with water. But the only metal surfaces near the grain bed were the bin walls and such a small area was exposed that very little water collected there. There is a possibility that the surface of a grain bed could cool down below the dew point due to heat loss by radiation from the surface. This would depend on the roof temperature as well as that of the grain bed surface but this effect was not observed in the experiment described earlier.

This suggests that the way to avoid the problem of an increase in surface moisture content when drying wet grain is to prevent moisture condensing outside the grain bed and dripping back onto it. This could be achieved by spreading straw on the grain surface which would allow the air to flow through but absorb any moisture dripping onto the surface. A permanent solution would be to insulate the roof or use fans to extract the moist air but either may be expensive if the avoidance of condensation were the only reason. Some systems which use solar energy to dry grain (Ferguson and Bailey 1981) use a double skinned roof and wall to collect the energy. This would help prevent condensation and the extra heat provided by this method allows wetter grain to be dried than can be dealt with by using continuous ventilation without heat. Condensation also occurs when no heat is used so some means of preventing it would be beneficial.

7 Conclusions

A fan producing the maximum recommended airflow of 432 kg h^{-1} m^{-2} through a 3 m deep bed could, in the 10 years considered, always safely dry grain with a moisture content of less than 0.27 dry basis (21% wb). If the moisture content were above this level a reduction in the bed depth of approximately 0.2 m for each 0.01 increase in moisture content would allow the grain to be dried safely. An alternative method of drying wet grain is to use a heater. With a 5°C temperature rise an extra 0.5 m can be safely dried or, with a 3 m deep bed, grain with a moisture content up to 0.30 dry basis (23% wb) can be dried safely. The problem with using a heater is the condensation, outside the grain bed, of water which falls back on the surface. This increases the suface moisture content and makes mould more likely. A temporary method of avoiding this would be to spread straw on the surface of the grain bed to collect the moisture dripping onto the surface. A permanent solution would involve some modification to the grain drying building, such as improving the insulation or using fans to extract the moist air.

Heat can be used to dry grain with a moisture content of 0.27 dry basis (21% wb) and above but, below this level, unheated air should always be used to dry the grain because it is much less expensive to do so.

As an alternative to using a heater, a larger fan could be used but the comparative costs would have to be carefully considered. Most farmers with a near-ambient drier already have a heater but to increase the fan size a farmer would have the large cost of replacing the existing fan and the extra running cost. The cost of using a heater would only arise in the years when the grain was very wet. In any case, a heater could be used with a larger fan to dry a deeper bed of grain.

It must be emphasized that heaters should only be used with wet grain when the problem of condensation has been dealt with.

Acknowledgements

The author wishes to acknowledge the valuable

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Reliability and the operation of large tractors

J N Tullberg, J F Rickman and G J Doyle

Summary

PERFORMANCE tests have been carried out on 240 tractors under typical operating conditions. Of these, 82 had experienced a major failure, commonly in the transmission components. Analysis of the differences between 28 pairs of tractors (failed and non-failed of the same make and model) clearly demonstrates that drawbar pull is the most significant area of difference between pairs of tractors. Failed 2WD and 4WD tractors were pulling 35% and 25%, respectively, more than non-failed tractors. A significant correlation occurs between an axle load ratio and tractor life prior to final drive failure.

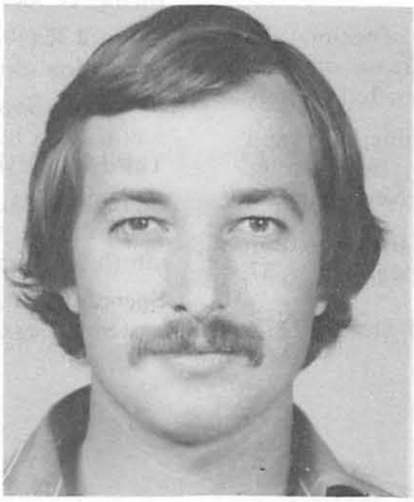
1 Introduction

THE reliability or otherwise of large tractors was first questioned by the Queensland Graingrowers Association in 1978. A preliminary study of the problem (Tullberg and Rickman 1980) confirmed that this was indeed a major problem in some areas, and provided guidelines on methods of setting up and operating tractors to reduce the risks of failure.

It is difficult to make any statement on the incidence of failure. Kruger and Logan (1980) noted that approximately 30% of tractors experience major breakdowns in the first three years of life in a survey of tractor costs covering 33 tractors on 16 randomly selected farms. Tullberg and Rickman (1980) did not choose their tractors at random but, in two areas where more than 70% of the total tractor population was surveyed, premature failure had occurred in more than 30% of tractors.

The objectives of the present work were to:

(a) gather further information on the performance characteristics of failed and non-failed tractors and hence provide a better basis for guidelines on avoiding failure, and



Joe Rickman

Jeff Tullberg

Gerard Doyle

(b) to gather data that will be relevant to a study of the economic optimum level of power utilisation when factors such as reliability, fuel economy, and timeliness costs are taken into account.

2 Procedure

One hundred and fifty seven tractors were tested between March and September 1981. The tests were carried out on-farm and during normal operations whenever possible. When this was not possible the operator's subjective judgement was relied on to operate the tractor under conditions as close as possible to those of normal operation, using the commonly-used implement which provided the heaviest load for the tractor.

Tractor drawbar pull was measured using a strain-gauge force transducer (pullmeter). This unit was hinged at each end and fitted with a large bubble-tube to indicate its angle with respect to the horizontal. This allowed calculation of the vertical component of the implement force on the tractor as well as the horizontal force (pull).

Other measurements included speed and wheelslip using reference conditions of self propulsion on the nearest available firm surface. Measurements of the physical dimensions of the tractor and tyres included all the information required to use the tractor performance equations developed by Wismer and Luth (1974). Operating parameters and wheel loads were calculated using the methods given by Tullberg (1980), modified to include the effect of vertical forces on the drawbar.

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Three "Normal Operation" runs were carried out with each tractor and the results given below are based on mean tractor performance over these three runs. The operator was subsequently encouraged to attempt to change operating conditions by, for instance, changing forward speed and or reducing drawbar pull.

Because the procedure was very similar to that of the preliminary study, tractors from that preliminary study have been included in several of the analyses presented below. It is important to recognise that the tractors included in these surveys were not selected at random. Most of the tractors were tested as a result of farmers learning that the project officer was in the district and requesting a test. The population from which this sample of tractors was drawn was thus one which could be expected to include a disproportionate number of farmers who had experienced tractor problems.

3 Results

A total of 240 tractors were tested during the preliminary and subsequent programs. Of these, 82 were initially classified as "Failed". Ten of the latter group were later reclassified as "Non-Failed" because the problem appeared to be unrelated to load.

These included cases of electrolysis in the engine cooling system, cylinder liner glazing, and early failures — for instance in universal joints — which could be classified as "infant mortality". Failures were classified according to failed unit, and the distribution of failures regarded as important is shown in table 1. As several tractors had suffered multiple failures, the total number of failures is larger than the number of tractors. Whilst the overall mean time to failure was 1555 hours, the mean time to the first failure was only 1480 hours.

In addition to the failures noted in the table, there were over 50 miscellaneous failures excluded as not relevant to this work. These included hydraulic failures, general overhauls, or failures occurring at more than 5000 tachometer hours. Although universal joint failure was relatively common, and was sometimes apparently related to load, such failures involved little downtime or expense and were excluded if there was no other problem with that tractor. The results from three small tractors (< 50 kW) were also disregarded.

Table 1 Failure types and mean tractor life at failure

		Failed unit				
		Engine	*Gearbox*	*Diff*	*Final Drive*	*Total*
2WD	Number	5	18	10	17	50
	Mean life, h	1780	1660	1730	1210	1533
4WD	Number	3	16	8	17	44
	Mean life, h	850	1450	1940	1510	1580
Total	Number	8	34	18	34	94
	Mean life, h	1431	1560	1820	1360	1555

Table 2 Gross mean performance of failed and non-failed tractors

Gross mean performance	*2WD*		*4WD*	
	Failed	*Non-failed*	*Failed*	*Non-failed*
Power, pto kW	91.7	88.6	188	155
Slip, %	11.9	10.2	8.7	7.3
Speed, km/h	6.8	6.9	7.7	7.9
Pull, kN	24.5	20.6	50.2	38.0
Mass, t	8.13	7.83	14.9	12.3
Power utilisation, %	75	69	78	72
Tractive efficiency, %	70	68	74	74

4 Performance characteristics

Gross mean performance parameters for all failed and non-failed two wheel drive (2WD) and four wheel drive (4WD) tractors from the present work are shown in table 2. These results may be compared directly with those from the earlier survey (Tullberg and Rickman 1980). Caution is necessary when considering this information because the average failed tractor was larger (ie of greater pto power) than the average non-failed tractor, particularly in the case of four wheel drive tractors.

More useful comparison can be made between the performance of pairs of tractors of the same make and model, one of which has failed whilst the other is non-failed. Fourteen pairs of 2WD and of 4WD

Table 3 Performance of failed and non-failed tractors — paired means

Performance	*2WD*			*4WD*		
	Failed	*Non-failed*	*Significance level*	*Failed*	*Non-failed*	*Significance level*
Power, pto kW	98.7	98.7		174	174	–
Slip, %	13.5	9.7	0.1	8.9	7.3	0.1
Speed, km/h	6.9	7.4	0.2	7.7	7.5	N.S.
Pull, kN	29.6	21.7	0.02	47.2	37.9	0.01
Mass, t	8.3	8.4	N.S.	13.4	12.0	0.05
Power utilisation[1], %	79	68	0.1	80	68	0.05
Angle of pull, deg	9.8	7.7	0.2	10.0	11.5	N.S.
Rolling resistance, kN	6.7	6.5	N.S.	9.8	9.2	0.1
Life[2], tachometer h	1126	2225	/	1349	2322	/

[1] *Calculated as axle power/0.95 × pto power (Nebraska or best available estimate)*

[2] *Tractor life prior to failure (failed) or at test (non-failed)*

tractors were available for this purpose.

Results of the paired analysis are shown in table 3. Statements of statistical significance level shown here are based on a paired "t" test.

For both 2WD and 4WD tractors, drawbar pull was the most significant single factor of difference between failed and non-failed tractors. The average pull of failed tractors was 35% and 25% greater than that of non-failed tractors, for 2WD and 4WD tractors, respectively. Wheelslip and power utilisation were also both significantly greater in failed tractors.

Failed 4WD tractors were heavier than non-failed 4WD tractors, but, surprisingly, there was no significant difference in the total mass (or static rear axle weight) of failed 2WD tractors. Failure was not associated with speed or angle of pull in 4WD tractors but these factors approached significance in 2WD tractor pairs. A subsequent analysis showed that the dynamic load on the rear axle of failed 2WD tractors was significantly (P = 0.05) greater than that of non-failed tractors, the mean difference being 4 kN. These results tend to confirm the importance of the weight addition effect suggested by Palmer (1980).

Most manufacturers state a maximum allowable operating weight for their tractors. Assumed values for tractors from one manufacturer who does not quote maximum allowable weights were found by using the slide-rule type tractor weight guide produced by that manufacturer, for the minimum allowable speed indicated on the guide. If this can be taken as a statement of the load carrying, or torque capacity of the transmission system, then an "Axle Load Ratio" (ALR) can be defined as the ratio of the resultant force on a tractor's axle bearings to the maximum allowable weight on that axle (equations 1 and 2). For the purposes of this study, the maximum allowable weight on the rear axle of 4WD tractors was taken as 50% of the maximum allowable total weight and that for 2WD tractors was taken as 82.5% of the maximum allowable total weight.

$$ALR_{2WD} = \frac{\{[R_{RS} + P_G h/w + P_N \sin\theta\,(1 + d/w)]^2 + P_G{}^2\}^{0.5}}{0.825\ R_{T\,Max}} \qquad (1)$$

$$ALR_{4WD} = \frac{\{[R_{RS} + P_G h/w + P_N \sin\theta\,(1 + d/w)]^2 + 0.5P_G{}^2\}^{0.5}}{0.5\ R_{T\,Max}} \qquad (2)$$

ALR	axle load ratio	P_N	drawbar pull, kN
d	drawbar overhang, m	R_{RS}	static rear weight, kN
h	drawbar height, m	$R_{T\,Max}$	max. allow. weight, kN
P_G	gross thrust, kN	w	wheelbase, m
		θ	angle of pull, deg

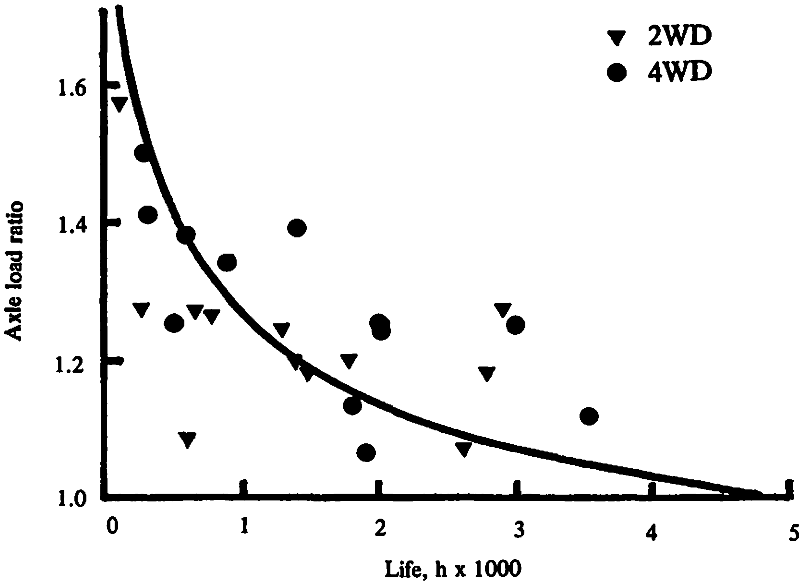
Regression Equations		R^2	
2WD Life	$= 5660\ (ALR)^{-8.7}$	0.527	(3)
4WD Life	$= 4810\ (ALR)^{-6.0}$	0.545	(4)
All tractors Life	$= 4750\ (ALR)^{-6.9}$	0.473	(5)

Correlation and regression of axle load ratio with life before failure for tractors with final drive failure gave significant and relatively similar regression equations (3 and 4) independently for 2WD and 4WD tractors. Combining the two gave a rather less significant equation (5).

Data points and the regression line are shown in figure 1.

It is important to note that this information applies to failed tractors only. Whilst failure appears to be related to loading in most cases, the data probably includes some cases where failure was brought on by, for instance, lubricant contamination. It would thus be incorrect to conclude from these relationships that the average tractor will fail at 4750 hours when operated at an axle load ratio of 1.

Fig 1 Load: life characteristic of tractors, with final drive failure



5 Discussion

During this survey, 96 different tractor models from 22 different manufacturers were encountered. It is clear from the data that all major tractor manufacturers have had their share of drive train problems in the black soil areas of Queensland and Northern New South Wales.

The results appear to show that drawbar pull (or perhaps gross thrust) is the most significant single factor affecting the probability of transmission failure. Other factors (eg speed, slip, total mass) are important because they affect drawbar pull. Power utilisation might be expected to have an independent effect, particularly with respect to gearbox failure, but the results do not confirm this.

The correlation of axle load ratio with life prior to final drive failure is remarkably good considering the "one-shot" survey technique and the variability inherent in all aspects of this study. That the exponents of the regression equations are of similar magnitude to the values expected from the load-life characteristics of bearings and that of the bending failure of gear teeth (Reed 1967) supports the hypothesis that premature failure is related to load.

Much more information on failure and on general tractor and implement performance is available from the data gathered in the survey. It would be surprising if the use of multiple regression did not yield more detailed, and more useful relationships. The survey also uncovered several non-failed tractors that were grossly overloaded, and several cases of the reverse situation: A probabilistic approach will be necessary in examining the economics of different levels of power utilisation.

The immediate problem is to ensure that farmers and machinery dealers are aware of the consequences of overloading and have access to practical methods of ensuring that any particular tractor is normally operating in a condition that will minimise the probability of premature failure. The guidelines proposed by Tullberg and Rickman (1980) are a first step in this direction but they cannot cope with the situation when the implement load includes a substantial vertical component.

There is little doubt that the most satisfactory short-term solutions would specify the use of a drawbar pullmeter with an angle measuring device for setting up tractors with implements.

6 Conclusions

The survey identified 94 failures amongst 240 tractors in the extensive graingrowing areas of Queensland and Northern New South Wales. In statistical terms, greater drawbar pull was the most significant single factor associated with failed tractors.

Guidelines on tractor operation to reduce the probability of failure (ie ballast within manufacturers recommendations, operation at field speeds greater than 8 km/h and at continuous engine power outputs of less than 75%) appear substantially correct. Direct measurement of drawbar pull and its vertical component would be more satisfactory.

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WREKIN BRANCH CONFERENCE

The Institution of Agricultural Engineers

MANUFACTURING AT MINIMUM COST

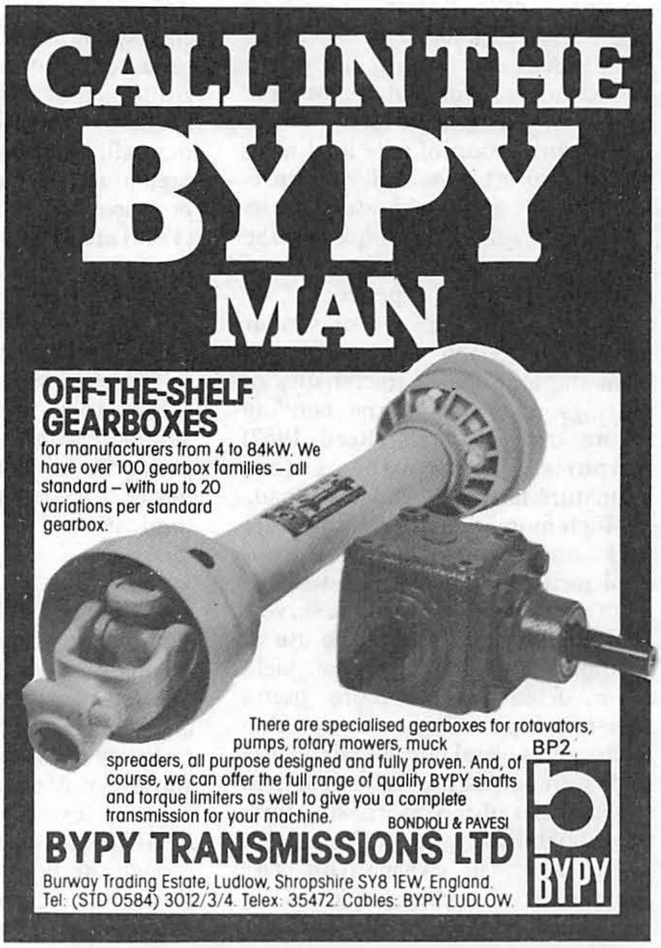
Conference Date: TUESDAY, 13th MARCH 1984
Venue: J C Bamford (Excavators) Limited, Rocester, Uttoxeter, Staffordshire
Chairman: J V Fox, NDA, NDAgrE, FIAgrE. Chairman & Managing Director, Bomford & Evershed Limited

Programme:

09 30 Conference opens. Coffee and registration
10 15 Introduction
10 25 Paper 1 **Fabrication Methods Brought Up-to-date**
J E Middle, CEng, BTech, MSc, MIProdE, MIMechE, MWeldI, Senior Lecturer, Department of Engineering Production, Loughborough University of Technology
11 20 Paper 2 **Potential for Use of Polymers in Agricultural Engineering**
R C McGregor, BSc, PhD, ARCST, Technical Adviser, Development Department, Imperial Chemical Industries PLC, (Petrochemicals and Plastics Division)
and
T E Creasey, Design Engineer, Motor Industry Business Group, Imperial Chemical Industries PLC, (Petrochemicals and Plastics Division)
12 15 LUNCH
13 30 Hosted Examination of Relevant-On-site Manufacturing Processes
14 30 Paper 3 **Metal Finishing Processes, Including Plastic Coatings**
Norman Tope, BSc, CEng, FIMF, MIProdE, MIM, Consultant
15 25 Paper 4 **The Elements of a CAD/CAM System-converting Design Data into Manufacturing Instructions**
P Marshall BSc(Eng), Manager, Automation and Control Department, Research and Development Division, PERA
16 20 Discussion Forum
16 35 Closure of Conference and Tea

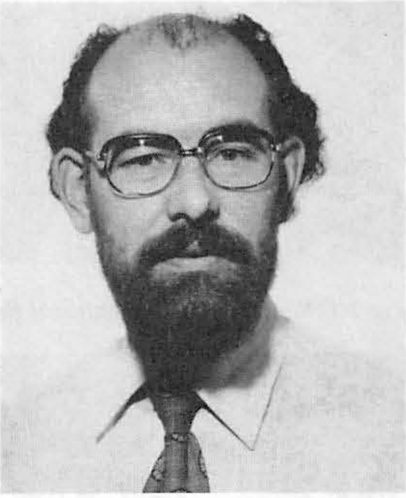
NOTE: 15 minutes have been allowed for discussion after each paper

Conference Administrator: S D Cartmel, Staffordshire College of Agriculture, Rodbaston, Penkridge, Staffs ST19 5PH



The mechanisation of forest harvesting

A J G Hughes



Summary

THE main breakthrough in the mechanisation of forest harvesting came in the early sixties with the introduction of efficient powered chainsaws. Chainsaws continue to play a major part in the tree felling, but the operation can be mechanised by the use of high output felling machines which fell and place the trees on the ground in any desired position.

Traditionally, felled trees were extracted to forest roadsides by skidders, but currently there is a switch towards extraction by trailer systems when the trees are cut to short length products in the forest and extracted fully suspended on the trailers. In steep terrain, slopes of 50% and above, cable cranes are in use.

Developments in mechanisation in recent years have been towards machines to remove the branches once the tree is felled. This removes the expensive element of tree felling which in a manual operation accounts for about 65% of the tree felling time.

Introduction

APART from the introduction of wheeled tractors and crawlers for dragging timber from the woods in the forties and fifties, it was not until the introduction of chainsaws in the early sixties that mechanisation of harvesting operations really took a step forward in the UK. Traditionally, trees had been felled using axes and cross-cut saws, but with the introduction of powered chainsaws, the whole operation changed in a very short period of time.

Felling

Initially the saws were heavy, cumbersome units, often operated by two men in a similar fashion to the old cross-cut saws on large diameter trees. This quickly changed to one man saws, still relatively heavy, but small enough to be used for both felling trees and removal of the branches, known as delimbing. This was an important step forward because about 65% of the time in felling a tree is the time for delimbing alone. Over the last 10–15 years considerable improvements in saw design have taken place, resulting in considerable weight saving, eg todays lightweight saws weigh about 6 kg, compared with 9–10 kg in the late sixties. Engine power and reliability has improved, giving a high power: weight ratio, and, with improvements in bar and chain design, give much higher cutting speeds. The chainsaw remains a dangerous tool but, with lower noise levels, lower vibration and improved anti-kickback design of the bars and chains, it is an efficient tool when used correctly, following adequate training. It remains the main method of felling standing trees, and is likely to be so for the foreseeable future.

The saw allows a tree to be severed from the stump in the felling operation but, in order to fell the tree in the required direction, it is necessary to make the correct felling cuts and to lever the tree over in the desired direction. This can be achieved using a 'breaking bar' (fig 1) which requires a high physical effort on the part of the operator or by utilizing an attachment on the chainsaw (fig 2). This makes use of the exhaust gases from the chainsaw to inflate a rubber bag, known as a felling cushion, which is placed in the felling cut. The felling cushion is encased in a strong cover of woven glass fibre, and connected to the saw via a pipe and quick release coupling on a valve block on the saw (fig 3). The valve block controls gas pressure piped from the non return valve in the cylinder head. The cushion is inflated by manual depression of the control knob, whilst the throttle is open. When the knob is released, it returns to the neutral position, holding the pressure even when the saw is switched off. This allows a lifting force of over 3000 kg from a saw in the 40–45 cc range, with virtually no effort by the operator.

Much of the heavy, arduous work has therefore been taken out of manual felling, but it is possible to go a stage further by total mechanisation. Purpose built felling machines are available which allow the man to work from the comfort of an air conditioned cab and to place the tree on the ground in a desired position (fig 4). Such machines are heavy, in order to maintain stability, require high performance cranes, commonly about 14 tonne metre capacity and are expensive at close to £100,000 in capital cost. They are designed for felling only and do not remove the branches, but present the whole trees on the ground for subsequent mechanical processing or extraction to a processing site. Output levels are high, in the order of 80–90 trees per hour, largely irrespective of tree size because the cycle of reaching for the trees, severing and placing on the ground is more or less a fixed cycle time. The actual severance can be done by

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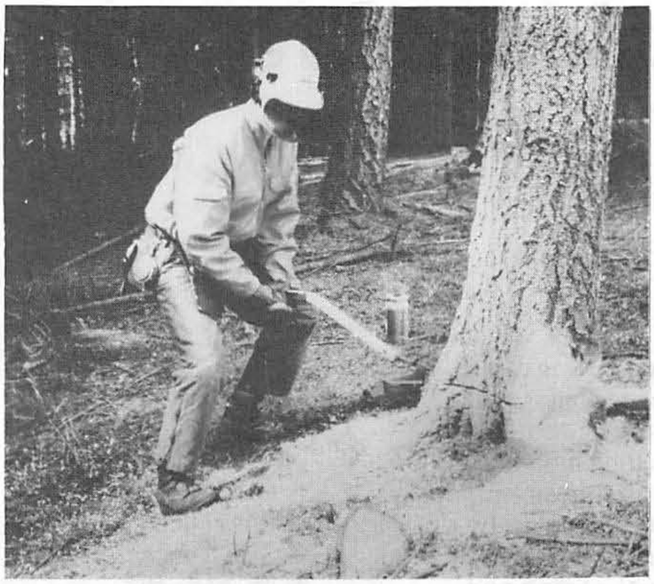


Fig 1 Felling using a conventional Breaking Bar

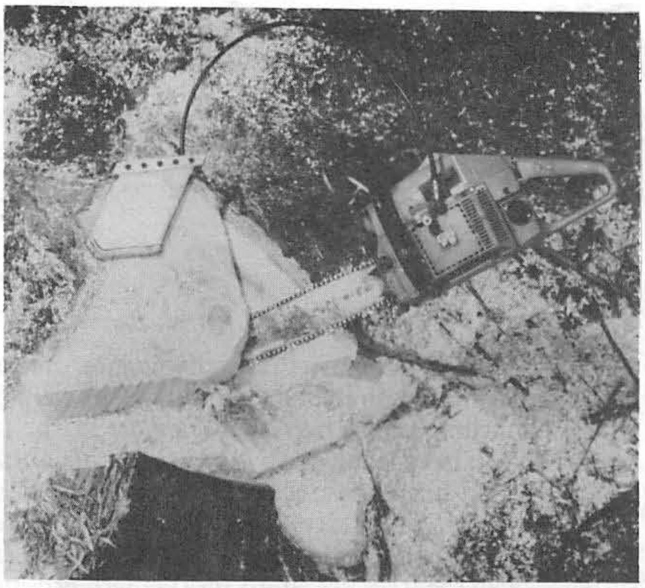


Fig 3 Close-up of Felling Cushion attachment to chainsaw

Fig 2 Felling using a Felling Cushion

hydraulically operated shears or hydraulically driven saws of conventional chain and bar design similar to a chain saw (fig 5), or by a revolving saw plate (fig 6). Saw felling is generally preferred because the stresses, created in the trunk of the tree when shears are used, tend to lead to splitting up the stem, causing deterioration in the lower stem which is the most valuable part of the tree. Because of the high output of such machines, it is often difficult to balance the subsequent operations with the felling phase.

Extraction

Once the tree is felled and trimmed of branches, it has to be extracted to the forest roadside. In the past, this was done in the pole length using tractors, dragging the poles attached to winches mounted on the rear of the

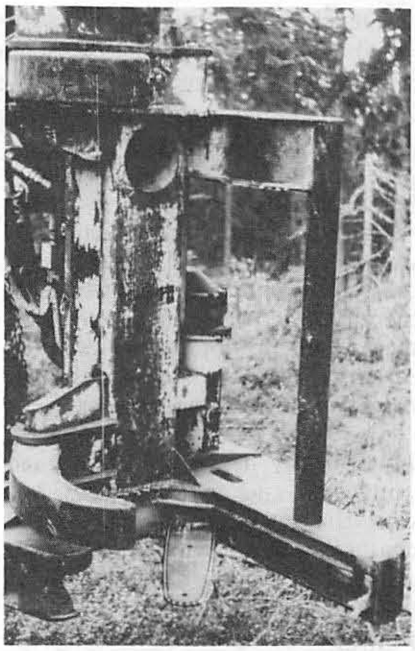
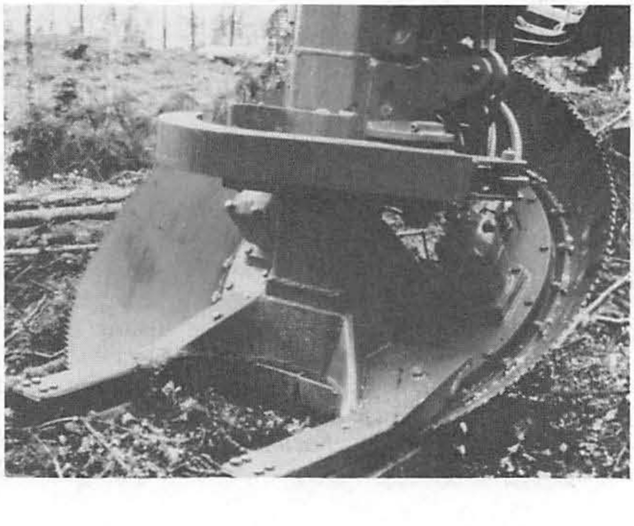


Fig 5 Close-up of Felling Head showing clamping arms, chainsaw and bar

Fig 4 Purpose built Feller Buncher

Fig 6 Close-up of alternative rotating 'Cone-Saw'



tractors. The modified tractors, known as 'skidders' in forestry terms, are based on agricultural tractors of 50 kW or larger, rigid frame construction with full underguarding, cab guarding and normally double drum winches mounted on the rear. Base units are commonly Ford County tractors with 4-wheel drive, equal sized wheels fitted with wide section tyres for flotation and often operated with wheel chains for better traction in difficult forest terrain. In normal use, loads of 3–5 tonnes are assembled and skidded from the wood.

Alternatively, higher powered, purpose built forestry skidders are used, specially designed for the job with stronger frame construction and normally an articulated frame steer design (fig 7). They have advantages in that the winches can be mounted over the rear axle for better weight distribution compared with the rigid frame design where the load carried well to rear gives an imbalance front to rear.

Fig 7 Purpose built Forest Skidder

The winches can be manually controlled, but there are strong ergonomic and operational advantages in using radio controlled winches. The use of winch line skidders allows working in difficult site conditions because the load can

Fig 8 Tractor/trailer 'Forwarder' combination

be collected on the winch ropes over a radius 50–70 metres and when travelling difficult ground, the load be dropped and winched in to the tractor once the tractor has moved beyond any obstacles.

An alternative to the use of line skidders if the use of grapple skidders when the load is carried partially suspended. In this case, an inverted grapple is used instead of the winches allowing the load to be attached without the driver leaving his cab to attach winch ropes. Such skidders can give high outputs, dependent on the size of grapple used, but have the disadvantage that the load cannot be dropped temporarily when obstructions are in the way.

In recent years there has been a switch in extraction system, certainly within the Forestry Commission, where the poles are cut to individual product lengths in the wood and extracted fully suspended on trailers by what are known as forwarders (fig 8). Forwarders, in their simplest form, are a combination of tractor and trailer with a knuckle boom loader fitted either on the tractor or trailer. The shortwood pieces are loaded on to the trailer using the knuckle boom loader which allows the operator to work entirely from within the cab and generally to achieve a higher output by carrying larger loads. Stability and manoeuvrability of tractor/trailer units are limited, and again, purpose built forwarders have advantages. They are normally 4, 6 or 8 wheeled drive units with the trailer section attached to the ending, transmission, cab unit at the articulation point in the frame design (figs 9 & 10). Such units have varying load capacities, ranging from 7–15 tonnes in use in this country. They are designed to give a good weight distribution and terrain capability and are ideal for our soft and steep ground conditions. They are used with front wheel chains and rear bogie band-tracks to give the required aggression and flotation in the forest.

Skidders and forwarders are normally used on slopes up to about 50% dependent on soil and climatic conditions (fig 11). Beyond the limits of wheeled vehicles it is necessary to use cable cranes where the timber, poles or shortwood, is extracted

Fig 9 10 tonne class 6 wheeled forwarder fitted with front wheel chains and band tracks on rear bogie

Fig 10 8 wheeled 7 tonne class 'high flotation' forwarder

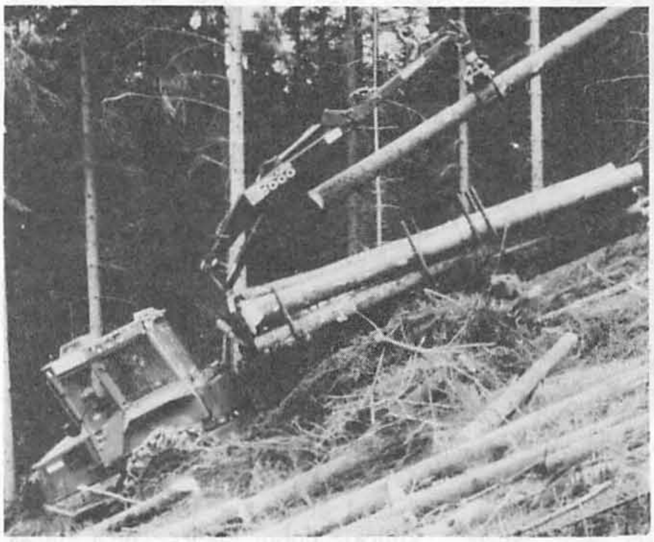
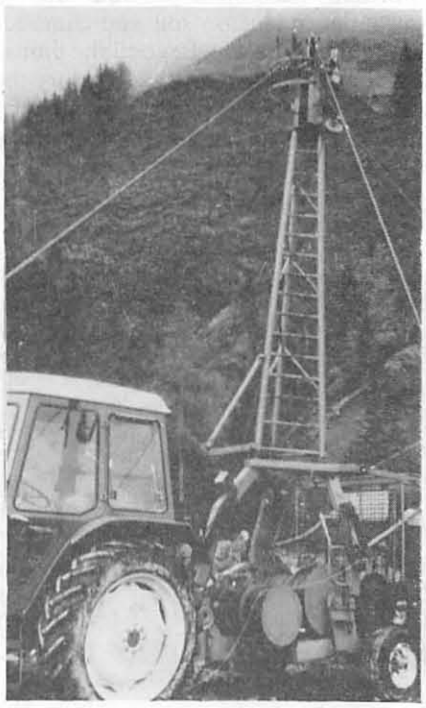


Fig 11 10 tonne class forwarder loading on steep (46%) slope

Fig 13 Compact 4 wheeled processor loading tree for processing

along cableways (fig 12). The cable cranes, which can be either tractor mounted or trailer units, consist of a relatively short tower 6–8 metres high, a suspended cableway and two winches for hauling in and hauling out simple carriages which carry the loads. The systems used in the UK are low tension units which allow lightweight rigging, utilising crop trees as spar trees and intermediate supports for the cableway where necessary. They work over a range up to 500 metres, carrying loads up to $1\frac{1}{2}$ tonnes. The combination of difficult terrain and small loads make the extraction of timber from steep sites particularly expensive, but under current technology, cable cranes are the only way to achieve extraction of the produce from such sites.

Fig 12 Trailer mounted cable crane working over a range of 600 metres



Processing

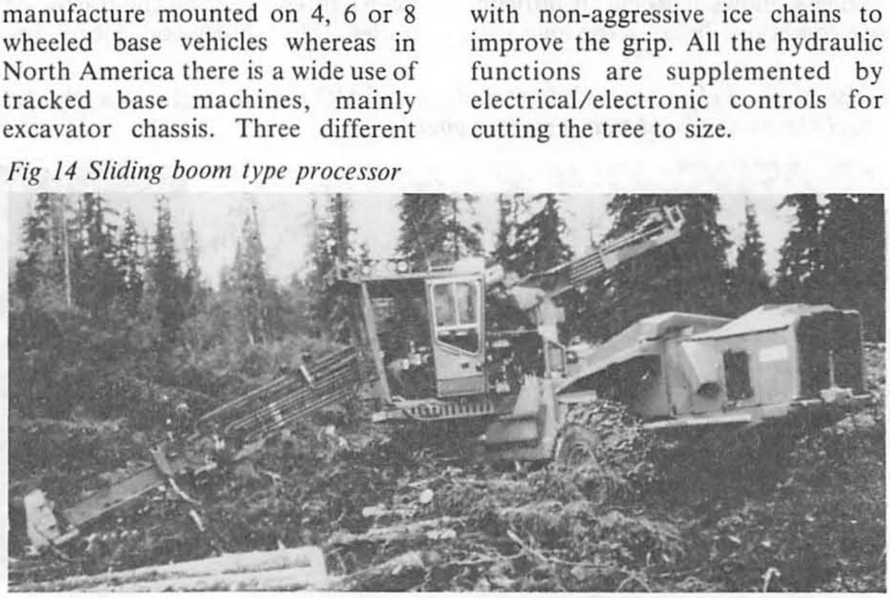
As mentioned earlier, the expensive part of tree felling is removal of the branches and developments in mechanisation in recent years have concentrated on this aspect of the work. Initially, machines were developed to remove the branches, known as Delimbers, leaving the tree as a trimmed out pole. More recently, the delimbing function has been extended to include cutting up the pole to various lengths for specific products. Such machines, known as Processors, are in common use processing trees which have been felled either manually or mechanically (fig 13).

The machines used in this country are mainly of Scandinavian manufacture mounted on 4, 6 or 8 wheeled base vehicles whereas in North America there is a wide use of tracked base machines, mainly excavator chassis. Three different principles have been adopted in the design of processors.

(a) Bed processors

The trees are picked up by a conventional knuckle boom crane with a grapple and dropped into the processor bed where the tree is pulled through delimbing knives, generally a fixed bottom knife and two moveable knives, to give a complete wrap around the tree. The tree is driven through the processor by feed rollers which close around the tree giving a feed speed of 2–2.5 metres/second. Initially the feed rollers were steel wheels with spikes to provide grip, but because of the damage created by the spikes — pushing bark into the white wood, it is now common to use tyred feed rollers. When slippage occurs in spring and summer, when the sap is rising in the trees, the tyres are fitted with non-aggressive ice chains to improve the grip. All the hydraulic functions are supplemented by electrical/electronic controls for cutting the tree to size.

Fig 14 Sliding boom type processor



(b) Sliding Boom Processor

These consist of box section sliding booms with the knives attached to the boom, one set fixed at the inner boom and one on the outer boom (fig 14). Feed is provided by holding the tree in one set of knives and sliding the boom with the other to push/pull the tree through the knives. An advantage of such an arrangement is that there are no feed problems as there are with feed wheels. The control systems are similar to bed processors.

(c) Grapple Processors

As the name implies, these are mounted in the grapple on the end of a knuckle boom loader (fig 15). The feed system is similar to bed processors with small feed wheels providing the feed system. An advantage of such units is that processing can start once the tree is picked up and the products can be placed on the ground easier than with alternative systems. They are primarily designed for the smaller tree sizes, but even so require powerful base units with an engine power of at least 75 kW to give the required hydraulics and relatively large cranes of about 7 tonne metre to carry the grapple processor.

Current technology is taking mechanisation a stage further where we are now able to combine the felling and processing operations in today's Harvesters. Considerable development over the last 3–4 years has meant that the sophisticated, multifunctional harvesters have been developed to a reliable standard, and are being used in the operational role. Such units have a similar base to the large forwarders with an overall weight of 20 tonnes plus. The processing function is carried out on a bed processor of identical design to the stand alone processors, but the knuckle boom loader of 9–11 tonne metre carries a compact felling head with a capability up to 65 cm diameter in the larger machines (fig 16). Once the tree is felled, it is pulled towards the processor bed, dropped in and processed without ever hitting the ground until it is cut into the different products.

Fig 15 Grapple processor mounted on a modified forwarder chassis

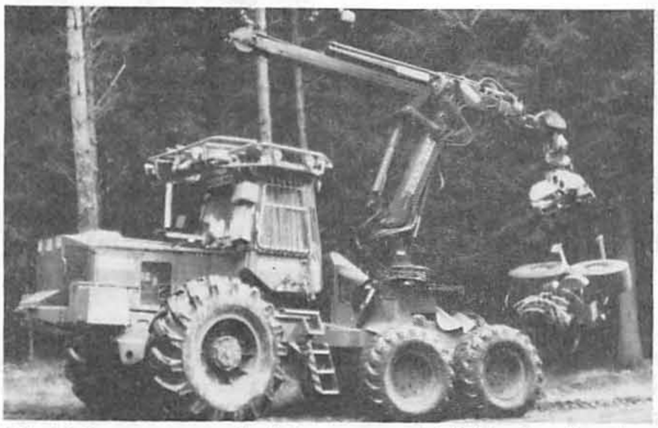


Fig 16 Large purpose built harvester with felling head on the crane boom

Fig 17 Harvester in operation felling a tree prior to processing

New current developments are towards small, compact harvesters which can be used for thinning in standing crops by the removal of selected trees. Early thinnings tend to be of low value because they only provide a small proportion of the more valuable sawlogs, and the introduction of a high output, cost effective mechanised system is a breakthrough that is eagerly awaited. Current work is towards the design of grapple harvester similar to grapple processors but with the additional capability of felling the tree (fig 17). Because they are required for thinning in standing crops, this puts a restriction on their weight and dimensions, and one has to balance their stability with a practical operational role.

Productivity and ergonomics

The switch to forwarders and the wider mechanisation of forest harvesting is giving a marked improvement in the operators working environment. The possibility of working in the comfort of an air conditioned, quiet cab is appreciated but demands totally new skills from the operators who need a high interest in, and knowledge of their machines and the aptitude to operate multi-functional machines.

The experience gained in Scandinavia has allowed the development of a high standard of good ergonomics in the cabs and the control functions. Hydraulic functions are standard and with the development of electro-hydraulic controls, the heat and noise from the hydraulics are isolated outside the cab. Driving controls are kept simple by the use of tiller steering in rough terrain, crane controls are commonly 2 lever control systems, and with the advent of the silicone chip most felling and processing functions are automated, but with manual override when necessary. This allows a relatively low level of mental fatigue for the operators, and allows an operator to work continuously for periods of 6–8 hours.

Farm fencing — a review

R T Pringle

Summary

THIS article reviews the systems of fencing in use in Scotland today. The basic concepts behind the fences are explained, the important details of their construction given, and costs and fence selection recommendations included. The bibliography lists the main publications on the newer fencing systems that are in use. Comments on the use and misuse of permanent electric fencing are made, and other aspects including developments for the future are discussed.

Introduction

THIS review is intended to trace the logic behind the many fencing systems available today. The descriptions of fence detail and erection are more fully covered elsewhere. The reader that wishes more detailed construction information is recommended to consult the bibliography. Aspects of fence life, selection, and costs are included, and matters of safety are covered. There is much folklore attached to fencing, much of which is true and some of which is false. The information here has been gleaned from fence constructors, manufacturers, advisers and farmers over a period of fourteen years; therefore, hopefully, there is more fact than fiction.

How stockproof need a fence be?

When deciding upon the type of fence to erect, this should be the first question to be considered. If stock is to be kept out of a field of cabbages, a fence that is virtually completely stockproof is required. However, if a hill reseed is to be subdivided to better manage the grass, the escape of a few animals into the next paddock is of little concern.

A further consideration is the determination of stock to get through a fence. If there is plenty of feeding in their present paddock, there is little reason to escape. If, however, the field is virtually bare earth, few fences will hold the stock in. The farm cropping policy, the proximity to farm roads, and the farm management policy will therefore all affect the type of fence to be selected.

Traditional fences

There are three types of traditional fences that are still very popular today. These are the plain wire fence with one barb wire, the 5-barb wire fence, and the woven wire mesh fence. All are made with galvanised mild steel wire, usually 4.0 mm dia (8 gauge) plain wire, and twin twisted wire for the barb. The woven wire is usually thinner.

a) Plain wire fence

This fence has strainers every 80 to 150 m, posts every two or three metres, and between 4 and 6 plain wires with a top or second top barb wire. It has the advantage that the skills to erect the fence are within the farming community. It has, however, the basic flaw that the wires stretch due to the contractions and expansions caused by cold and hot weather. The mild steel wire must therefore be retensioned every year or two by tightening the radiseurs, or else the wires will take on the common "washing line" type sag between the posts. Stock will then easily push between the wires.

b) Five barb wire fence

A solution to the slack wire problem is to make all the wires barb. Few stock will push through such a fence. However, barb wire often makes the hides of cattle less valuable for leather, removes the fleeces from sheep, and is most unpleasant to handle for the fencer.

c) Woven wire mesh fence

Often called "Rylock", hinged joint fencing, or pig netting, this fencing can be slack and still remain very stockproof. It has none of the snags of the previous fences, apart from conventionally having a top barb wire. This fence would probably be the most popular in Britain, but for one problem, the price.

A welded square mesh fence is often used instead of the hinged joint fencing, but it has not the flexibility at the joints to enable it to conform to the ground contours without the risk of fracture at the welded joints.

High tensile fences

Early fences

The first high tensile fences in Scotland that I know about were put up using tough unyielding high tensile wire, with tension springs fitted between the wires and strainer post to maintain the wire tension regardless of ambient temperatures and any strainer post movement. This overcame the problem of stock being able to push between the wires. Such fences are still used in Australia. However in New Zealand and Britain, high tensile wire was manufactured with a considerable degree of spring in the wire, and this is now used exclusively.

Wires

High tensile wire having a tensile strength less than 1550 N/mm^2 (100 t/in^2) is just referred to as high tensile wire, whilst high tensile wire with a tensile strength greater than 1550 N/mm^2 is called spring steel wire.

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There are three types of wire that can be used for high tensile fencing (table 1).

Table 1 Wire specification chart (metric/imperial)

Gauge, *mm*	*(swg)*	*Wire type*	*Length/ 100 kg,* *m*	*Tensile strength,* *N/mm²*	*(t/in²)*	*Breaking strain,* *kg*	*(lb)*
2.50	(12½)	Spring steel	2 605	1 850	(120)	916	(2 019)
2.64	(12)	Spring steel	2 385	1 550	(100)	915	(2 017)
3.15	(10)	High tensile	1 641	1 080	(70)	915	(2 018)

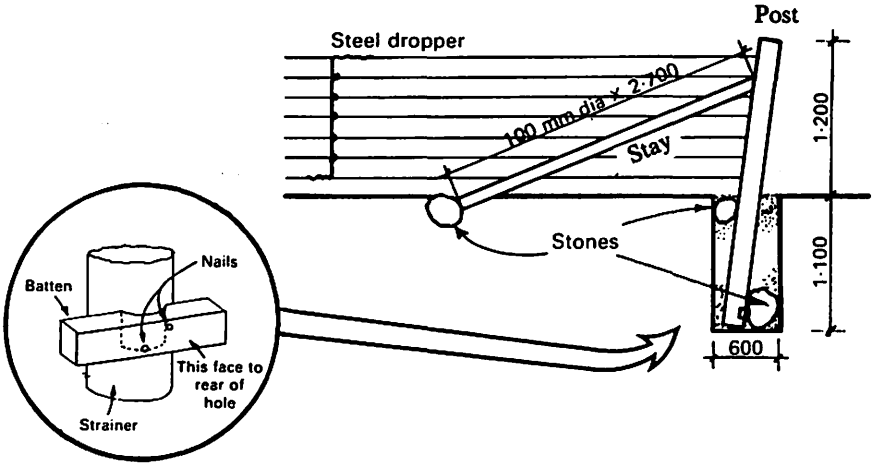


Fig 1 Strainer assembly for high-tensile fencing

On no account should the high tensile wire used for permanent electric fencing (ie 2.5 mm dia, 1080 N/mm²), be used for high tensile fencing.

If a tension of 3 500 N is put on both the 3.15 mm and the 2.50 mm dia wire, they will extend by 220 mm and 350 mm, respectively, for every 100 m of wire. There is, therefore, considerably more spring left in the thinner wire to cope with strainers moving when settling in, and expansion and contraction. The 2.5 mm and 2.64 mm dia wires should therefore be used in preference to the 3.15 mm dia wire, as this will produce a fence that is more likely to maintain its tension than one using the thicker wire.

Fence construction

Full details for this are given elsewhere. Pringle *et al* (1979). The critical components in a high tensile fence are the strainer assemblies.

The force taken by these assemblies can be as much as 24000 N (2·5 tons force) when the fence is tensioned. If strainers fail, they usually first tilt forward, so that the post is supported almost totally by the stay, the stay then lifts in an arc, lifting the strainer post straight out of the ground, and sending it skyward like a rocket. Four design features prevent this from happening. The rearward lean of the posts and the extra long stay improves the geometry of the structure, the flat stones at the heel and breast of the strainer post distribute the load on the sides of the hole, and the batten checked into the heel of the post prevents the post lifting vertically.

The distance between strainer assemblies is important as the amount of spring in the wire is proportional to the length of wire between the strainers. There must be sufficient spring available to take up the 50–70 mm movement in each of the strainers as they settle in, and also to cope with the contractions and expansions due to temperature changes. A strainer distance of 100 m is regarded as a minimum. Generally, the longer the length of strain the better, straining distances of 1 km being not unknown. If a field with a side of less than 100 m is being fenced, then a turning post rather than a strainer can be put in at the corner to increase the length of the strain.

The strongest and easiest way to connect wires to the straining post is by using wire connectors (fig 2).

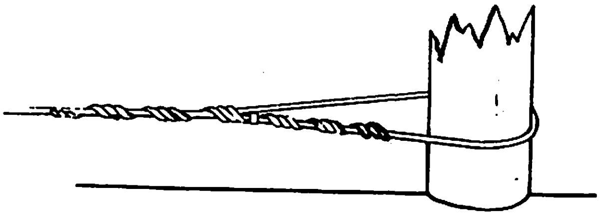
One half of the connector is wound round the end of the wire, the wire is put round the post, and the other end of the connector is wound round the wire again. At the other strainer, the wire is tensioned using a wire puller suitable for straining thin high tensile wire (fig 3).

The correct tension is reached when the handle becomes hard to crank. A second wire connector is then fitted. The wire puller is then released, the spring in the wire taking up any slack. No radiseurs are requested with this system.

Apart from making a better, more stock proof fence, the other attraction of a high tensile fence is the reduction in the number of posts required. The posts that are put in, however, should be 150 mm longer than normal, and where the ground is soft, stiffening posts 125 mm in diameter should be put in every 80 m.

Posts can be between 8 m and 20 m apart, and spacing is determined by the ground undulations. Posts should be put on the top of rises, and anchors connected to the fence using stainless steel wire, should be put in

Fig 2 Connector at base of post



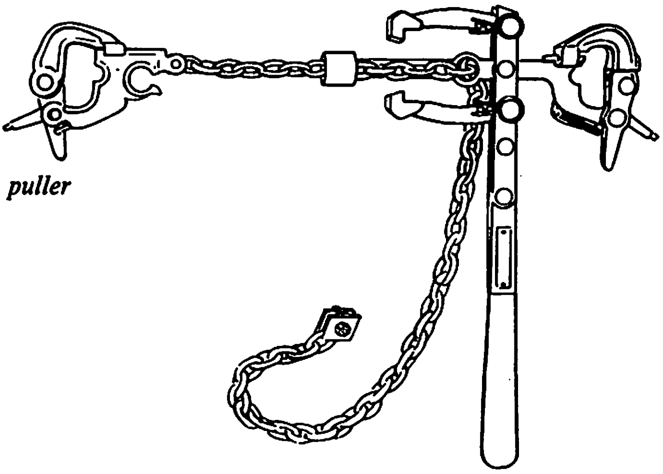


Fig 3 Monkey wire puller

dips. A post in a dip that is not anchored, will simply lift straight out the ground due to the tension in the wires. This may happen some time after the fence is erected, so occasional fence inspection is required.

Droppers are fitted every 2 m to prevent stock pushing through between the wires. Steel droppers are to be preferred to timber ones, as they do not slide along the fence, are more easily fitted, and do not keep the wire moist due to contact with wet timber.

Since there are fewer posts in a high tensile fence, the wires do not hug the ground so closely as a conventional fence. The ground must be made up to the fence in any hollows, using a spade. Otherwise stock may push under the fence.

A high tensile fence that is well erected gives a most attractive fence, as well as being a most effective barrier to stock (fig 4).

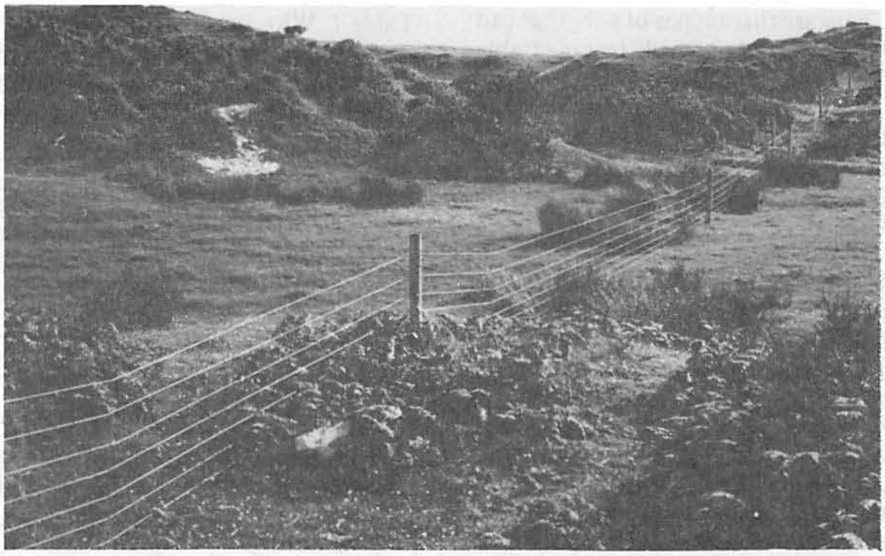


Fig 4 A high tensile fence with steel droppers

Concern has been voiced by some people of the danger from whip lash should a wire break during tensioning. If the wire is unreeled from a reel unwinder to prevent kinking, there is virtually no danger of breaking. The only type of wire to be watched is single strand high tensile barb wire, as this often has a non uniform cross section. It should be strained only to a low tension.

Woven wire high tensile fence

This fence has been manufactured and used in New Zealand for ten years or more, but was only recently imported into the UK. It is now manufactured here by two companies, thereby reducing the price on the market.

The fence has most of the advantages of the mild steel woven wire fence, but because less posts are needed, the fence is considerably cheaper.

The strainer assemblies are the same as for the high tensile fence, the rest of the fence being erected as follows (Campbell 1983). A guidance high tensile wire is put up 100 mm off the ground, so that posts can be put in a straight line. The woven wire is attached to the strainers at either end of the fence line using wire connectors, or special high tensile wire knots. The woven wire is then rolled out along the fence line, the 100 m rolls being joined in sequence using wire connectors, reef or figure of eight knots, until the end of the woven wire attached to the one strainer meets the roll of woven wire attached to the other strainer. Special steel clamps are fitted to the end of the roll from the one strainer, and the roll from the other strainer. The gap between the clamps should be 1.5 m for every 100 m of fenceline. The spare end of the one roll is cut off, and the two wire pullers tensioned up until the ends of the wire come together (fig 5). They are then joined using wire connectors or reef or figure of eight knots.

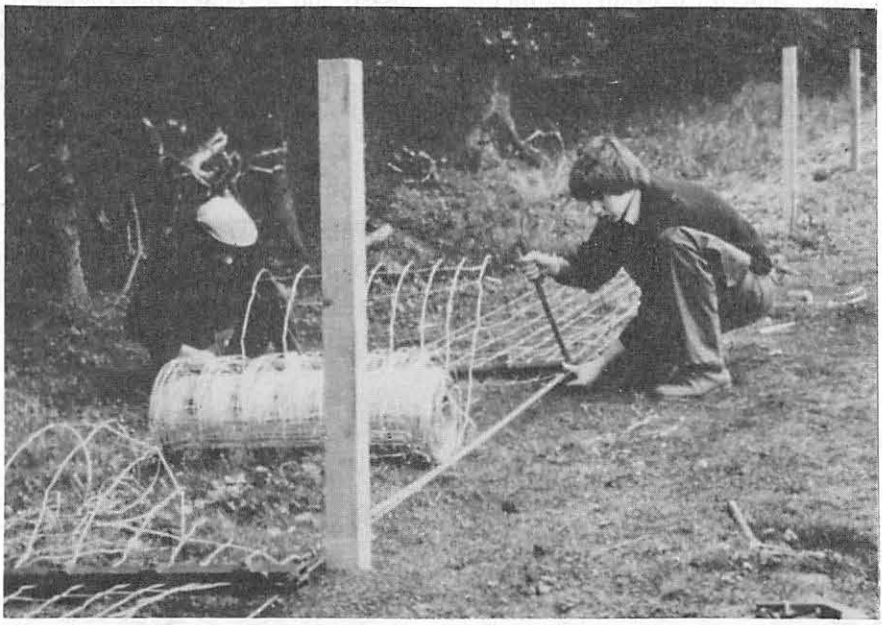


Fig 5 Straining a woven wire mesh fence (photograph courtesy of Balfour-Westler)

The woven wire is then stapled to the posts, and pulled down into hollows, using the wire puller to do this where necessary. A top barb or electric wire can be put on if required.

Once the technique is mastered, it is apparently an easier fence to erect than a conventional high tensile fence (Burdon-Cooper 1982).

Permanent electric fences

The breakthrough with electric fencing was the development in New Zealand of the high energy, mains powered energisers that could maintain their output voltage even when there was considerable shorting of electricity from the fence to the ground. These units are in a different league from strip grazing energisers and their "kick" is painful in the extreme.

To be eligible for agricultural grants, energisers must comply with British Standard 2632 — 1980 (also the European Standard CEE Pub No 5 — second edition.) This standard allows a peak output of 10,000 volts, a maximum energy output of 5 joules when a resistive load of 500 ohms is connected across the output of the controller, and a minimum time interval between pulses of 1 second. Various fail safe conditions are also required to prevent both a multi-pulsing condition and the mains supply connecting with the fence.

These standards have been found to be safe in experiments which include those performed on murderers being electrocuted in the electric chair in the USA. The critical factor is the time between each pulse, which allows a person or animal to unclench or get away from the wire. If the current pulses were more frequent, this could not be possible.

The concept

By electrifying a fence, the concept of the fence is changed completely. No longer is the fence a physical barrier. It is the fear of a shock that deters the stock from going through the fence. Droppers are therefore no longer required. However, other aspects have to be considered when changing to electric fencing.

The stock must be trained initially to respect the fence, by putting feed outwith the fence to encourage them to touch the wires. The fence need not be strongly constructed, or highly tensioned, as there will be no stock pushing or rubbing against the fence. As animals like humans vary psychologically, the occasional animal will go straight through the fence regardless.

Construction

Full details of construction are available elsewhere (Armstrong *et al* 1981, Bryce 1982, Gallacher.) The fence energiser should be mains operated, and have an output of 5 joules if any length of fencing is to be electrified. Battery operated energisers with high outputs are available but they require quite large batteries to operate them, with all the problems involved with their recharging, and maintenance.

The energiser should be installed in a dry shed, and plugged into a standard 13 amp socket. If the ground is always damp, the fence line earth return can consist of three or more galvanised pipes 2 m or more long driven into the ground at least 3 m apart, and 10 m or more from the nearest building. A special insulated galvanised high tensile fencing wire is clamped to each of the earth rods in turn, and then led to the energiser fence earth connection. For normal and dry soil conditions, it is better to get a mechanical excavator to dig a hole 3–5 m deep, and to bury a 5 m long sheet (or sheets) of galvanised corrugated iron, and connect the earth return wire to it. Poor earthing is the main cause of electric fence failure on farms.

On no account should the earth installed by the Electricity Board for the mains supply be used as an earth return for the fence.

Power is led out from the energiser, again using insulated, galvanised, high tensile wire. This wire can be put underground, preferably double protected by alkathene pipe, or fixed to the sides of the steading until the fence line is reached. This wire should be connected to the fence wires using a bolt-on, line clamp.

If the fence line to be electrified is on the far side of existing fences, a single, galvanised, high tensile, lead-out wire can be attached to the existing fences using insulators or insulated offset brackets. Any barb wire on the existing fence must be removed, however, as a child's clothing could get caught, and the child could eventually die through exhaustion caused by repeated electric shocks. The obvious solution is to replace the barb wire with a single electric wire, and this will deter stock going over the fence.

If the lead-out wire is over a kilometer in length, a second wire, alongside the first, may be required to reduce the voltage drop in the lead-out.

The electric fence line itself should be carefully planned so that sections of fence can be isolated easily by throwing switches. If a short occurs on the fence, the easiest way of finding the defect is to switch out sections in turn. When the voltage on the fence returns to normal, you know that the section of fence switched out contains the fault. Only this section of fence need be walked to find the offending leak. Good siting of switches and fencing sections can save a considerable amount of walking.

The fence itself consists of either four or five high tensile (2.5 mm diameter, 1080 N/mm^2 tensile strength) wires, the one nearest the ground and in closest contact with the grass always being dead. In Britain, this wire is not usually earthed, as this can encourage shorting of the fence, and the ground is usually wet enough to give a good earth return. The four wire fence is adequate for sheep on hill reseeds, but where better control is required the fifth wire should be fitted.

The live wires should all be connected together at the start and end of each strained section. This reduces the voltage drop in the wires to a minimum.

The straining posts need only be 125 mm in diameter as the tension on the wires is very low. If flat stones are put in at the heel and breast, the stay can be dispensed with. This is an advantage, as otherwise the wires, if live, need to be kept off the stay (fig 6).

Insulators taking the strain of the wire should be porcelain, or the special hard Bryce plastics pads. Wire will eventually pull through most plastics unless there is a metal insert to spread the load.

Posts can be put in from between 8 to 20 m, the ground undulations determining where they should go. The wires are pulled down into dips using some sort of insulated tie down and anchor combination.

Insulators on posts must have as long a distance as possible of insulation material between the wire and the post. A minimum distance of 20 mm is required (fig 7).

Black thermoplastic insulators designed specifically for the job should be used. Coloured insulators will deteriorate in sunlight, and "home made" insulators will soon become useless. Thermoplastic tube insulators (but not alkathene pipe) can be used, and stapled to the posts, but the correct number must be counted out to match the number of posts, and threaded on to each line prior to straining the wires.

Instead of timber posts and insulators, "Insultimber" posts made from Australian desert hard wood can be used, as the wood has good insulating properties. Posts and droppers are available in this material and, as they are so hard and virtually impossible to saw, grooves are already milled in the posts to take the wires. The posts made therefore must be driven exactly the correct depth if the wires are to be parallel to the ground.

The wires are usually tensioned by fitting a simple radisseur in the centre of each wire (fig 8). Alternatively, a butterfly radisseur can be fitted between the strain insulator and the strainer post.

Fig 6 Electric fence strainer assembly

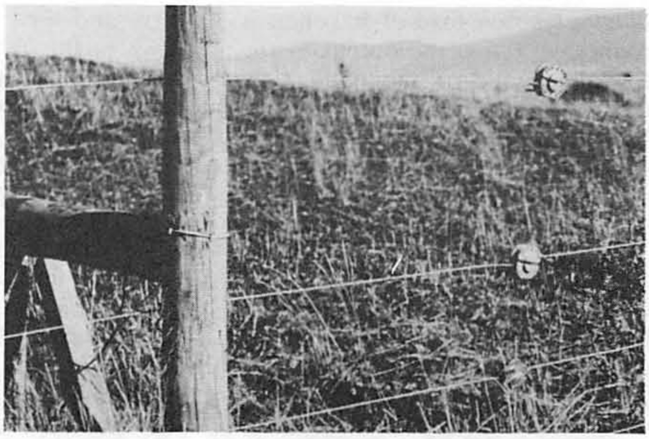
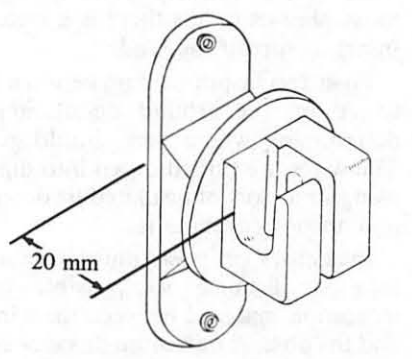


Fig 8 Radisseurs fitted to centre of wire

Fig 7 Distance of insulation material between wire and post



The electric current can be carried passed a gate by burying insulated high tensile wire under the gate (fig 9).

Gates need not be of timber, and woven wire mesh can be made into a simple gate, that is made live when it is closed.

Stiles should be installed whenever the public or farm staff wish to cross the fence.

If electric fences are to be put across rivers, they should be put high enough to be kept clear of flood water. For effective stock control, chains hanging down can be electrified via a small resistor. If the water rises, the resistor prevents too much voltage drop to shorting.

Fig 9 Carrying the current passed a gate

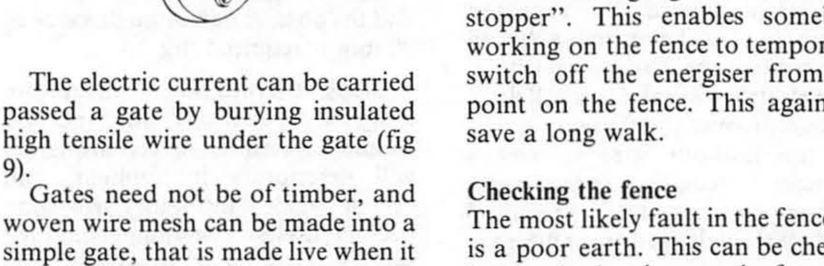
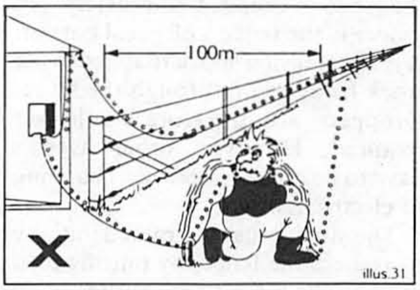
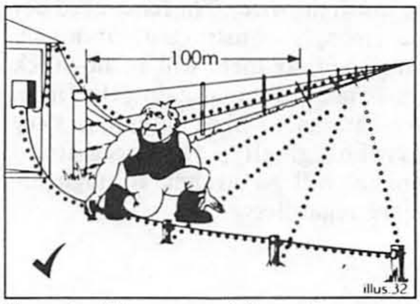


Fig 10 Testing the earth (Sketch courtesy of Gallagher Agriculture Ltd)



Test your earth system.



There should be no power in the earth.

Various gadgets are available for electric fencing. One excellent one is the remote monitor. A monitor panel has five neon lights for each of four sections of fence line. A monitor nailed to a fence line post in each section measures the voltage in that section. It sends the information down the fence line, and the respective number of neons light up to give an idea of the fence voltage in each section. The farmer can see, at a glance, whether or not the fence line is at full voltage.

The other gadget is the "shock stopper". This enables somebody working on the fence to temporarily switch off the energiser from any point on the fence. This again can save a long walk.

Checking the fence

The most likely fault in the fence line is a poor earth. This can be checked by simply shorting out the fence line 100 m away from the earth with some steel rods. You then put one hand on one of the earth pegs, and the other is outstretched to touch first the grass and then the ground (fig 10). If a shock is felt at all, then the earth must be improved by driving further galvanised tubes in the ground.

If the earth is good, and the fence voltage is low, you must go round the fence with a volt meter testing where the voltage is low. This is where the apt siting of switches can help greatly. Contrary to folk lore, high energy energisers cannot cope with a great deal of lush grass growth touching the wires. Periodic spraying under the fence line may be necessary to keep the voltage at a satisfactory level.

Poor connections between wires can result in loss of voltage, and should be checked. They are also a source of radio interference, that can be a real nuisance to any music lover in the vicinity.

People who do not understand electricity can find faults in electric fences exasperating and confusing. Make sure that the stockman who is to check the fence is well schooled in its operation, and believes that the fence is effective.

Safety

Electric fences are quite safe so long as the safety recommendations are adhered to. There should be no barb wire in a fence that has any of its wires electrified. There should never be two energisers connected to the same fence line. The fence lines should not run directly under high voltage power cables, in case a mains voltage is induced in the fence wire. The Electricity Board earth must never be used as the fence earth return. Warning notices must be attached to the fence every 100 m if the fence goes along a public path or highway.

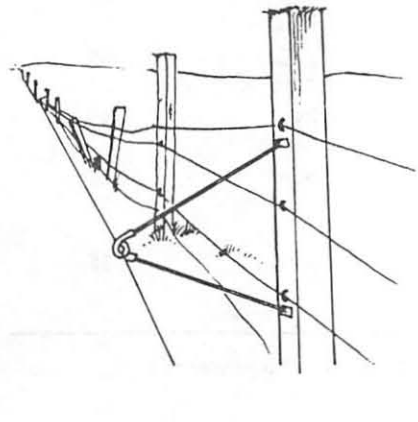
Apart from these safety recommendations, which are in practice often ignored, there are some recommendations that I should like to add. Electric fences should not be erected along side paths used regularly by people with young children and dogs. With the relatively small amount of electric fencing in existence, there have already been a number of complaints to the police where such fences have been installed. Electric fences should not be erected alongside the major roads where accidents are more likely, and the chance of travellers urinating against a fence in the dark is more likely.

Where walkers regularly cross agricultural land, stiles should be put up to enable them to cross electric fences in safety. Where farms are near towns, electric fences have been shorted out due to people being angry at the shock they have received from the fence. Fences in such areas, therefore, should not be electric.

Single electric wires

There is no reason why an electrified wire can not be added to any fence. Such a wire can replace a barb wire, reducing stock pressure on the fence, and avoiding the hide damage which the leather industry finds so wasteful. The life of an old fence can be extended by fitting offset insulated brackets (fig 11) and running and electrified wire through them. Any barb wires on the fence must be removed, however.

Fig 11 An electrified wire on offset insulated brackets upgrading an old fence



Stone walls can be made more secure by the addition of one or two electrified wires (fig 12). If stock are on both sides of the wall, fences must be erected on both sides to prevent stock jumping up on the wall then over the wire.

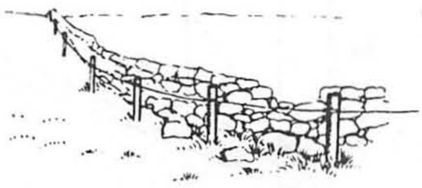


Fig 12 A live scare wire can be used to reinforce an old wall

Rabbit fences incorporating non electrified rabbit netting and electrified top wires can be effective. It is also claimed that deer can be deterred from jumping a farm fence by putting in a single electrified wire just at the point of take off.

Temporary electric fencing

Temporary electric fencing is very useful for the control of strip grazing of grass, turnips or kale. If the farm has permanent electric fencing, the temporary wire simply needs to be connected to the field fence. Otherwise battery units with an energy output of about one joule per pulse are recommended.

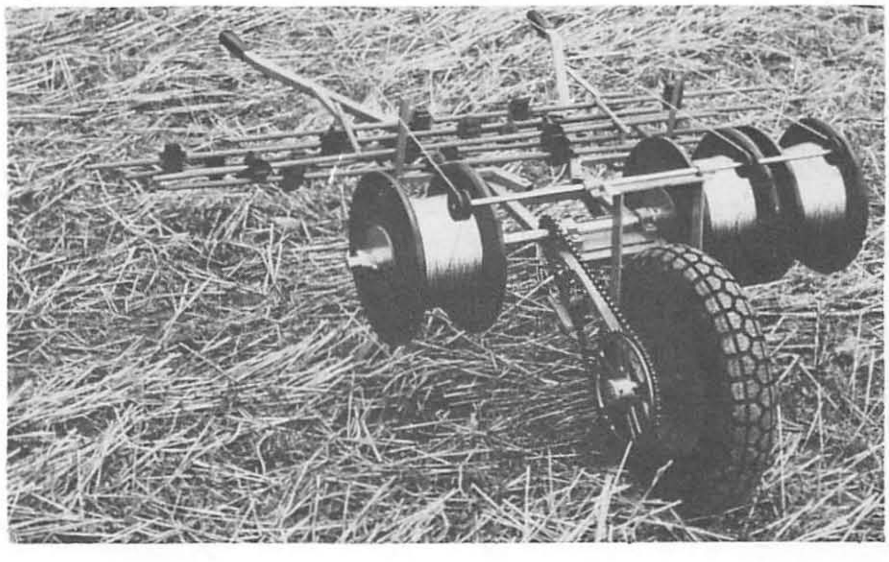
Various systems are available, but most use multiscore stainless steel wire on plastic reels. A single wire will suffice for dairy cows, but sheep require three wires. Dispensers in the shape of a wheel barrow (fig 13) are available to enable the three wires to be put out at one time. Plastics posts are pushed in the ground to support the wires. Polypropylene netting with a wire through it provides an alternative barrier.

Life of fences

Timber

Timber posts rot most at just below ground level. The harder and less porous the timber, the longer its life will be. Hence untreated European Larch is more durable than untreated Scots Pine (Countryside Commission for Scotland, 1983). However, preservative treatments for timber are available and the more porous the timber, the more effective the treatments become. Larch is moderately resistant to treatment, whilst fir is moderately easy to treat. Larch is therefore used untreated, whilst fir is always treated. Treated fir posts would appear to have a life of 15 years or more whilst untreated Larch posts are liable to start breaking after 10 years (O'Toole 1982). Estimates for the life of posts, which have been vacuum/pressure treated with creosote or copper chrome arsenate, are put at 40 years (Countryside Commission for Scotland 1983). The four preservative types available are the organic solvent preservatives (eg Cuprinol), pentachlorophenal in heavy oil, water borne copper chrome arsenate (CCA) preservatives (eg Celcure, Tanalith) and creosote.

Fig 13 Temporary electric fence dispenser



For timber in ground contact, the CCA, creosote and pentachlorophenal in heavy oil preservatives are preferred, and these should be applied with vacuum/pressure equipment or hot and cold tank treatment plants. Care must be taken that timber for sale has been properly treated, and not just dipped in a tank solution for a few minutes.

Wire life
Wire depends almost entirely on its surface coating of galvanising to prevent its life. Once the coating is gone, the fence will fail if under tension, within a couple of years. The galvanising will decay faster in polluted areas near factories and near the sea, than inland non-polluted areas. British Standard 443: 1982 requires agricultural fencing wire to have a galvanised coating by weight of 270 g/m^2. The life of this coating is shown in fig 14. In practice, these figures would appear to be pessimistic.

Wire is available in the UK which is coated with wiped galvanising with a weight of 90 g/m^2. This does not conform to BS443, and should not be used for agricultural fencing.

Every effort should be made to avoid scraping the galvanising from the wire with wire pullers, pliers or hammers. Staples should be angled to prevent wire vibrating in the wind and corroding at the staples. Alternatively, plastic tube grommets should be put between the wire and the staple to prevent wear. In practice, where the steel is exposed in damaged areas, the galvanising will sacrificially corrode, thereby protecting the exposed steel.

There would appear to be no evidence to corroborate the allegation that galvanising cracks when high tensile wire is highly tensioned, thereby encouraging corrosion. Only if wire was tensioned in excess of its plastic limit, could this occur.

Burning

Where burning of moorland is practiced, fence selection should take account of this. Experiments have shown that a fence is at risk from fire in proportion to its tension (Garden 1967). Thus, a conventional plain wire fence that has completely cast its tension is least at risk, an electric fence with some tension is more at risk, and a high tensile fence with a considerable degree of tension is most at risk.

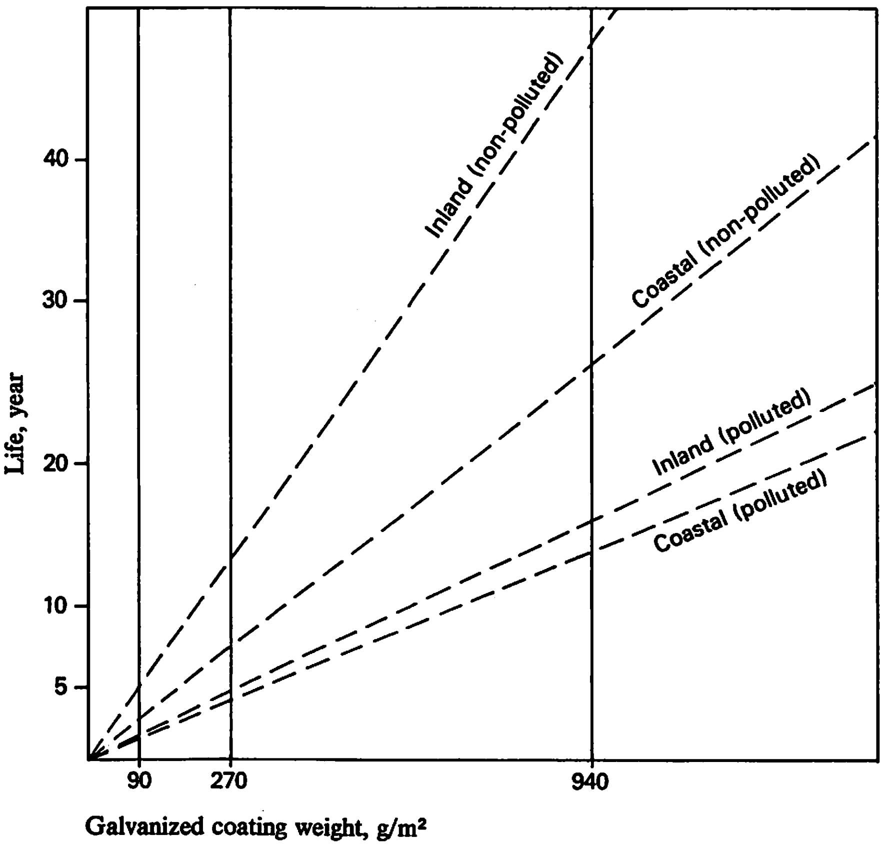


Fig 14 Life of galvanised wire (Sentinel)

Government grants as a disincentive to progress

Government grants for fencing in Scotland in the less favoured areas are 50% of either the total cost of the fence or standard costs. The cost of a fence is approximately 67% materials and 33% labour. As a farmer or crofter will not consider the cost of his own labour, the amount that he has to pay out for fencing is a mere 17% of the material cost. It is little wonder, therefore, that so much traditional fencing is still erected.

Fence costs

The costs outlined (SAC 1983) are for fence materials only, and the type of construction and materials chosen

Table 2 Costs of fences

Type of fence	*Post spacing, m*	*No of wires*	*Cost, pence/m*
Conventional plain wire	3	5 plain 2 barb	93
	2	5 plain 2 barb	109
Mild steel woven wire	3	1 plain 1 barb	110
High tensile	8	6 plain 1 barb	67
High tensile woven wire	8	1 plain 1 barb	95
Permanent electric* 5 wire fence	10	4 live 1 dead	45
Permanent electric* wall reinforcement fence (one side only)	10	2 wire	27
Permanent electric* scare wire reinforcing existing fence	–	1 wire	15

**Add cost of energiser £130, earth £20, and lead-out wire at 8 pence/m.*

are those most commonly in use in Scotland today (table 2). The costs are calculated for a 300 metre long fence.

Fence selection

An approximate guide to fence selection is tabulated below (table 3).

The future

Permanent electric fences are likely to increasingly be used due to their low cost, effectiveness and relative ease with which they can be erected, once the basic construction techniques have been mastered. It is to be hoped that farmers will be sensible, and only install them where the general public in any numbers are unlikely to come in contact with them. In the event of a conflict of interests, the general public will inevitably win and a most useful system may be lost.

High tensile plain and woven wire mesh fencing will continue to play a considerable role in fencing, especially as boundary fences, lambing park enclosures, and where high security fences are required.

So long as the present grant structure remains, high cost mild steel woven wire fences will continue to be erected in substantial quantities.

It is to be hoped that there will be a gradual reduction in the amount of five barb wire fences in the country, as they re being replaced with electric or high tensile fencing. This will please both the tanning industry and the fence erector alike.

For these developments to take place, new skills must be learned, and encouragement must be given for colleges to teach their students these skills and for farmers to request for Agricultural Training Board courses.

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Table 3 Selecting a fence

Type of fence	*Appropriate type of stock*	*Strain distance, m*	*Security*	*Location*	*Expertise*	*Cost*
Conventional 5 plain 2 barb	Cattle, adult sheep	40– 150	Medium	Internal or boundarys	Well known	High
Mild steel woven wire mesh fence	All stock, inc young lambs	40– 150	High	Internal or boundarys	Well known	High
High tensile 6 plain 1 barb	All stock	100–1000	High	Internal or boundarys	Attend Agric Training Board course	Medium
High tensile woven wire mesh fence	All stock, inc young lambs	100–1000	High	Internal or boundarys	Attend Agric Training Board course	Med/high
Electric 4-wire	All stock	40–1000	Medium	Internal fencing Hill sub division	Attend Agric Training Board course	Low
Electric 5-wire	All stock	40–1000	Med/high	Internal plus boundaries by agreement	Attend Agric Training Board course	Low
Electric single wire to reinforce old fence or wall	All stock	40–1000	High	Internal plus boundaries by agreement	Attend Agric Training Board course	Low

The applicability of groundwater heat pumps to space heating

R Kitching

Summary

GROUNDWATER heat pumps are capable of supplying space heating at high efficiencies for long periods even when ambient temperatures are low. In contrast, the efficiency of the air source heat pump drops when the heat demand is greatest at low ambient temperatures. Groundwater occurs at many locations in the UK and, if available at a reasonable cost, is the preferred source for heat pumps. Gas and diesel engine power sources for heat pumps are not at present as reliable as electric motors but offer the possibility of higher efficiency. Where groundwater is available, heat pumps offer payback periods of 1–10 years, depending upon whether boreholes already exist and the local geological conditions. Possible applications to horticulture are considered.

Introduction

THE rapidly rising price of oil during the last ten years has led to the need for conservation of energy resources and a search for alternative, more efficient systems for space heating of houses and of industrial and horticultural premises. When basic fossil fuel costs were low, it was not necessarily economic to burn the fuel efficiently if, in order to do so, extra capital costs of new boilers or other equipment had to be incurred.

Recently, the very high cost of fuels has led to a situation where extra capital costs of more efficient equipment may be recoverable from the considerable savings in fuel used over a reasonable period. The heat pump clearly falls in the category of highly efficient but capital intensive heating systems. In particular, the groundwater source heat pump is capable of operating at high efficiency for long periods even when ambient air temperatures are low. This article describes the operation, economics and possible application of the groundwater heat pump to horticulture.

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Theory of the heat pump

The principle of the heat pump is that heat may be extracted from a low temperature source and given up to a higher temperature sink. The heat pump must be supplied with energy to perform the transfer of heat but, in general, the amount of energy supplied to operate the heat pump is less than the total heat given to the sink.

The domestic refrigerator is a good illustration of the practical application of the heat pump principle. In this case, the low temperature source of heat is the food within the fridge and the higher temperature sink is the radiator usually at the back of the cabinet which radiates warmth while the compressor is working. Electrical energy is supplied to the compressor to achieve this transfer of heat from the inside to the outside.

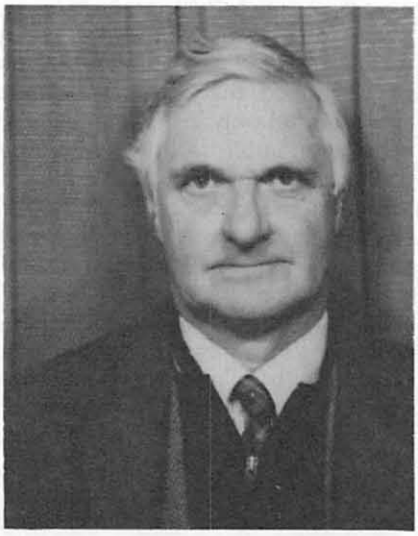
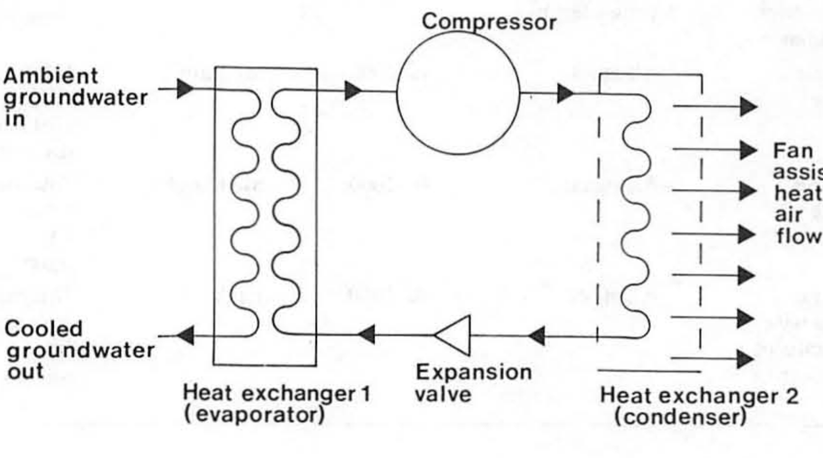


Figure 1 (after Day and Kitching, 1981) shows the layout and basic components of a groundwater heat pump used for space heating. The refrigerant fluid (typically freon) flows around a closed circuit between the compressor and expansion valve via the two heat exchangers. These heat exchangers have large surface areas to achieve efficient transfer of heat between the input and output

Fig 1 Layout and components of a groundwater heat pump



media. Groundwater at about 10°C flows through the primary circuit of the first heat exchanger (evaporator) and is cooled by the cold refrigerant vapour in the secondary coil. After receiving heat from the groundwater, the refrigerant fluid is compressed; this raises its temperature and causes it to condense in the second heat exchanger (condenser). Heat given out during the condensation process passes to the space heating medium (air or water) in the secondary coil of the condenser. The refrigerant then passes through the expansion valve which cools and vaporizes it in the evaporator ready to begin the cycle again.

The efficiency of such a heat pump system can be expressed in terms of the total heat provided at the higher temperature compared with the total energy supplied to effect the transfer. Thus:

$$\text{Coefficient of Performance (COP)} = \frac{\text{Total heat output}}{\text{Total energy input}}$$

For a typical space heating application using groundwater at about 10°C, the coefficient of performance is approximately 3.0. This indicates that for every three units of heat produced by the heat pump, only one unit of energy (say electricity) is required to operate the system. The remaining two units of heat are derived from the groundwater which is returned (slightly cooled) to the natural aquifer whence it came.

Comparison of air and groundwater systems

Consideration of the theory of the heat pump cycle shows that the efficiency, or coefficient of performance, is inversely proportional to the difference between the source and output temperatures. For greatest efficiency, therefore, the source temperature should be as high as possible and the temperature of the output medium (air or water) should be as low as possible.

When ambient air is used as the source for the heat pump, the temperature and, therefore, the efficiency fluctuate throughout the year. In particular, the source is at its lowest temperature when the demand for space heating is at its peak in winter. Unfortunately, this means that the efficiency of the air source heat pump is least when the maximum amount of heating is required. The efficiency is even further reduced by the need to defrost the evaporator coils when the ambient air temperatures are around freezing point. Air source heat pumps are therefore likely to need considerable and expensive backup heating at times of peak demand.

Heat pumps using groundwater as a source do not suffer these disadvantages as its temperature is practically constant (about 10°C within much of Britain) throughout the year. The efficiency is uniform, even during cold spells, and there is no need to defrost the heat exchangers in freezing weather. Consequently, backup heating is not required at times of peak demand to maintain the output.

Other possible sources for heat pumps are surface water (ponds, rivers) or the ground itself. Surface water, in general, will have a temperature intermediate between that of groundwater and ambient air. It may be suitable as a source for a heat pump, provided that it is available in sufficient quantity, but the efficiency will not be as high as with groundwater. As with an air source, the efficiency of surface water will fluctuate during the heating season and will be at its lowest at about the time of maximum heat demand. Groundwater, if available at reasonable cost, is the preferred source.

Groundcoil systems

Where groundwater is unavailable, it is sometimes possible to bury a coil of pipe in the ground and extract heat from it using a suitable circulating fluid. Alkathene pipe of 25 mm internal diameter has been used with 25% ethylene glycol as a circulating fluid. The groundcoil is placed in series in a loop with the evaporator of the heat pump and a suitable circulating pump. In order to achieve transfer of heat through the ground to the coil, lower evaporating temperatures are used than with the simple groundwater-fed heat pump. Also more energy may be used by the circulating pump than by the submersible pump so that the efficiency of the groundcoil system may not be as great as with the groundwater heat pump. Nevertheless, the groundcoil system may be a viable alternative where groundwater is unavailable but where sufficient area of land is available to install a horizontal coil.

The depth of installation of the groundcoil can vary from 1–4 m and a length of approximately 300 m of alkathene pipe is required for a 100 kW installation. The pipe should be spaced to cover an area of about 300 m^2, in order to achieve adequate recharge of heat in summer. The relatively large area of land required for this system may be a disadvantage in many applications. In order to overcome this space requirement, some systems have been proposed which use an array of vertical boreholes or even one deep borehole with the groundcoil inserted in the holes. Some systems, which circulate the refrigerant fluid in vertical coils in boreholes, have also been proposed. However, any groundcoil system with a horizontal area of less than that specified above or any vertical coil system may have problems in ensuring adequate recharge of heat to the surrounding cooled ground. If the summer recharge is inadequate, gradual cooling of the ground will occur which will lead to a steady falloff in the efficiency of the system over a period of a few years. In any groundcoil system, it is, therefore, important to ensure that sufficient summer recharge of heat can balance winter losses.

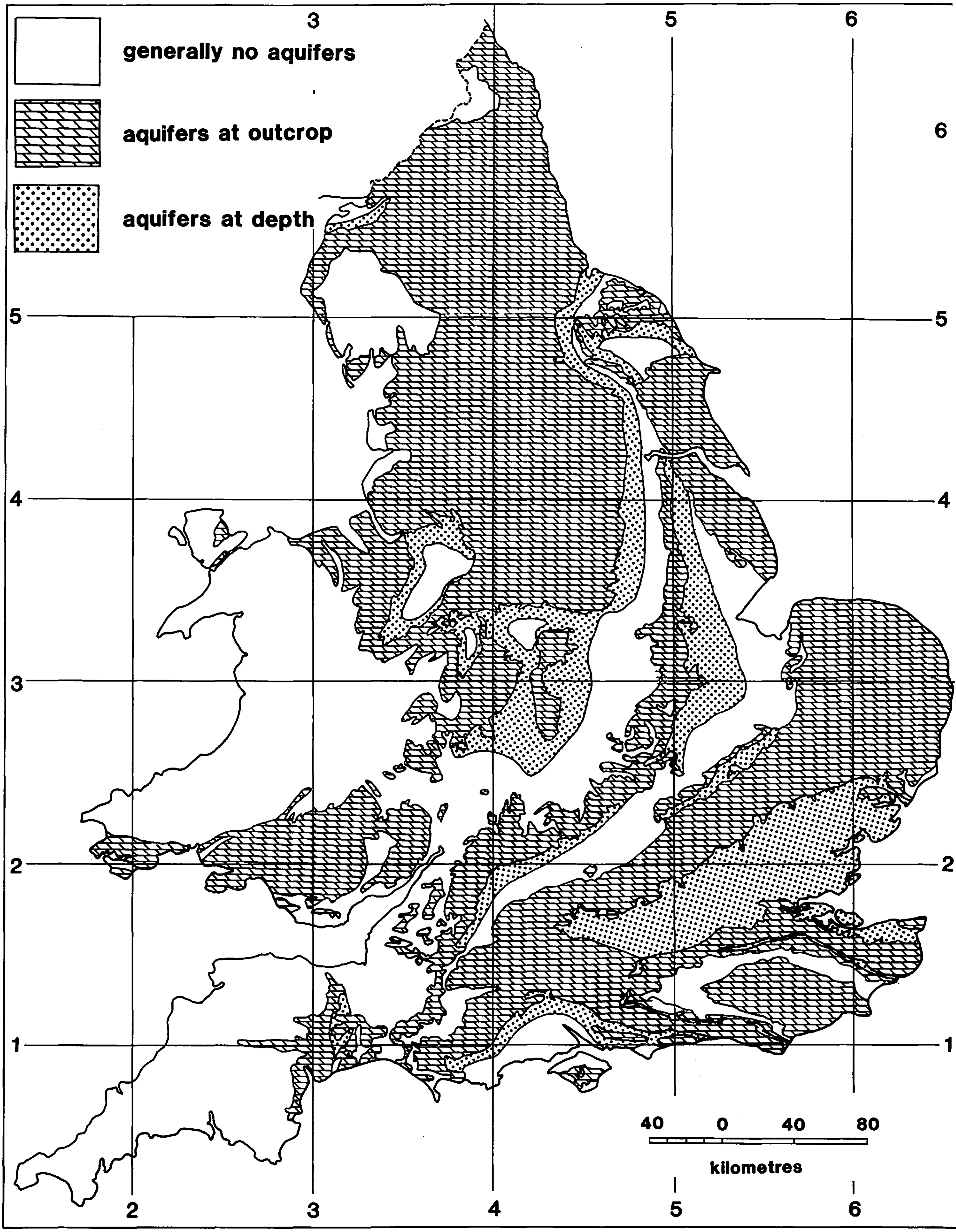
Availability of groundwater

Groundwater is available at many locations in Britain, but in variable amounts depending on the local geology.

Shallow groundwater is frequently found in superficial alluvial deposits of sand and gravel which occur in river valleys, basins and estuaries. Heat pumps require about 25 litres/minute for 10 kW heat output which would be an adequate size for medium size, domestic premises. Larger sizes of heat pumps would use proportionally more groundwater.

More extensive aquifers (water bearing rocks) occur at greater depths, especially, but by no means exclusively, in the East and South of England. Such aquifers supply a large proportion of water for public and industrial supply. Large scale use of groundwater for heat pumps would necessitate the assessment of priorities in relation to this public water supply. However, groundwater heat pumps do not make any net use of the water as it may be (and should be) returned to the aquifer from which it was obtained, but at a slightly lower temperature. A typical temperature drop on passing through

Fig 2 Distribution of principal acquifers in England and Wales



the evaporator of a heat pump would be about 4°C. Possible pollution hazards might cause Water Authorities some concern.

In many areas, groundwater is saline and, whilst unsuitable for public water supply, could be acceptable for heat pump use. Care would have to be taken in the design of the evaporator heat exchanger to avoid corrosion.

Figure 2 shows the distribution of principal water bearing formations in England and Wales. When alluvial deposits and glacial sand and gravel are also taken into account, it is apparent that groundwater is available over about 50% of the area of the UK.

Where groundwater is used to supply heat pumps directly, it is desirable to discharge it again to the same aquifer. This should be done via another borehole or, if appropriate, a surface soakaway located down the hydraulic gradient from the abstraction borehole in order to minimize recycling of the water. The spacing between the abstraction and recharge boreholes will depend upon the aquifer properties, the abstraction rate and the natural hydraulic gradient.

The Institute of Geological Sciences has a computer model groundwater programme to calculate the borehole spacing required under various aquifer conditions.

Prime movers

Most heat pumps currently available operate electrically. In general, they require a three phase supply and use electricity at the full rate tariff. However, if there is a heat demand at night or if it is possible to store heat during the night for daytime use, then low cost off-peak rates may apply.

As an alternative to electricity, heat pumps may be powered by gas or diesel engines. The chief advantage of an engine drive is that considerable extra useful heat may be obtained from the cooling and exhaust systems. Electrical generation at power stations is only normally about 30% efficient and the excess heat energy is wasted. It is this waste heat that may be recovered when an engine drives a heat pump. The availability of this excess heat means that the heat pump size and, therefore, capital cost may be reduced as well as the running costs.

However, the total capital cost of engine drives is higher than for electric motors and the costs of maintenance are also likely to be greater. Furthermore, engine drives tend to be noisier and there is less long term operating experience of the cheaper types of automotive power.

At present, therefore, the electric motor seems a more reliable power source than an engine but it is possible that improvements in design and reliability will further enhance the position of the gas or diesel engine.

Table 1 Heating costs (summer 1983)

Fuel system	*Cost, p/kWh*	*Efficiency, %*	*Cost of useful heat, p/kWh*
Electrical heat pump			
Full rate	3.74	300	1.25
Off peak rate	1.67	300	0.56
20% full: 80% off peak rate	2.08	300	0.69
Propane	1.70	70	2.43
Natural gas	1.04	70	1.49
Gas oil, 35 sec	2.26	70	3.23
Heavy fuel oil	1.50	70	2.14
Industrial coke	1.09	70	1.56

Legal situation

In England and Wales, abstraction of groundwater for heating of commercial premises would require a licence from the appropriate Regional Water Authority; a small charge based on quantity used would be made for water returned to the same geological strata.

The legal position on the abstraction of groundwater for heating domestic premises by a heatpump is uncertain. Licences are not normally required for groundwater abstracted for 'domestic purposes', but it is unclear as to whether groundwater used in heat pumps for space heating would constitute 'domestic purposes'. In the past, Authorities have differed as to what is, and is not, licensable.

It is desirable that, after use in a heat pump, groundwater should be put back into the aquifer from which it was obtained. This will ensure no net use of water and is more likely to result in the Water Authority looking favourably upon the abstraction. Discharge of water would require the consent of the Water Authority. Discharge into surface water courses might be allowed in some cases.

Economics of the system

The chief advantages of groundwater heat pump systems are in their low running costs. Table 1 shows the costs of useful heat for conventional and heat pump systems (prices quoted for bulk supplies June 1983).

It will be seen that the running costs of groundwater heat pumps using full rate electricity are a little less than those of natural gas and considerably lower than oil. If off-peak or a combination of full/off peak rate electricity may be used, then the advantage of the heat pump is even greater.

However, the capital costs of groundwater heat pump installations are somewhat higher than conventional oil or gas systems. The heat pumps themselves are expensive and to these must be added the cost of boreholes for abstraction and discharge and also the cost of extending the electricity supply if required. It is impossible to give generally applicable costs as these will vary with particular circumstances including local geology.

For a 200 kW system such as might be suitable for a 0.1 ha glasshouse, the extra capital cost of a groundwater heat pump system might be of the order of £5000–15000 more than for oil or gas, depending upon the availability of groundwater and the depth of boreholes required. If suitable boreholes already exist for supply of irrigation water, then additional costs would only be for the heat pump itself. Assuming 2000 hours operation, the saving on running costs over heavy fuel oil would be £3560 per annum (using full rate electricity). However, if a substantial part of the heating load were at night when off-peak electricity could be used, then very considerable savings could be achieved.

Furthermore it might be advantageous to use a smaller heat pump for the base load and top up the heat output with oil at times of maximum demand. This would save on capital costs of the heat pump and allow the heat pump to operate efficiently at maximum load for longer periods. Sizing of the heat pump would depend upon the particular heating load and its fluctuation. The payback period of the system against oil would vary from about 1–10 years depending upon the application.

The following characteristics would cause a system to yield a lower payback period:

1) high heating demand for a large proportion of the day and night;
2) heating demand at night;
3) existence of boreholes for irrigation purposes;
4) availability of three phase electricity supply of sufficient capacity.

Application to horticulture

White (1977) estimated the use of petroleum based fuels in agriculture in the UK (1972/1973) as:

tractors and self powered machines	48.5%
vehicles, lorries, vans and cars	15.8%
glasshouse heating	25.2%
heating, drying and lighting	10.5%

Thus, glasshouse heating accounted for 25% of total energy used at that time and is still likely to be a substantial amount. It is an area where application of groundwater heat pumps could effect considerable savings of energy to the nation as well as yield lower heating costs for horticulturalists.

Other possible applications of groundwater heat pumps include heating of farm buildings, especially where heat is required for a large part of each day eg poultry houses.

Crop drying is a less likely application as the period of operation is limited.

Reliability of groundwater heat pumps

The main components of groundwater heat pumps are the compressor and heat exchangers.

Compressor technology has advanced considerably in the last 30 years and modern machines for deep freeze applications are required to have a long and reliable life. Experience of these systems indicates that a ten year life is not unreasonable.

The problems associated with heat exchangers are likely to be those of scaling and corrosion. Scaling of the heat exchanger may occur if the system pressure is reduced. It may be minimized by maintaining water pressure in the system.

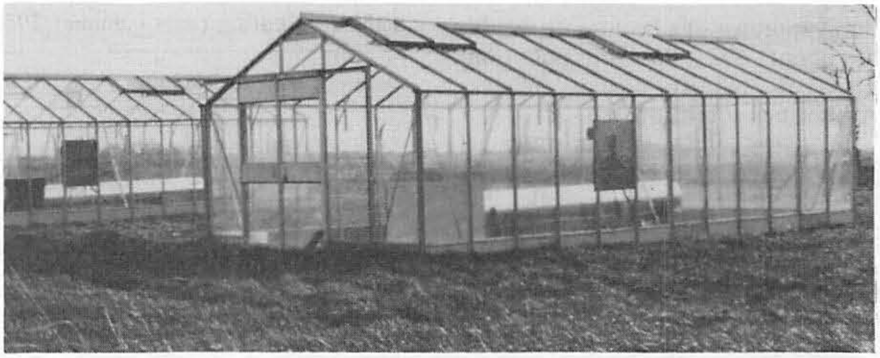


Fig 3 Set of glasshouses with groundwater heat pumps

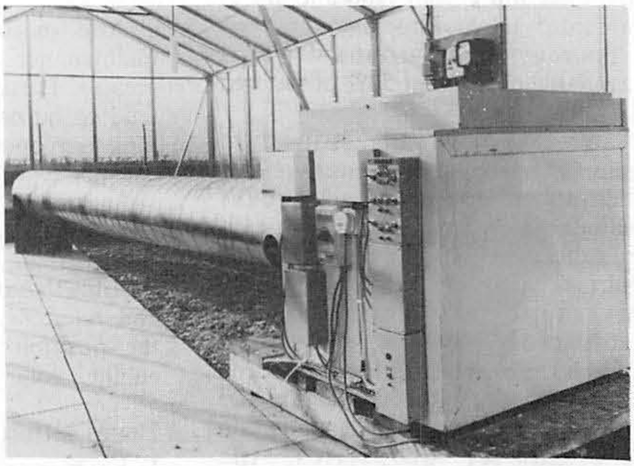


Fig 4 A directly fed groundwater heat pump

Corrosion results from electrochemical reaction and careful consideration of the chemical constituents in the water in relation to the materials of the heat exchanger is necessary to minimize it. Plastics or special steel pipes and casings may be necessary under some circumstances.

Experience of groundwater heat pump schemes

Many groundwater heat pumps have been installed in the USA. They are used for both domestic and commercial applications and are often used for combined air conditioning and heating applications. In Western Europe, there is a large number of groundwater heat pump installations and, particularly in West Germany, there are many heat pump manufacturers and suppliers. In Sweden, the emphasis has been on the ground coil system as groundwater is not readily available.

In the UK, the Institute of Geological Sciences has been operating some small (10 kW) demonstration groundwater heat pumps in glasshouses and domestic premises (figures 3 and 4). These are of American manufacture and have yielded coefficient of performance values of 2.7–3.0 over several years. Reliability has been good. Larger units are available from some manufacturers but long term evaluation of reliability and performance is not yet available.

Conclusion

Groundwater heat pumps offer the prospect of low running costs due to their high efficiency (300%). Where groundwater is available, they offer payback periods of one to ten years depending upon whether boreholes already exist and the local geological conditions.

Acknowledgements

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The Agricultural Engineer

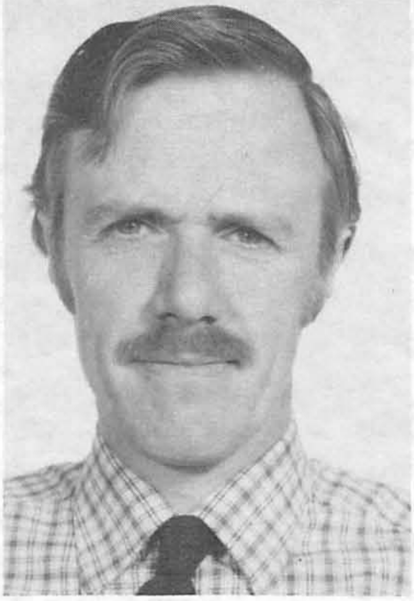
AgEng Items

Broiler chicken catching and transportation systems

M J B Turner and P J Kettlewell

IN the UK, the broiler industry started to grow in the 1950s and thereafter increased very rapidly. The annual consumption of poultry meat rose from 10.7 kg/head of population in 1971 to 13.5 kg/head in 1980, whilst the number of broiler chicks grown per year increased from about 299 million in 1971 to about 403 million in 1980.

Broiler chickens are usually grown on specialised sites, each of which may have ten or more bird houses on it. The number of birds in a house varies but is normally between 10,000 and 20,000. The houses, currently in use today, are insulated timber buildings some 60–100 m long by 10–15 m wide. They are fitted with heaters and ventilation systems designed to maintain temperatures between 20 and 30°C whilst keeping ammonia and dust levels within acceptable limits. Before the birds are put in the house the floor is covered with litter, usually wood shavings, and automatic feeders and drinkers are fitted. Food is usually supplied on an *ad-libitum* basis throughout the growing period. Typically, broilers achieve a liveweight of around 2 kg, the normal processing size in the UK, in about seven to eight weeks. Once the broilers have attained the desired size, they are caught and taken from the growing site to the processing factory.



Mike Turner

Peter Kettlewell

The majority of broilers are processed in large centralised plants, which means that the overheads, and hence costs per bird, are low. Hygiene and grading standards can also be better maintained in a centralised plant. Normal processing rates at the factory are between 5,000 and 10,000 birds per hour, so if the factory is to operate at maximum efficiency, the broilers must be caught and transported at this rate otherwise the processing line is not kept working at full capacity and costs/bird rise. A reserve of birds is often built up at the factory with birds waiting in a lairage for unloading so that, should there be problems during transportation, the factory can carry on processing.

The transport of broilers from the farm to the processing factory needs careful planning and execution. Because the birds are transported live, they need gentle handling during catching, loading, transporting and unloading to avoid bruising and subsequent downgrading.

It is difficult to obtain reliable figures for injury and downgrading because improvements are continually being made in handling methods and grading standards vary. Published estimates made in the late 1970s for downgrading from any cause vary from 3–35%, averaging somewhere between 10 and 15%. Estimates of downgrading due to bruising and injury alone vary from 0.5 to 20%. The number of birds arriving dead at the factory averages between 0.3 and 0.4%, but on very hot and humid days can reach as high a figure as 10%. Many of these deaths are caused by heat stress occurring during transportation or in the lairage.

The loss to the industry caused by injury of the birds or premature death during transportation may be as much as £10M.

There are at least seven operations prior to slaughter which can increase the amount of injury and bruising beyond that occurring during normal husbandry. They are the removal of food some hours before slaughter, the removal of feeding, drinking and heating equipment prior to the catching operation, the catching, carrying and sometimes transfer of birds

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Mike Turner, former secretary of the BSRAE Association, is now in the Farm Buildings Division at the National Institute of Agricultural Engineering and is the subject specialist for livestock handling and feeding.

Peter Kettlewell is qualified in both physiology and agricultural engineering and is working on the mechanization of broiler chicken catching and transportation.

This item was prepared for the British Society for Research in Agricultural Engineering Association Members' Day on Engineering for Livestock Production at the National Institute of Agricultural Engineering on 11 May 1983.

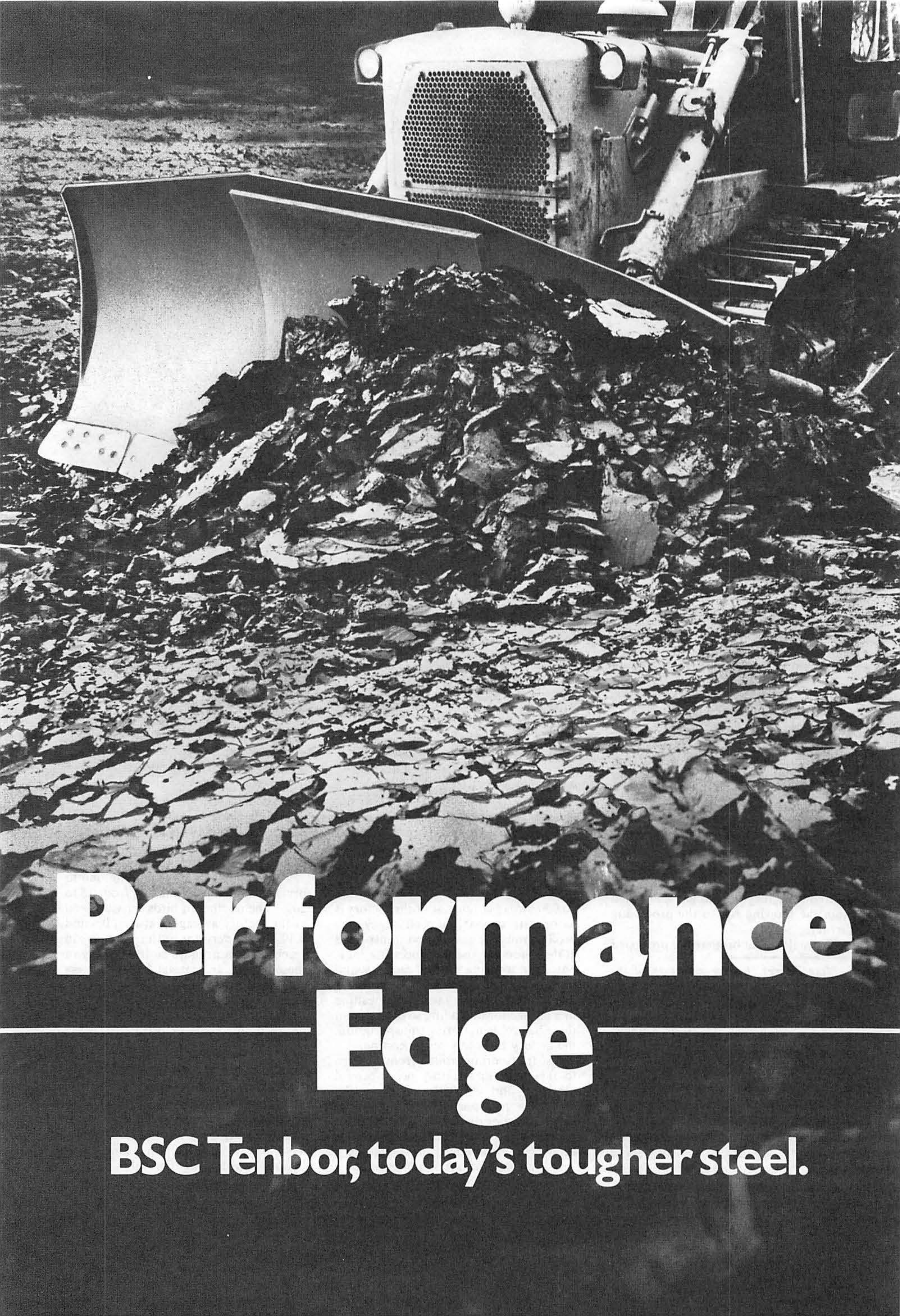

Performance
Edge
BSC Tenbor, today's tougher steel.

Fig 1 Catching broiler chickens and passing man to man to the transport crates (NIAE Photo)

from man to man (fig 1), the loading of birds onto the crates or of crates onto the lorry, the transport of birds from the growing site to the processing plant, the unloading of crates and the hanging of birds into the shackles, and the flapping of the birds whilst on the shackles. Of these, most injury appears to occur during catching, carrying, transfer, loading and unloading of the birds and it is these operations that need to be improved.

Other factors influence the degree of bruising or injury and they include the quality of the staff employed in catching, the presence or absence of adequate supervision, the ambient temperature, the breed and temperament of the birds, the fleshing of the birds, the position of the crate on the lorry, the disease status of the birds and the time the birds spend on the lorry.

With so many factors influencing bruising, it is hardly surprising that the figures available are so variable. Further, it is relatively easy to assess objectively the efficiency of catching and transporting birds in terms of manpower employed, manual effort involved, economics and throughput but it is extremely difficult to predict the level of bruising because it is so sensitive to the attitude of those doing the work. Any of the present catching systems can produce extremely low levels of damage if everyone is careful and conscientious.

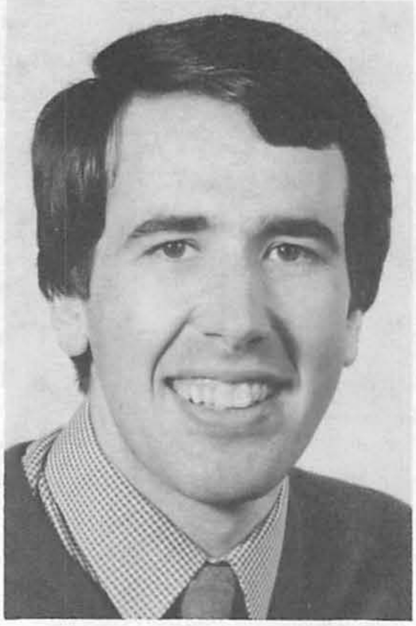
The National Institute of Agricultural Engineering is investigating new harvesting methods with the aim of reducing injury to the birds and making the task of catching more acceptable so that the high level of supervision necessary to avoid damage can be reduced. Apart from the physical damage and bruising of birds during loading and transport, there are additional physiological problems which can arise in transit between the growing farm and the processing factory. Producers are aware that precautions need to be taken when transporting broilers in extremes of weather if losses are to be avoided. These measures are generally subjective approaches, such as reducing the number of birds per crate during warm weather, the size of the reduction being based on previous experience. To understand better how these physiological problems arise and arrive at possible solutions, the National Institute of Agricultural Engineering is studying the environmental conditions on lorries while birds are being transported and the effect these conditions have on the birds. The aim of this work is to enable prediction of the onset of unfavourable conditions and suggest preventive measures which can be taken before loading the lorry.

Further reading

Kettlewell P J, Turner M J B. A review of broiler chicken catching and transportation systems. *J agric Engng Res* (In press).

Ground pressure measurement

C Plackett



ALTHOUGH the prediction of soil compaction effects is a very complex subject, which is not yet fully understood, it is generally accepted that the ground pressure exerted by a vehicle is a good indicator of the compaction it is likely to cause in the upper layers of the soil. Until recently, however, there was no widely recognised method of defining ground pressure and many conflicting claims were made by manufacturers of low ground pressure vehicles. Accordingly, in 1982, the Agricultural Engineers Association formed a committee together with the National & the Scottish Institutes of Agricultural Engineering to determine a common definition and method of measurement. It was agreed that the ground pressure under a wheel or track should be defined as the mean ground pressure determined from the weight on the tyre or track divided by the area of contact, on a hard surface, allowing only for penetration of the lugs or grousers. Measurements made on a hard surface were considered to be valid since if minimum compaction is to be caused by the passage of a wheel, then the depth of rut left by the wheel must be minimised, and the situation approaches that of a wheel running on a hard surface.

The rig constructed at the National

Chris Plackett is a member of the Tractor Research Department at the National Institute of Agricultural Engineering.

This item was prepared for the British Society for Research in Agricultural Engineering Association Members' Day on Tractors and Farm Vehicles at the National Institute of Agricultural Engineering on 12 October 1983.

Fig 2(a) typical print from lugged tyre

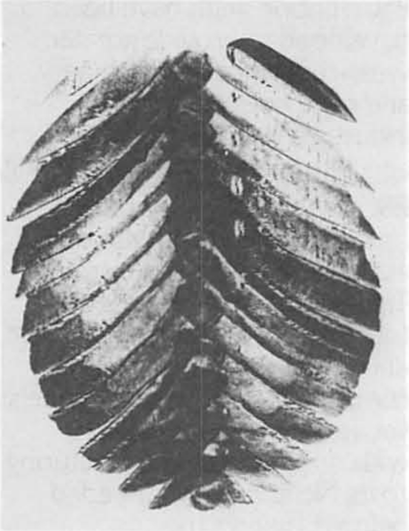


Fig 2(b) Typical print from lugged tyre using multiple overlay technique

Fig 1 Tyre loading bay

Institute of Agricultural Engineering for measuring the mean ground pressure of agricultural tyres in the laboratory is shown in fig 1. It consists of a gantry mounted over a flat steel plate, supported on load cells. The tyre whose ground pressure is to be measured is fitted to a wheel on an axle in the gantry. This axle can then be driven down by hydraulic rams so that the tyre is pressed against the plate until the vertical load, which is recorded on the load cells, is of the required value. The area of contact is measured by painting the surface of the tyre with black ink so that an imprint of the contact patch is made on a piece of white card laid on the steel plate. With lugged tyres, a print similar to that shown in fig 2 (a) is obtained which gives little information about the contact area of the tyre with full lug sinkage. It is necessary, therefore, to superimpose several imprints at different angular positions of the wheel to ensure that the contact area is fully defined as shown in fig 2 (b).

Measurements show that the mean ground pressure is equal to the inflation pressure plus a carcass "pressure" derived from the stiffness of the tyre carcass. This would appear to be a constant for a tyre of a particular size and construction. Therefore, it is only necessary to measure the carcass "pressure" for each tyre and then the mean ground pressure for any application can be calculated by adding the appropriate inflation pressure. Some examples are shown in table 1 for tyres which might be fitted to a two wheel drive tractor having one tonne on the front axle and four tonnes on the rear axle.

Table 1 Mean ground pressure of tractor front and rear tyre sizes

Tyre	*Inflation pressure,* *bar*	*(psi)*	*Carcass pressure,* *bar*	*(psi)*	*Mean ground pressure,* *bar*	*(psi)*
	Front axle, 500 kg/wheel					
7.50–16 Cross-ply	1.5	(22)	0.35	(5)	1.85	(27)
12.0–18 Radial	0.8	(12)	0.3	(4.5)	1.1	(16.5)
400–17.5	0.8	(12)	0.45	(6.5)	1.25	(18.5)
31 × 15.5–15 "Terra-Tire"	0.4	(6)	0.25	(3.5)	0.65	(9.5)
	Rear axle, 2000 kg/wheel					
16.9–34 Radial	1.4	(19)	0.1	(1.5)	1.5	(20.5)
16.9–34 Radial, Duals	0.8	(12)	0.1	(1.5)	0.9	(13.5)
600–30.5	0.8	(12)	0.35	(5)	1.15	(17)
67 × 44–25 "Terra-Tire"	0.35	(5)	0.05	(1)	0.4	(6)

The Institution of Agricultural Engineers
1984 Annual Conference and Luncheon
Wednesday, 9 May 1984, The National Agricultural Centre, Stoneleigh, Warwickshire

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"AGRICULTURAL ENGINEERING TOWARDS 2000"
(A view from the manufacturing industry)

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Aims:

To examine some of the major factors which are likely to influence developments in the agricultural engineering and allied industries over the next 15 years.

To consider the nature of these developments in terms of products, markets, performance and structure of the industry.

* * * * * * * * * * * * * * * *

Background:

A Government Department, a learned society and a university have each studied and published reports on the British agricultural engineering manufacturing industry.

The Institution of Agricultural Engineers is devoting its 1984 Annual Conference to giving representatives of the manufacturing industry the opportunity of presenting views about future developments in, and prospects for, the industry.

The Conference will form part of a 2-year series of activity initiated by the Institution, intended to take stock of the agricultural engineering industry and profession as it prepares for entry into the 21st Century.

* * * * * * * * * * * * * * * *

Programme:

10.00 - 10.30	Coffee		
10.30 - 10.50	Conference will be opened by the President		
10.50 - 11.10	Paper 1	The Group concept	John Young
11.10 - 11.20	Discussion		
11.20 - 11.40	Paper 2	Prospects for the smaller company	Geoffrey Evans
11.40 - 11.50	Discussion		
11.50 - 12.10	Paper 3	Starting a new company	David Elder
12.10 - 12.20	Discussion		
12.20 - 15.00	Lunch		
15.00 - 15.20	Paper 4	A European view	Michael Bealing
15.20 - 15.30	Discussion		
15.30 - 16.00	FORUM		
16.00	Tea and disperse		

Registrations & Enquiries:
Conferences Section
The Institution of Agricultural Engineers
West End Road
Silsoe, Bedford MK45 4DU

Telephone: Silsoe (0525) 61096

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The Principal Guest will be John Butcher MP, Parliamentary Under Secretary of State for Industry

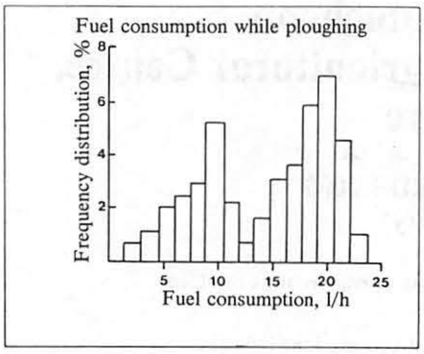
Collecting data from tractors in everyday use

J Palmer

THE Scottish Institute of Agricultural Engineering has developed equipment which automatically collects data on tractor and machine work. It is usually used on tractors etc which are working under ordinary commercial farm conditions and it interferes very little with normal operation.

It can collect data to determine such things as:

- the operational time and frequency of use for manual controls such as clutch and brake;
- the gear in use;
- engine speed, wheel speed and, approximately, the wheel slip;
- steering angle and slope of the land;
- fuel consumption, wheel torque, pto torque, wheel power and pto power.



Percentage time:	
In neutral	18
with differential lock engaged	4
with pto engaged	69
Operations per hour:	
clutch	63
right foot brake	75
left foot brake	69
differential lock	2

This sort of information can be used to build pictures of:

- the utilisation of controls while doing particular jobs eg steering brake applications while harrowing on hillsides;
- the range of loads to which machines are exposed in practical use;
- the proportion of the operator's time and attention which is absorbed in operating controls, steering adjustments, etc — this is time which is not available for supervising machine performance and job quality.

The apparatus is being adapted so that the Scottish Institute of Agricultural Engineering can investigate:

- making a first approximation to the mapping of the variation of yield in the field;
- deriving data on the loading cycles spectra which are experienced by soil working implements with various soil types and conditions, thereby helping implement design.

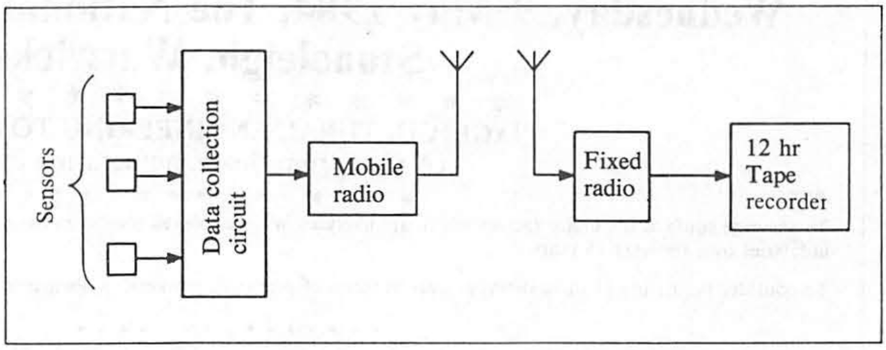


Fig 1 Data Collection apparatus

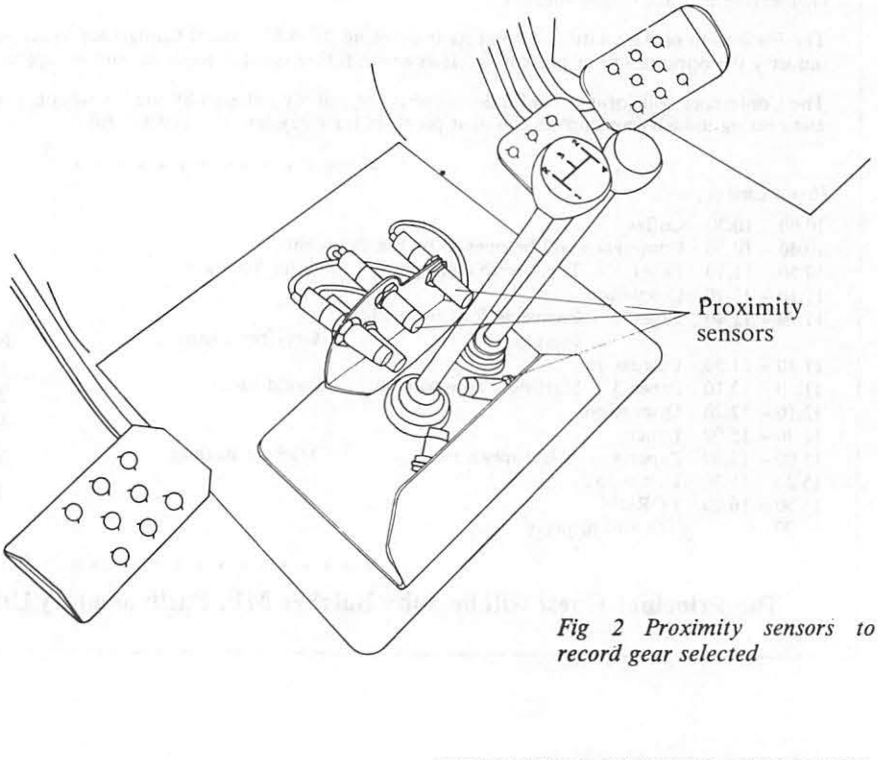


Fig 2 Proximity sensors to record gear selected

John Palmer is Head of the Controls Section at the Scottish Institute of Agricultural Engineering.

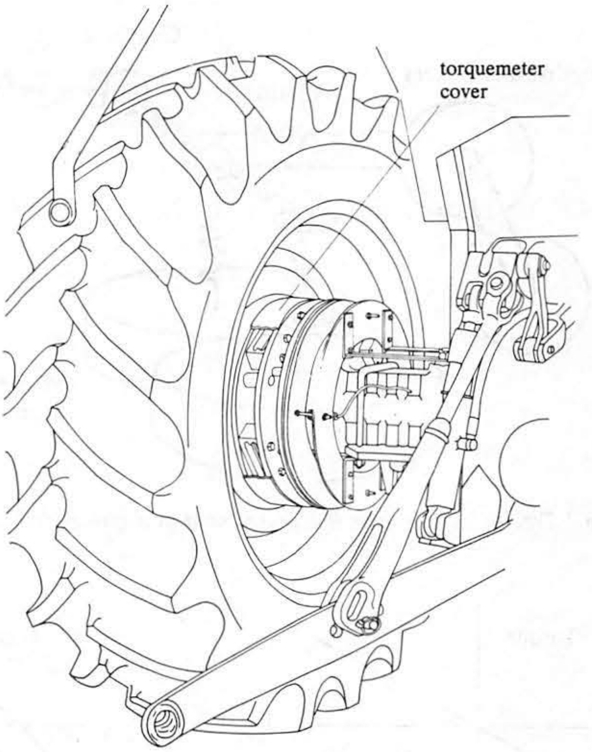
This item was prepared for the British Society for Research in Agricultural Engineering Association Members' Day on Tractors and Farm Vehicles at the National Institute of Agricultural Engineering on 12 October 1983.

The apparatus consists of many sensors which feed data into a data collection circuit where it accumulates for a short time. (Fig 1) At regular intervals the collected data are either sent by radio to a big tape recorder or are stored on a local recorder. The day's accumulated data are subsequently sent to a large computer where they are processed to derive relationships like those outlined above. The sensors range from very simple devices such as proximity switches to more complex arrangements which involve strain gauge bridges or high quality, more expensive components.

Proximity detectors are used to indicate the state of controls, eg whether a brake pedal is depressed, which gear has been selected (Fig 2). They are also a cheap way of measuring speeds of rotation, eg by showing the passage of tractor wheel nuts, or of a flap bolted to the engine front vee-belt pulley.

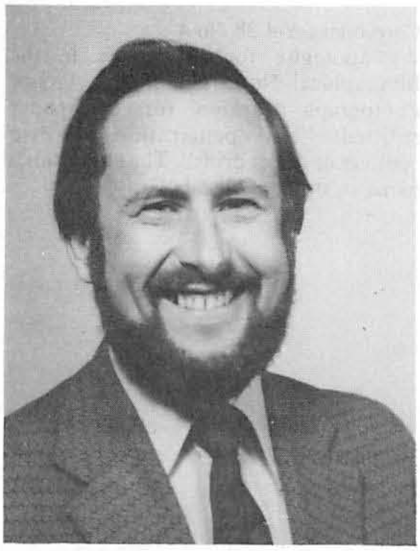
The wheel torquemeter is an example of a more complex sensor. It is fitted between the wheel dish and the axle. It consists essentially of four shear blocks laid out mechanically and electrically so that they respond to torque but not to radial loads (Fig 3).

Fig 3 Tractor rear wheel torque meter



Driveline dynamics and overload protection

J Chisholm



Dr John Chisholm is Head of the Machine Dynamics and Reliability Department at the National Institute of Agricultural Engineering.

This item was prepared for the British Society for Research in Agricultural Engineering Association Members' Day on Tractors and Farm Vehicles at the National Institute of Agricultural Engineering on 12 October 1983.

PTO drivelines must withstand not only a mean torque needed to do work on the soil or crop but also a high level of fluctuating torque due to:

- variations in resistance of soil or crop;
- individual blades etc engaging soil or crop;
- resonances in the driveline.

These fluctuations can damage driveline components in two ways:

- the continuous variation in loading causes fatigue;
- occasional very high peak levels can cause sudden failure.

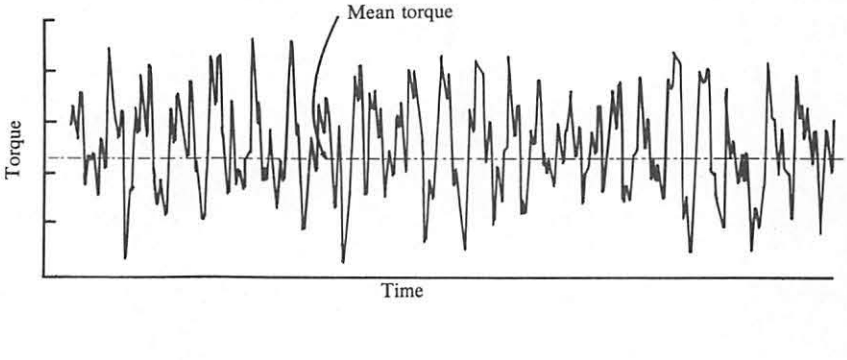
Overload clutches

Occasional overloads can be prevented by friction clutches, ratchet clutches or shear bolts. Only friction clutches continue to transmit enough torque while slipping to help clear blockages.

The National Institute of Agricultural Engineers has tested many friction clutch materials, assessing them according to three main criteria:

- — consistent breakaway torque to give uniform protection;
- — high slipping torque to clear blockages;
- — plates should not adhere together when the machine is out of use.

Adhesion of plates can lead to very high overloads when a machine is next used. As well as looking for better materials, the National Institute of Agricultural Engineers has developed *a more radical solution*, a clutch in which the plates are



automatically unloaded when the driveline comes to rest. This is done by combining overrun and overload protection in one clutch. The overrunning action unloads the friction plates and allows high driveline inertia machines to slow gradually when the tractor pto stops.

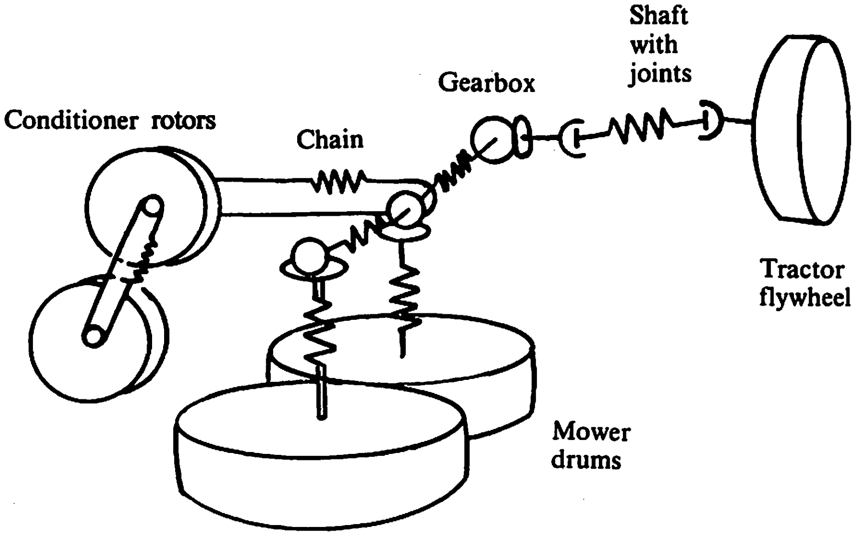


Fig 1 Tractor/mower drive line represented as a spring-inertia system

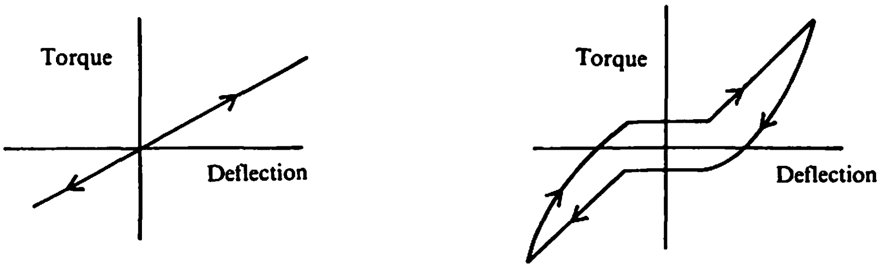


Fig 2(a) Pure spring-linear and (b) Spring with backlash and friction — non linear

Driveline dynamics

The tractor and machine driveline behaves as a spring and inertia system. The inertias are the tractor flywheel and large heavy rotating machine components, such as mower drums. The springs are the driveshafts that connect the inertias (Fig 1).

As in any spring-inertia system there are resonances, when small disturbances result in very large torque fluctuations. Disturbances can be caused by soil or crop forces, or by machine components such as universal joints.

This behaviour, and the scope for reducing torque fluctuation, are being investigated by mathematical models. Equations relating torque and rotation in the driveline are built into computer situations that allow the vibration to be predicted. The analysis is complicated because drivelines are 'non-linear' — torque is not directly proportional to angular deflection (twist) because of backlash, friction etc (Fig 2).

The frequency response of a machine driveline can also be measured in the laboratory. Simple sine-wave inputs at different frequencies are applied by a servo-hydraulic ram operating through a torque-arm.

Corrections Vol 38 No 4

We apologise for the errors in the Biographical Notes and in the Author Photograph Caption for the paper entitled: "Soil penetration by disc coulters of direct drills". The co-author's name is, in fact, **Alistair Gray.**

Fluid power technology today

If it's sown, cut, picked, ploughed, or spread then Danfoss fluid power components are probably involved. Danfoss hydraulic motors and full power steering equipment are used extensively on many forms of agricultural equipment.

The following list shows that wide range of equipment: tractors, harvesters, planters, fertilizer spreaders and sprayers, trenchers, mowers, conveyors, silage handling equipment and fork lifts.
The complexity of modern agricultural equipment demands originality of design and hydraulics in general and Danfoss motors and steering units in particular allow those designs to become reality.

Agriculture

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Small sized large power output hydraulic motors drive conveyors, fans and wheels in positions inaccessible to mechanical transmission shafts.

Due to the inflexibility of a pto drive in many cases it is often more practical to use the tractor hydraulic power take off to drive auxiliary equipment such as post hole drills or saw benches driven by Danfoss motors.

Driving positions on specialist harvesters and spreaders often preclude traditional steering boxes, vehicle weight and terrain conditions likewise demand power steering. The flexibility given by Danfoss hydraulic steering units, using flexible hoses to connect the steering unit with the steering cylinder is often the most practical solution. A new generation of units using load sensing signals uses only that flow and therefore power that is required. This allows more power for other vehicle functions, thereby saving energy or permitting greater output. Computer aided steering selection is available on request.

Please contact our sales office who will be pleased to supply full technical information, catalogues or arrange for one of our technical sales engineers to visit you.
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