THE AGRICULTURAL ENGINEER

Volume 40, Number 2

SUMMER 1985

The Institution of Agricultural Engineers

Journal and Proceedings

The views and opinions expressed in papers and individual contributions are not those necessarily of the Institution.

The Hon Editor reserves the right to edit any material sent in to the Journal.

In the interests of factual reporting, reference to trade names and proprietary products may be inevitable. No endorsement of the named products or manufacturers is intended and no adverse criticism is implied of similar products which are not mentioned.

Front cover:
South Dakota State University battery powered tractor (SDSU photograph)

THE AGRICULTURAL ENGINEER is published quarterly by the Institution of Agricultural Engineers
West End Road, Silsoe, Bedford MK45 4DU
Tel: 0525 61096

Price £4.50 per copy, annual subscription £18.00 (post free in UK)

THE AGRICULTURAL ENGINEER

Volume 40, Number 2 **SUMMER 1985**

Contents

SCIENTIFIC PAPER	**Automatic collection of data on practical use of field machines,** by J Palmer	**42**
CONFERENCE PROCEEDINGS	*Two papers presented at the East Midlands Branch Conference on Power for Mechanical Farming in the 21st Century, 27 September 1984*	
	Power requirements for field machines, by M J Dwyer	**50**
	Internal combustion engines for future field machines, by A R Chowings	**60**
TECHNICAL ARTICLES	**A battery powered tractor,** by R Alcock and and L L Christianson	**69**
	Ergonomic workplace assessment with the aid of a computer program, by D H A Zegers	**74**
AGENG ITEM	**The Engineering Section of the European Association for Potato Research,** by D C McRae	**80**
INFORMATION	**Book reviews**	**78**

ISSN 0308-5732

Automatic collection of data on practical use of field machines

J Palmer

Summary

PRINCIPLES of some equipment for continuous collection of detailed data from field machines are described. Data on machine use can be collected throughout the working day from operations on commercial farms. Types of sensors are catalogued and operating experience is related. Design and operational procedure recommendations are made.

1 Introduction

The Scottish Institute of Agricultural Engineering (SIAE) has developed equipment for collection of detailed data on the use of field machines (Palmer 1971). It has been applied to three main ends:—

(i) building a sound data foundation for operational research on the grain harvest by monitoring the performance of component parts of combine harvesters;

(ii) contract assistance to manufacturers by collecting data on everyday tractor usage on farms;

(iii) constructing maps of the distribution of grain yield in the field.

The feasibility of the last of these is still under investigation.

The equipment has been designed to collect data throughout the working day under arduous working conditions with as little interference as possible to normal farm operations. The data are collected in digital form and are entered ultimately to a computer where they can be automatically edited and analysed.

There are two surveying strategies.

(i) Several farmers' machines are equipped for data collection, and performance on each farm is monitored throughout the season. All combine data have been collected in this way.

(ii) A few machines are equipped and are loaned to farmers for a few days each, to be used in place of their own machines. Most tractor data have been collected this way.

2 Apparatus

2.1 General

Data may be telemetered by radio from the field machine to a fixed station, or recorded on the machine. Telemetry is commoner, so that case is described first.

There are several parts to the data handling equipment (fig 1) (Duncanson 1972a & 1972b, Tilson 1973, Palmer 1972). On each machine there are sensors and data converters, a data assembler, a collection executive and a mobile VHF radio. At the base at SIAE is a fixed VHF radio, a data collection commander and a tape recorder capable of handling 12 hours of material.

Operation is controlled by the data collection commander at the base. At 2.5s intervals, it causes the base transmitter to radiate the call-sign of one of the machines; if there are up to 4 machines involved, the sequence repeats every 10s and if 5-8 machines, every 20s. All mobile radios hear each call-sign but only the collection executive on the called machine responds; it stops the further collection of data, turns on the mobile transmitter and feeds it with digital signals from the data assembler which represent stored sensor outputs. By this time, the base data collection commander has switched the base transmitter off and the base receiver on, so the incoming data can be stored by the 12 hour tape recorder. At the end of the data transmission, the collection executive switches the mobile transmitter off and re-connects the data assembler to the sensors so that data may be accumulated until the next interrogation. In between sending each complete set of machine call-signs, the date and time of day are recorded at the base from an electronic clock.

The data stored by the tape recorder are arranged in a non-standard format which suits radio transmission but not computing. They can be converted to computer compatible form by a translator. This device is used in two ways. While data collection is going on, it can monitor the performance of any one of the machines, displaying by means of a teletypewriter the indicated responses of each sensor and thus permitting early detection and correction of faults in the apparatus. Once the day's data collection is over, the tape recorder can be run at eight times recording speed and, in 1.5 hours, the translator can send the data recorded over 12 hours to the Edinburgh Regional Computing Centre's ICL 2988 mainframe computer, to await analysis.

Much of the mobile equipment is in waterproof boxes. In most cases, these may be put on top of the machine (fig 2) but tall machines have them strapped on one side so that there is less risk from the lintels and roof beams of low buildings (fig 3).

Machine mounted tape recording equipment has been developed too. This replaces the radio equipment on sites which are beyond radio range and on hilly sites where radio communication is difficult. The recorders again store about 12 hours data.

John Palmer is Head of the Machine Loads Section at the Scottish Institute of Agricultural Engineering, Penicuik, Midlothian EH26 0PH.

Refereed paper: manuscript received 4 December 1984 and accepted in revised form 29 March 1985.

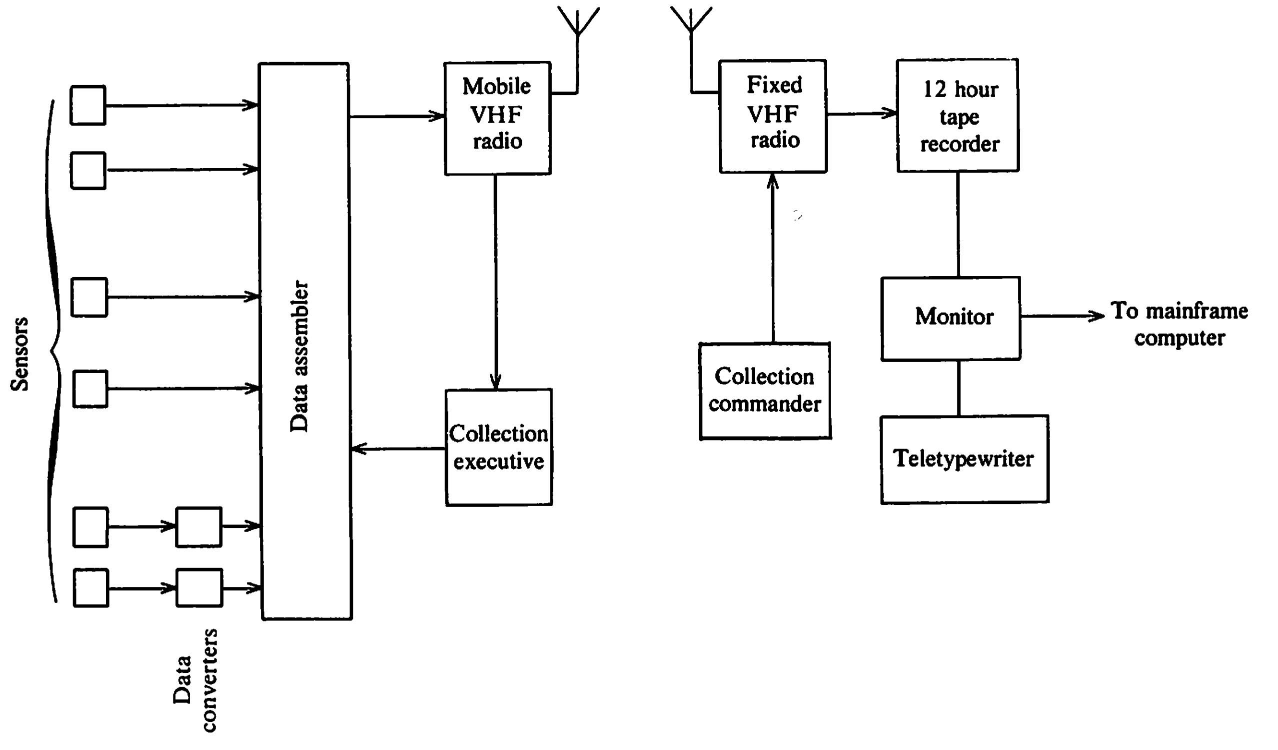
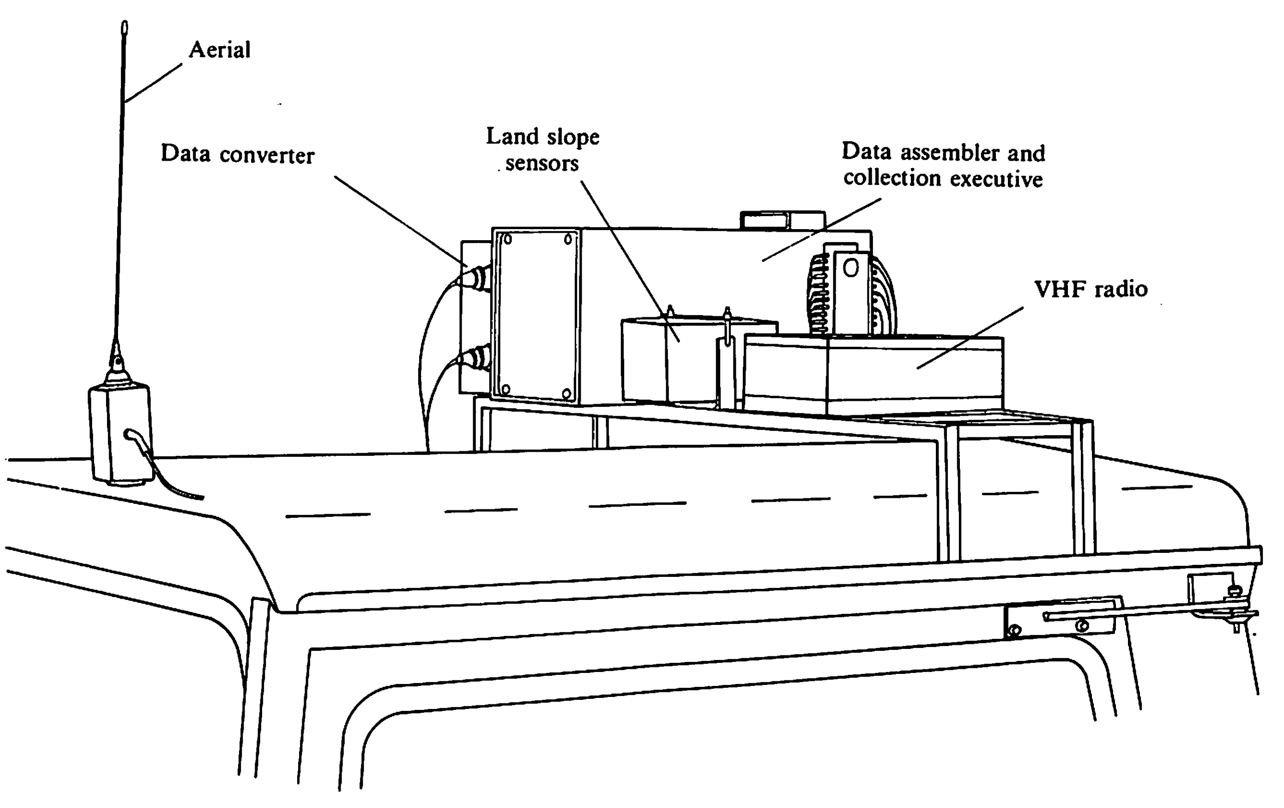


Fig 1 Block diagram of data collection equipment

2.2 Registers
Sensor indications are either naturally digital or are converted to digits. The data assembler marshals these digits in a shift register which is emptied serially into the transmitter when the machine is interrogated by the base station. Thus the size of the shift register sets a limit on the total amount of data which can be handled.

Shift registers are either 120 bits or 240 bits in size, depending on the amount of detail wanted. The shift register is divided into 24 or 48 registers, each of 5 bits.

Fig 2 Data collection equipment



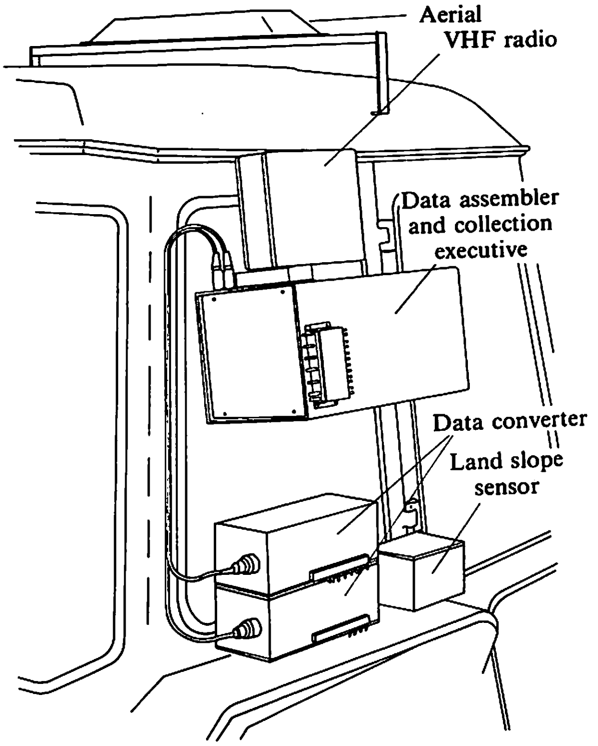


Fig 3 Data collection equipment on a high tractor

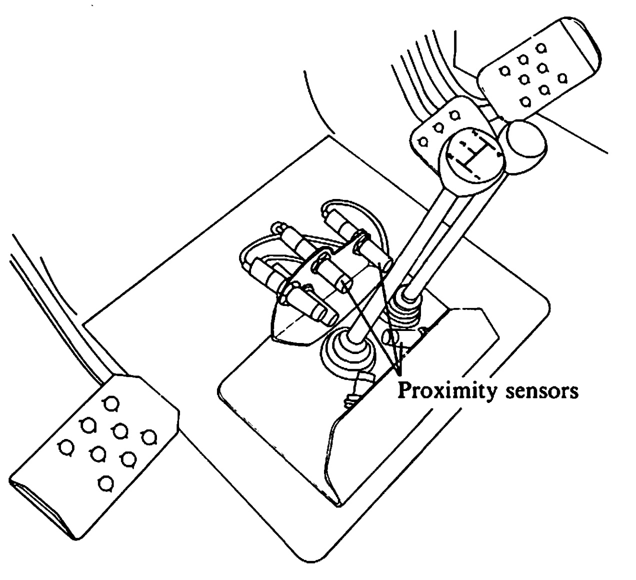


Fig 4 Monitoring gear selection

The sensor registers are sometimes shortened where appropriate to form 1-bit counters covering the range 0–1 (see Section 2.3) or divided to form both a 1-bit counter and a 4-bit counter covering the ranges 0–1 and 0–15 (see Section 2.4).

In addition registers can also be paired to form 9-bit counters (not 10-bit because of some design characteristics) which cover the range 0–511. Naturally, pairing reduces the number of sensor registers and hence sensors. A typical machine might have its 48 registers reduced to 34, of which 14 would be 9-bit and 5 would be 1+4 bit. As protection against noise (Duncanson 1972b), all counter inputs are filtered to prevent triggering by pulses which persist less than 1.5ms.

2.3 Two-state devices

1-bit counters show whether or not a particular control is in use at the instant of interrogation. For example, monitoring of gear selection is done by an array of sensors so placed that the appropriate one is operated when some gear is engaged (fig 4). Other examples are the position sensing of clutch, brakes, differential lock and spool valves on tractors or cutting, threshing and unloading controls on combines.

2.4 Repeated operation of two-state devices

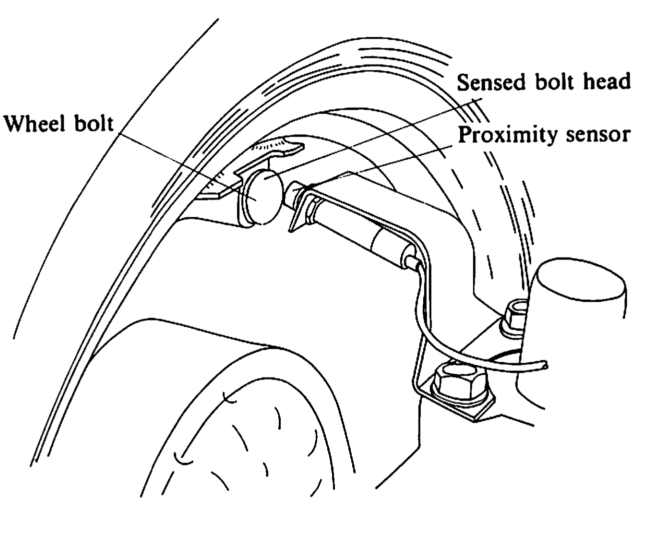
In many cases, the analyst wishes to know not only if a two-state device like a brake is in use at the instant of interrogation but also how often it has been used since the last interrogation. The 1+4 bit counters are used for these cases, the 1-bit element indicating if the control was in use at interrogation time while the 4-bit part shows the number of uses made of it since the previous interrogation time.

2.5 Digital measurements

Some parameters are most easily measured by counting some sort of event, like wheelnuts passing a proximity sensor (fig 5). These are classed as digital measurements. They are allocated counts of 5-bit or 9-bit length according to the precision which is needed. For example, rear wheel speeds on a tractor are required both to show the full range of transport speeds and to discriminate between a number of low working speeds, so they are recorded in 9-bit counters. In contrast, undriven front wheels are used only for estimating wheel slip at low speed so these are recorded in 5-bit counters which overflow and must be ignored at transport speed.

Detection of the location of the edge of the standing crop relative to the out-of-crop end of a combine table is an unusual digital case (fig 6). It is done by an ultrasonic sender and receiver and an electronic clock, the timing pulses from which are counted in a fast counter between sending of an ultrasonic pulse and receipt of its echo. The accumulated count is then passed to a slow counter from which the standard sensor register in the system shift register can be loaded slowly enough to pass through the noise filtration in the input line.

Fig 5 Wheel rotation sensor



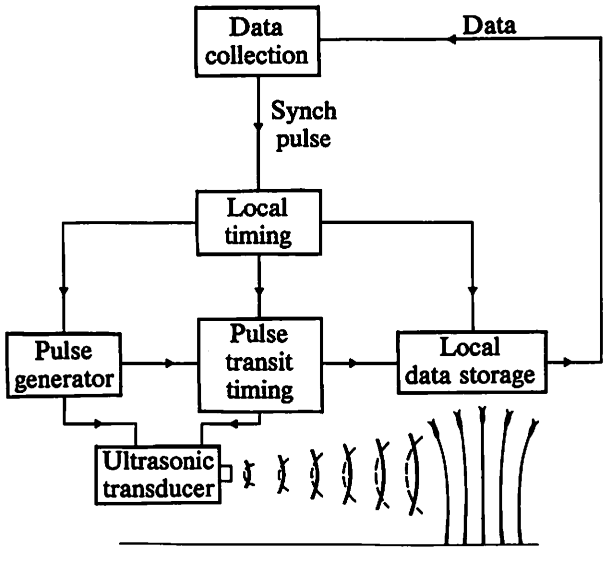


Fig 6 Ultrasonic crop edge sensor

2.6 Analogue measurements
Analogue signals must be converted to digital signals before they can be transmitted or recorded. The data converters are in separate boxes from the data assembler box (figures 2 and 3) so that the arrangement of a mixture of analogue and digital measurements can be changed easily. The digitally converted signals are then accumulated either in 5-bit or 9-bit counters, corresponding to counts of 0–31 and 0–511, respectively. Often the analogue sensor outputs are too small to generate such large counts, so the available precision of transmission cannot be utilised fully.

In some circumstances, the peak value of an analogue signal may be more informative than its value averaged over the 10 or 20s interval between interrogations. Accordingly, there are electronic arrangements to note the peak value during each interval between interrogations and to report it at the end of the next interrogation period. This technique can be applied to any of the analogue measurements and need not interfere with the reporting of their average values. However, this must be used with great caution because peak detection is very vulnerable to electrical or mechanical noise.

Wheel torque is measured in the SIAE wheel torquemeter by a style of shear block which distorts about flexure hinges and thus bends a central tongue which bears strain gauges (fig 7). It is very insensitive to all stresses other than those set up by shear in the required direction. A torquemeter consists of four shear blocks mounted tangentially on mutually perpendicular radii and sheared between two plates, one of which is attached to the hub and the other to the machine wheel (fig 8). An inboard inductive coupling transfers power from the machine electrics to the internal circuits of the wheel torquemeter. Another such inductive coupling transmits torque readings from inside the torquemeter; this has been accomplished without interference from the power inductive coupling which is coaxial with it. Wheel torquemeters have been found to be very robust and have survived months of heavy farm use without maintenance.

Pto torque is measured by a proprietary analogue torquemeter. Steering angle is sensed by a potentiometer and longitudinal and transverse land slopes by an

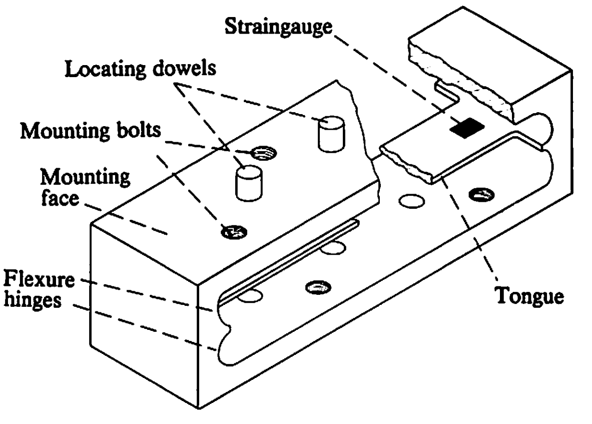


Fig 7 Wheel torquemeter shear block

assembly which contains two pendulum-operated potentiometers. This latter is mounted wherever is convenient, usually close to the data assembler box (fig 2).

Magnetic heading is sensed by proprietary flux gate magnetometers. These are analogue devices but conversion of their output to digits is more elaborate to allow for the numerically discontinuous transition from a mean reading of say 359 degrees to 1 degree can be handled. Apparatus developed for the SIAE by Wolfson Microelectronics Institute, Edinburgh, uses a microprocessor to resolve the heading during one interval between interrogations, convert it to digits during the next and report during the third.

3 Factors observed

Typical combinations of sensors for a combine with a 240 bit register are shown in table 1. Readings from many of these need only to be classified and converted to frequency distributions before use in operational

Fig 8 Wheel torquemeter

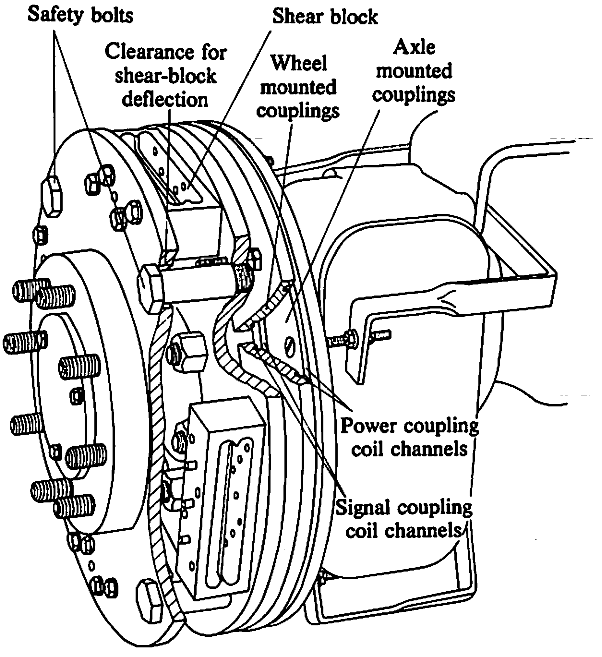


Table 1 Table of sensors

Parameter	*Sensor type*	*Class*
Controls		
Clutch	Proximity	
Gear 1	Proximity	
Gear 2	Proximity	
Reverse	Proximity	
Unload	Proximity	
Threshing mechanism	Proximity	
Cutting mechanism	Proximity	1 bit or
Table up	Proximity	1+4 bit
Table down	Proximity	
Speed up	Proximity	
Speed down	Proximity	
Reel up	Proximity	
Reel down	Proximity	
Steering wheel reversals	Microswitch	
Steering wheel deviations	Microswitch	
Machine factors		
Engine revolutions	Proximity	
Wheel speed	Proximity	
Straw walker grain loss monitor	Microphone	
Sieve grain loss monitor	Microphone	
Exhaust air grain loss monitor	Microphone	
Proportion of cutter bar in use	Ultrasonics	
Rate of grain flow by volume	Proximity	5 bit or
Rate of grain flow by weight	Strain gauges	9 bit
Heading	Magnetometer	
Longitudinal ground slope	Potentiometer	
Transverse ground slope	Potentiometer	
Steering angle	Potentiometer	
Table height	Potentiometer	

research applications. For example, figure 9 shows peak power while carting and spreading muck, and the relationship between the peak torque and fuel consumption.

However, some analyses depend on the interrelationship between several factors. For example, the timetable of combine stoppages in Table 2 depends on information on wheel speed, header height, and engagement of cutting, threshing and unloading mechanisms. Another case is observation of longitudinal land slope where it is essential to reject readings in which gravitational acceleration is mixed with machine acceleration, as evidenced by change in wheel speeds. Yet another is determining the speeds at which mounted implements are transported when out of work; this will be used with data compiled elsewhere on the shock loadings at various speeds to predict the shock loading histories to which the implements will be exposed.

Manipulation of such data is much easier if the computer on which the analyses are done is equipped with a language such as ADA or PASCAL which has structured data sets (Palmer 1981). For example, using the terminology of PASCAL, a "record" may have its "fields" named after the factors which they contain, eg "engine speed", "side slope". These can then be manipulated by boolean or other algebraic means. This leads to the writing of equations which though verbose are unambiguous and easy to comprehend and manipulate. For example data from interrogations of a particular tractor might be stored in an array of records called "Tractor 3". Each record would contain a full set of the sensor responses for the time when the corresponding interrogation took place. An analytical program could draw attention to conditions when the

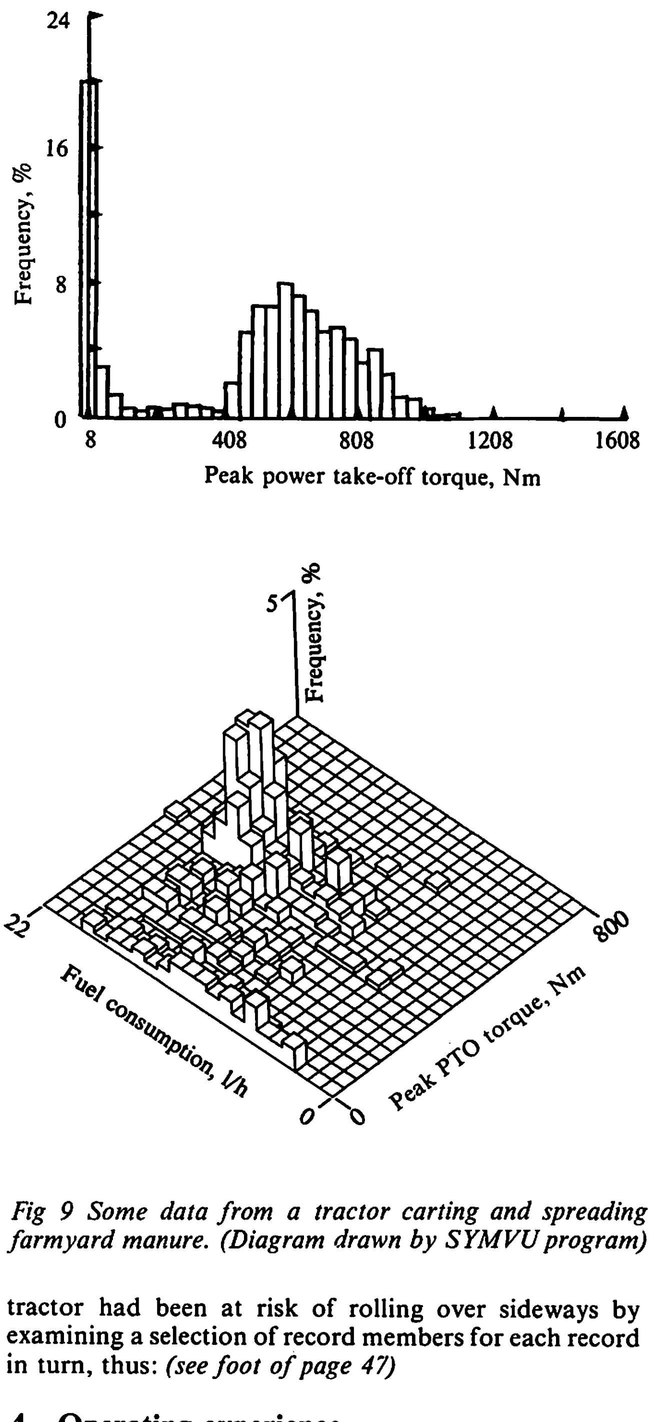


Fig 9 Some data from a tractor carting and spreading farmyard manure. (Diagram drawn by SYMVU program)

tractor had been at risk of rolling over sideways by examining a selection of record members for each record in turn, thus: *(see foot of page 47)*

4 Operating experience

The apparatus has been used for eight years, the first four in development (McGechan 1977 & 1979) and the remainder in intensive data gathering. The major part of this effort went into contract work for tractor manufacturers which investigated the distribution of tractor farm duties — eg wheel slip while in various gears and on various tasks, torque immediately before clutch disengagement or immediately after engagement.

The other principal activity was investigation of the use made of combine harvesters, broadly in three ways. Work patterns of the machines were examined, timetables of activities were derived and delays were analysed (Webb and McGechan 1982, McGechan 1982, 1984b & 1984c). The work of the operators too was assessed, using automatically collected data on frequency of operation of controls; these were manipulated to indicate the intensity of demand for attention which was

Table 2 A combining timetable

Day	*Hour*	*Minute*	*Second*		*Work elements*
42	13	25	33	Work started	
					Work started after 0.2 minutes
42	13	29	23	Table up	
					Work stopped after 3.8 minutes
42	13	29	59	Fast transport table up	
42	13	30	48	Work started	
					Work started after 1.4 minutes
42	13	41	52	Table up turning	
					Work stopped after 11.1 minutes
42	13	42	16	Work started	
					Work started after 0.4 minutes
42	13	43	29	Unloading	
					Unloading started after 1.2 minutes
42	13	45	42		
					Unloading lasted 2.2 minutes
42	13	50	45	Table up	
					Work stopped after 8.5 minutes
42	13	51	21	Work started	
					Work started after 0.6 minutes
42	13	54	34	Table up	
					Work stopped after 3.2 minutes
42	13	54	46	Work started	
					Work started after 0.2 minutes
42	13	54	58	Table up	
					Work stopped after 0.2 minutes
42	13	55	11	Work started	
					Work started after 0.2 minutes
42	13	56	11	Table up	
					Work stopped after 1.0 minutes
42	13	56	23	Work started	
					Work started after 0.2 minutes
42	14	1	13	Table up	
					Work stopped after 4.8 minutes
42	14	1	25	Table up turning	
42	14	1	49	Table up	
42	14	2	26	Work started	
					Work started after 1.2 minutes

```
FOR n : = 1 to [number of records] DO

IF          (tractor3 [n]. engine revs  > 50)                          If engine is running..
    AND     (tractor3 [n]. rear-right-wheel-speed  > 2)                ...and rear wheels ...
    AND     (tractor3[n]. rear-left-wheel-speed  > 2)                  ...are both turning...
    AND     (abs (tractor3[n]. rear-right-wheel-speed                  ..but at different speeds..
            — (tractor3[n]. rear-left-wheel-speed  > 4)                ..suggesting a steered turn..
    AND     ((tractor3[n]. accelerometer  > 111)                       ...and transverse acceleration...
      OR    (tractor3[n]. accelerometer  < 93))                        ...is far from quiescent value...
THEN
    write ln  (tractor3[n]. hour  :  2,                                ...then report the details
            tractor3[n]. minute  :  4,
            tractor3[n]. second  :  4,
            tractor3[n]. rear-right-wheel-speed  :  4,,
            tractor3[n]. rear-left-wheel-speed  :  4,
            tractor3[n]. accelerometer  :  4);
```

being made of the driver (McGechan 1983 & 1984c). Finally, the data collected over several seasons were combined with results from formal field experiments (Moore and Glasbey 1983, Palmer 1984) in an operational research study which assessed the benefits to be expected from automatic control of combine harvester forward speed. This last study demonstrated, before any machine development needed to be invested in this new potential apparatus, that at least under Scottish conditions such control could not pay (McGechan and Glasbey, 1982, Glasbey and McGechan 1983). This led to a further study of computer model based speed strategies (McGechan 1985) for which ways of forecasting combining work days were developed and tested against several seasons' automatic observation (McGechan 1984a).

Currently, the equipment is being used to collect data on combine location in the field, in terms of distance travelled and compass heading, together with information on the width of standing crop being cut and the rate of flow of grain into the tank; the object of this is to investigate the feasibility of mapping local grain yield within the field, leading to study by others of the causes in yield variation.

Electronic assemblies other than sensors have been fairly reliable. All circuit boards are plug-replaceable so defective units are not checked in situ, which would interfere with field work, but are swapped with spares and repaired at base.

Sensors generally have proved to be reliable, particularly the two-state or 1-bit ones. However, when there are such large numbers of sensors deployed the probability of failure by one is proportionately increased, so monitoring of data is most important.

The ability to monitor immediately is the main advantage of radio telemetry. Defective sensors and electronics can be noted and replacements fitted to the field machine at the first opportunity. Experience shows that, when on board tape recorders are used instead of radio, at least another 24 hours go by before the defect is dealt with. However, the tape recorders have been found more reliable than radios, the data records are less subject to noise and interference, and tape recording is most valuable on reverse hill slopes and inside buildings, where radio signals are weakened.

It is desirable not only to check the operation of sensors and electronics under conditions as similar as possible to working conditions but also to check their calibration too. A case in point is the combine heading data, which it is now suspected were spoiled by a magnetic deviation only generated when the header drive was engaged; pre-season checks had been made with all mechanisms in operation, except this one.

Finally, experience of analysis has shown how desirable it is to augment automatically-collected data by human observations in well-kept daily diaries. These are often difficult to incorporate in an analysis because they are non-numerate or not continuous yet they can do much to illuminate apparently strange results. For example, unusually high peak torque values, which it is suspected might be caused by noise, can be given more weight if an observer has noted that the tractor occasionally emitted black exhaust smoke. Similarly, an apparently illogical combination of large grain flow into the tank and small width of cut would be explained by a note that the combine came to a laid patch of crop at that time.

5 Conclusions

Equipment for automatic data collection from field machines should be:

*rugged and reliable,
*designed for quick exchange if found defective in the field,
*calibrated in as near as practicable to working conditions,
*augmented by observers' notes.

Preferably, analytical work should be done on computers which have languages with structured data sets mounted.

References

Duncanson I P (1972). Address and instruction decoder. Dep Note SSN 118, Scott Inst agric Engng, Penicuik (unpubl).

Duncanson I P (1972). Field data assembler. Dep Note SSN 119, Scott Inst agric Engng, Penicuik (unpubl).

Glasbey C A, McGechan M B (1983). Threshing loss stochastic variability on combine harvesters. *J agric Engng Res,* **28**, 163–174.

McGechan M B (1977). Operational research studies of the use of field machines: a discussion of terminology, review of literature and proposals for exploitation of automatic survey equipment. Dep Note SIN 230, Scott Inst agric Engng, Penicuik (unpubl).

McGechan M B (1979). Automatic survey data handling developments 1977–78. Dep Note SIN 250, Scott Inst agric Engng, Penicuik (unpubl).

McGechan M B (1982). Work timetables and analysis of delays during combine harvesting. Dep Note SIN 358, Scott Inst agric Engng, Penicuik (unpubl).

McGechan M B, Glasbey C A (1982). The benefits of different speed control systems for combine harvesters. *J agric Engng Res,* **27**, 537–552.

McGechan M B (1983). Work study investigation of driver's use of controls. Dep Note SIN 378, Scott Inst agric Engng, Penicuik (unpubl).

McGechan M B (1984a). Information used for testing combining work-days criteria. Dep Note SIN 396, Scott Inst agric Engng, Penicuik (unpubl).

McGechan M B (1984b). Analysis of data obtained in telemetry survey on combine grain loss and drivers' tactics, on sloping ground. Dep Note SIN 389, Scott Inst agric Engng, Penicuik (unpubl).

McGechan M B (1984c). Work study on combine harvesters using automatic telemetry equipment. *Agric Engr,* **39**, 131–138.

McGechan M B (1985). Combine speed strategies in cereal harvesting, Part 1: adjustment for long term crop variability. *J agric Engng Res* (in press).

Moore A B, Glasbey C A (1982). An investigation into the parameters affecting the design of an automatic throughput control system for a combine harvester. Dep Note SIN 331, Scott Inst agric Engng, Penicuik (unpubl).

Palmer J (1971). Project planning for application to control engineering in agriculture. Dep Note SSN 71, Scott Inst agric Engng, Penicuik (unpubl).

Palmer J (1972). A compact modem utilising integrated circuit elements. Dep Note SSN 104, Scott Inst agric Engng, Penicuik (unpubl).

Palmer J (1981). Procedures for analysing automatic survey data. Dep Note SIN 325, Scott Inst agric Engng, Penicuik (unpubl).

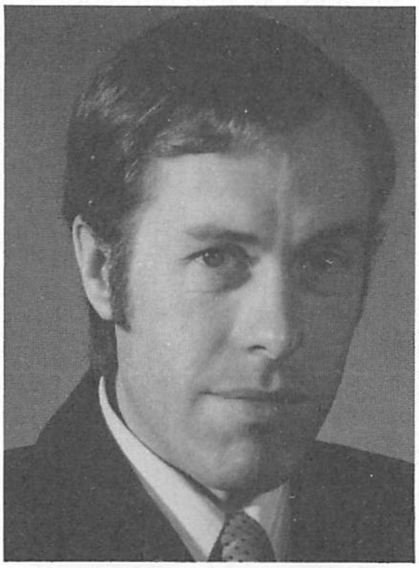
Palmer J (1984). Profitable automatic control systems. Paper No 84–1635, Am Soc agric Engr, Winter Meeting, New Orleans.

Tillson J R (1973). Automatic survey commander. Dep Note SSN 150, Scott Inst agric Engng, Penicuik (unpubl).

Webb D J McGechan M B (1982). Some work rate data from an automatic survey of the 1977–80 cereal harvests. Dep Note SIN 331, Scott Inst agric Engng, Penicuik (unpubl).

Power requirements for field machines

M J Dwyer



Summary

MEAN power levels required for different field operations relative to rates of work are reviewed. Cultivations followed by harvesting are shown to have the highest energy requirements. Fluctuations in load are discussed in more detail with regard to draught implements and pto-driven machines. Data on field measurements of pto torque variations are given for a range of forage equipment. Power requirements for transport operations are dealt with in more detail, since they are felt to be the least likely to be drastically reduced in the future. They are, however, low in comparison with current requirements for cultivation and harvesting. It is suggested that, although current field machines would benefit from tractor engines having better torque back-up characteristics and fuel control, in the future it is likely that improved controls on tractors and machines will greatly reduce these load fluctuations. The main requirement for a tractor engine will then be to run continuously at or near maximum power, under almost steady load.

1 Introduction

In general, the energy required to grow arable crops has not changed significantly over the years. As long as the land must be cultivated, the crop sown, harvested and transported, the energy requirement is likely to be approximately the same. The main changes which have taken place are that manual power has been replaced, firstly by animal power and then by engine power, but without very much change in the total energy used.

Factors which have caused an increase in energy requirements in the past have been the need to produce more food for a growing population and a rise in standard of living producing a demand for a more varied diet. This demand for a wider range of foods has often led to increased energy inputs, such as for irrigation and heating greenhouses.

Another consequence of the expectation of a higher living standard has been the demand for greater comfort and safety for those employed in agriculture. This has also led to an increase in energy requirement, for example, to provide heating, air conditioning and dust and fume-free environments for workers.

The most significant factor concerning the application of energy to agricultural production which has been apparent in recent years has been the increase in available power. This has been used to apply approximately the same amount of energy as in the past, but in a shorter period of time. The incentive for this is to carry out operations at the optimum time of year and to provide shorter working hours.

Looking to the future, the demand for more power is likely to continue, at least in the short term, for the same reasons as in the past. At the same time, however, the growing concern for energy conservation is leading to greater efforts to reduce, for the first time, the basic energy requirements for arable crop production. In theory the energy to place seed in the ground and harvest crops are minute compared with that actually expended. There is, therefore, considerable scope to reduce energy inputs to these operations in the future, leaving transport as possibly the largest ultimate energy requirement.

When considering the constraints which machinery requirements impose on the design of power sources, it is necessary to take account not only of the maximum power which must be made available, but also of the dynamic response to varying loads. The forces on field machines are never constant and it is important to know the magnitude and frequency of variations, if engines are to be designed to operate most efficiently under these conditions.

2 Mean energy requirements for different field operations

The energy used for different field operations has often been quoted in the past, usually in the form of power requirements or fuel consumptions. Quoting power requirement presupposes a given size of implement. Fuel consumption is a better indication of energy requirement, since, for a given operation in a given field condition, the fuel consumption will be approximately the same, for the same area covered, whether a large tractor and implement is used to do the job more quickly, or a small implement is used, taking longer, but using less fuel per hour. Whatever units are used, however, the values will inevitably vary dependent on the field conditions.

Typical average values of energy requirements are shown in table I. The units used are kWh/ha which are considered to be the most useful, since they enable the power

---

Dr Mike Dwyer is in the Agricultural Vehicles Division, National Institute of Agricultural Engineering.

This paper was presented at the East Midlands Branch Conference entitled: Power for Mechanised Farming in the 21st Century, held at the University of Nottingham on 27 September 1984.

requirement to be readily calculated by multiplying by the required rate of work in ha/h. This data is derived from fuel consumption figures given in papers published 10 to 15 years' ago (ADAS 1972 and Stansfield 1974), but comparisons with more recent unpublished data at the National Institute of Agricultural Engineering show that it is still valid. To allow for variations in conditions, the figures given may be halved for lighter conditions or doubled for heavier conditions.

The data in table I are for steady-state conditions. In practice, however, energy requirements are continuously changing in the field due to changes in soil or crop density or the need to climb slopes. Such variations lead typically to a doubling of the mean energy requirement level for short periods of time. The response required from an engine under these fluctuating load conditions depends on the nature of the operation, the design of the machine and the effectiveness of any automatic load control system which may be employed.

Table I Mean energy requirements for different field operations

Operation	*Energy requirement, kWh/ha*
Ploughing	70
Subsoiling/Moling	60
Forage harvesting	40
Rotary cultivating	40
Cultivating	30
Disc harrowing	30
Mowing	25
Drilling	20
Hoeing	20
Spring tine harrowing	20
Dutch harrowing	15
Rolling	15
Baling	10
Tedding	10
Spraying	5
Fertiliser distributing	5

Field operations may be very generally divided into three broad categories, draught, power take-off and transport. The requirements for each category are dealt with below, in separate sections.

3 Special requirements for draught operations

The effect of variations in the draught force on implements has been studied extensively, particularly with regard to the design of draught control systems (Crolla 1975). Variations in draught force are caused either by changes in soil density or by variations in implement depth, which, with fully mounted implements, occur frequently as the tractor pitches over uneven field surfaces. In this situation, it is necessary to compromise between constant depth of operation and constant load on the tractor engine. With improved implement control systems in the future it may be feasible to reduce draught force variations to less than ±10% but, where soil density varies, this must inevitably be at the cost of increased variation in cultivation depth. This may be of little importance since, for cereals at least, depth of cultivation is not critical, so long as subsoil is not brought up, or the implement does not come completely out of the ground. The advantage of such an improved draught control system would be that the tractor engine could be operated closer to its maximum power point without risk of stalling, thereby obtaining maximum work rate from a tractor of a certain power output. The effect on future design would be that engines would have to be capable of operating close to maximum power for longer periods, but with less fluctuation in load.

Many operators, however, will not tolerate such wide variations in cultivation depth. They use current draught control systems as a means of compensating for the depth variations which would otherwise occur as a result of tractor pitching on uneven ground and make manual adjustments to correct for changes in soil density. It is possible that, here too, future developments in implement depth control systems may give the operator something closer to what he desires. This will mean that, with existing designs, he will have to tolerate a lower work rate from a tractor of a certain power output, since it must work well below maximum power in order to have sufficient in reserve to get through areas of greater soil resistance, at constant depth. The effect which this would have on future tractor engine design would be to allow them to work at a lower mean power level but with wider fluctuations in load than at present.

It is common practice, particularly with two-wheel drive tractors, to use insufficient ballast to transmit the full engine power at normal working speeds. In fact, frequently the tyres fitted as standard to two-wheel drive tractors would be inadequate to carry the required weight. The operator often attempts to compensate for this by using as wide an implement as he can pull, with the wheel-slip consequently rising to 15–20%. In general, a higher rate of work would be achieved if ballast could be added to reduce wheel-slip to 10–15%, or the tractor were operated at a higher forward speed with a narrower implement (Gee-Clough 1980).

As far as the tractor engine is concerned, the tendency to work in a slip-limited rather than power-limited condition has two effects. Firstly, the average power utilisation is probably only about 70–80% of that available. Secondly, any large increases in draught force are likely to cause the tractor to stall due to wheel-spin before the potential increase in load is felt by the engine. However beneficial this method of operation may be with regard to providing an easy life for the tractor engine, it is unlikely to persist indefinitely. It is hardly an efficient way of operating to use substantially less than the full power available, when considerable economic benefits are to be gained by getting work completed in good time. Users are being made more aware of this (Dwyer 1978) and there is a tendency at least for four-wheel drive tractors, which are generally heavier for their power and more adequately tyred, to be operated closer to maximum power.

The first consequence of a general move towards greater power utilisation would obviously be a tendency for engines to be operated closer to maximum power for extensive periods of time. The second, especially if more accurate implement depth control sytems were also introduced, would be to transmit the full magnitude of any draught variations to the engine. Therefore, engine torque back-up would need to cope with probably up to 50% increases in load compared with the approximately 20% increases encountered at present.

The more arduous requirements for the engine caused by the tendency to operate closer to maximum power and with improved depth control could be alleviated by other developments. In many ways the most efficient system of operation would be to keep the implement accurately controlled at constant depth, with the engine running at constant speed and maximum power, while varying the transmission ratio according to the draught variations, to keep the torque on the engine constant. Such a system would require an automatic or continuously variable transmission which would obviously result in some power losses, but these might be more than compensated for by the other advantages. If such developments were realised, the requirement for the engine would obviously be to run continuously at maximum power with a minimum of torque fluctuations.

4 Special requirements for pto-driven implements

When the load varies on a pto-driven implement, the effect on the engine is generally more severe than with draught implements, since there is normally no system to control the load, equivalent to the draught control system. Neither, of course, is there the possibility of the load being removed by wheel-spin. There may be a slip clutch or shear bolt fitted to protect the drive-line from damage but, obviously, this must be set to operate at levels which are only likely to occur at very infrequent intervals. For the most part, load fluctuations, due to variations in crop density, for example, must be overcome by the inertia of the tractor and machine or the response of the tractor engine. Therefore, if the engine is already at or close to maximum power, good torque back-up characteristics are essential to avoid engine stall.

There is, however, one way in which load fluctuations on pto-driven machines are less severe than on draught implements. In general, the load on a pto-driven machine is approximately proportional to the forward speed, whereas, with a draught implement, forward speed has little effect. Thus, there is some degree of self-correction with a pto-driven machine in that as the load increases, the engine speed and, therefore, forward speed will drop, thereby reducing the load.

The dynamic effects of changes in the load on pto-driven machines have been analysed in the past particularly with reference to the design of tractor hydraulic pto clutches and slip clutches on machines (Crolla 1977). A similar analysis can be used to determine the effect of machine load fluctuations on engine loading, dependent on engine and machine inertias and the stiffness and damping in the shafts joining the two.

Data on typical fluctuations in pto shaft torque occurring during normal operation have been obtained on a representative range of pto-driven machines. To facilitate these analyses, the torques were recorded on magnetic tape in the field, the torque signal being obtained from the NIAE strain gauge pto torquemeter, fitted directly on to the pto shaft of the tractor. The strain gauge amplifier, an Ether type RML 6019 had a flat frequency response up to 100 Hz.

All the machines, chosen to represent many different types of mechanism, were used in the harvesting of hay or silage crops and the recordings were taken during normal operation.

The recorded torques were analysed using a digital technique to produce graphs of power spectral density and probability density. The power spectral density graphs show the mean square values of the torque signal, over a range of frequencies, obtained by passing the signal through a series of band-pass filters. A frequency range of 0–50 Hz with values at intervals of 0.5 Hz was chosen, as it was concluded from previous oscillograph records, that any torque fluctuations above this frequency would be of small amplitude. The probability density curves are derived from classification of the instantaneous torque values into 25 class intervals, the area under a graph between two torque limits represents the probability that the instantaneous value of the torque will be between these limits, ie it is the fraction of the total number of samples of the signal taken at regular intervals falling within these limits. The total area beneath the density curve is unity. The probability distribution curve is a cumulative illustration of the same data, and shows at any torque value the total area under the density curve up to that point.

The machines used were as follows.

Silage blower The blower was a paddle bladed fan in a 1.22 m (48 in) diameter casing, blowing pre-cut silage through a 229 mm (9 in) pipe to the top of a 21.4 m (70 ft) high tower silo. A variable speed auger fed the chopped material to the six-bladed impeller which was driven directly through the tractor pto shaft at 1000 rev/min. A County 'Super Six' tractor was used.

Rotary mower A This was a four-drum rotary mower, with a cutting width of 1.63 m (64 in), which was attached to the tractor three-point linkage. The drums, which each carried two cutting knives were driven at 3100 rev/min through bevel gears on a shaft in the top of the machine. Power from the tractor pto shaft was transmitted through a vee belt and bevel gears. A Massey-Ferguson 165 tractor was used in 5th gear (10.5 km/h) (6.5 mile/h) with a pto speed of 540 rev/min.

Rotary mower B The cutting knives of this mower were attached to four gear-driven discs, cutting a width of 1.7 m (67 in). Each disc had two knives and the train of driving gears operated in a gear box beneath the discs. The power input from the tractor pto was transmitted through vee belts and bevel gears. This mower was also attached to the tractor three-point linkage, and the tractor and speeds were the same as for the previous mower.

Flail mower This machine was a forage harvester with a special delivery chute to leave the cut grass in a windrow. It had twenty-one cutting flails mounted in three banks on a rotor powered through vee belts and a gear-box from the tractor pto. A Ford 5000 tractor in 8th gear (7.25 km/h) (4.5 mile/h) was used, with the pto speed set at 395 rev/min giving a rotor speed of 1000 rev/min.

Reciprocating mower This was a conventional reciprocating knife mower, mounted on the tractor three-point linkage, having a cutting width of 1.53 m (60 in). The shaft driving the knife was driven at 990 rev/min through vee belts from the pto shaft at 540 rev/min. A Ford 5000 tractor was used in 8th gear (10.1 km/h) (6.25 mile/h).

Mower conditioner This trailed offset machine employed a reciprocating knife with a speed of 1500 cutting strokes/min and a cutting width of 2.66 m (105 in). A reel, with four tine-bars, rotating at 67 rev/min carried the cut grass to the rubber covered conditioning rollers. The conditioned crop was left in a windrow behind the machine. The pto speed of the Ford 5000 tractor was 540 rev/min and was used in 8th gear (10.1 km/h) (6.25 mile/h).

Forage harvester A This was a trailed forage harvester with a cutter-bar and cylinder chopper and was capable of delivering chopped material to trailers at the rear or side. The knife had an operating speed of 1200 cutting strokes per minute and behind it a reel carrying four tine-bars moved the cut grass to the metering mechanism. This consisted principally of two ribbed rollers feeding grass to the chopping cylinder which had six knives to give a nominal 6.35 mm ($^1/_4$ in) chop at a speed of 970 rev/min. A Massey-Ferguson 175 tractor was used in 2nd gear (4.4 km/h) (2.75 mile/h) and the pto speed was 540 rev/min. The same tractor, operating at the same speeds, was also used with the following forage harvesters.

Forage harvester B This was a trailed, pick-up harvester, employing a flywheel chopper to chop and blow the crop into trailers. The pre-cut silage was conveyed into the metering mechanism by a tined pick-up reel and fed into the chopping mechanism. The flywheel chopper, rotated at 540 rev/min and was fitted with six knives to give a fine chop.

Forage harvester C This machine had a rotor fitted with thirty-two flails in four staggered banks, to cut the crop in a similar manner to a flail mower. The rotor speed was 1400 rev/min and the cut material was conveyed to the chopping mechanism by a rear

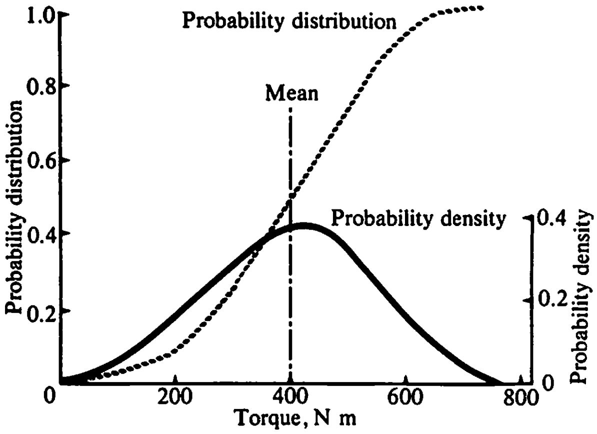


Fig 1 Silage blower

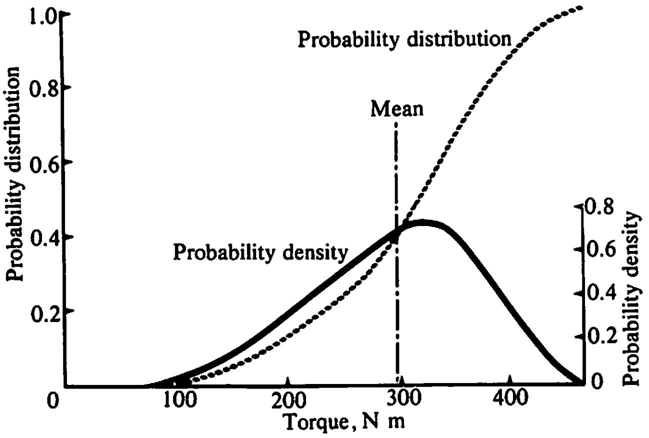


Fig 2 Rotary mower A

Fig 3 Rotary mower B

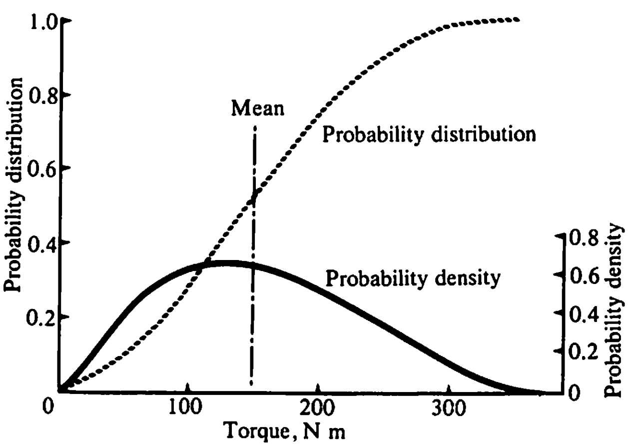


Fig 4 Flail mower

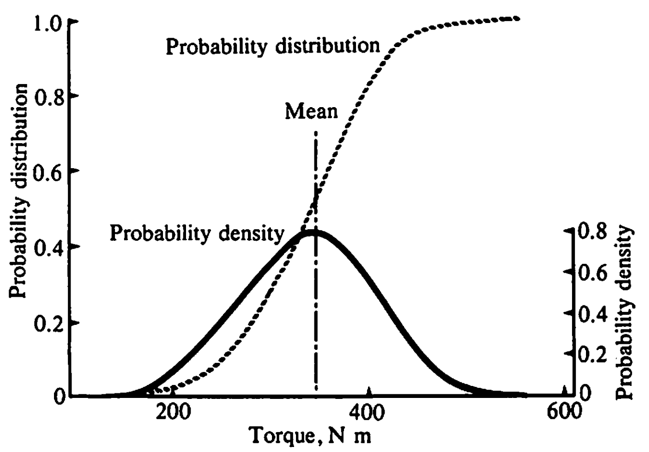


Fig 5 Reciprocating mower

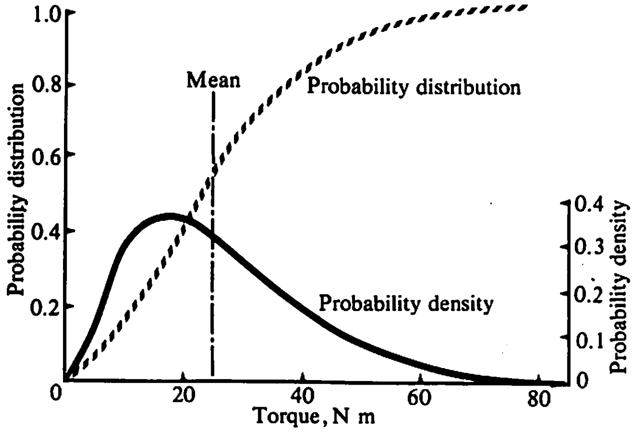
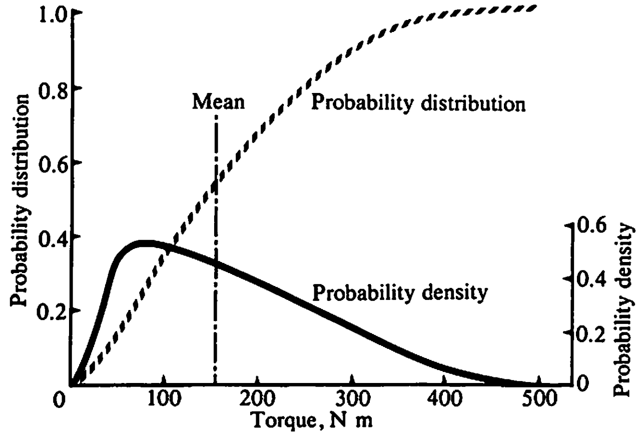


Fig 6 Mower conditioner



mounted auger. The flywheel chopper rotated at 810 rev/min and had six knives.

Balers A B and C The three balers were all similar mechanically. A pick-up reel with tines lifted the hay into the baler and feeder arms pushed the crop into the bale chamber during the return stroke of the ram. The ram operating arm was driven from the pto shaft via a bevel reduction gear-box. Large torques were caused by the compression strokes of the ram, which first sheared the hay and then compressed it into the bale chamber. The operating speeds of the three balers varied from 65 to 100 ram strokes per minute with a nominal pto speed of 540 rev/min. The tractor was a Massey-Ferguson 165 in 3rd gear (4.2 km/h) (2.6 mile/h).

The amplitude probability density and cumulative distribution curves are shown in figures 1-12 and a brief summary of torque values is given in table 2. In general, the probability density curves, for the machines requiring power for rotating mechanisms, eg rotary mowers and forage harvesters, are bell-shaped with the ratio of maximum torque to mean torque averaging about 1.5. The ratio for the rotary mower B, however, is 2.4 and the density curve has a pronounced positive skew, ie the maximum probability density value occurs at a torque value below the mean torque, and the curve is asymmetric with a larger range of

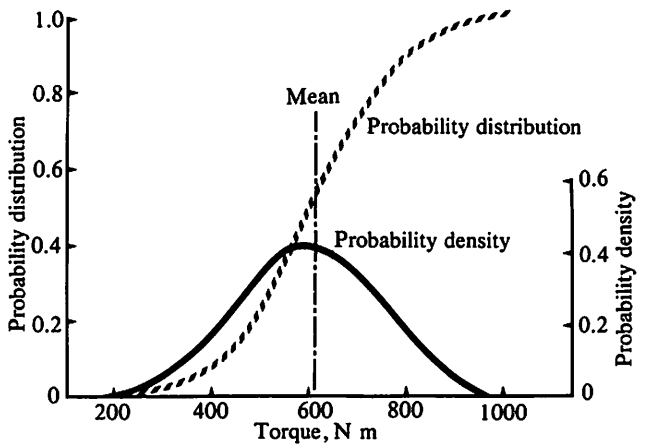


Fig 7 Forage harvester A

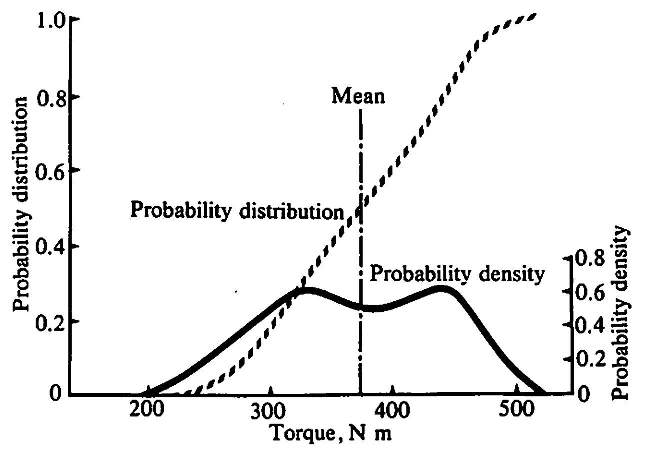


Fig 8 Forage harvester B

Fig 9 Forage harvester C

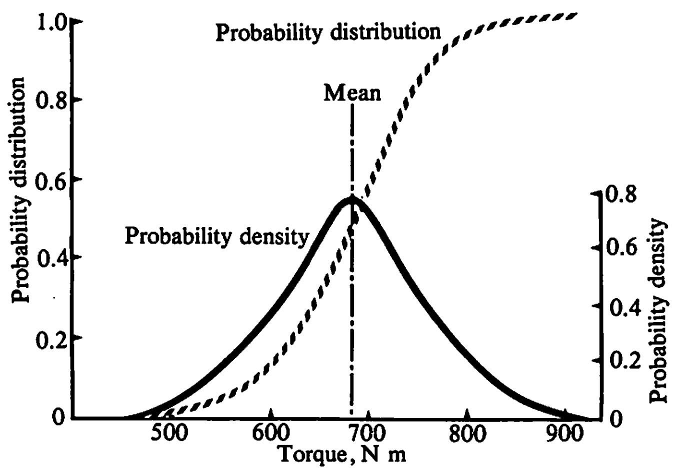


Fig 10 Baler A

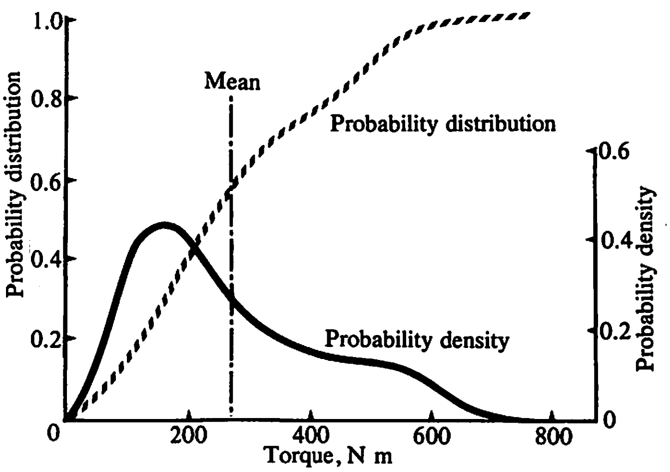


Fig 11 Baler B

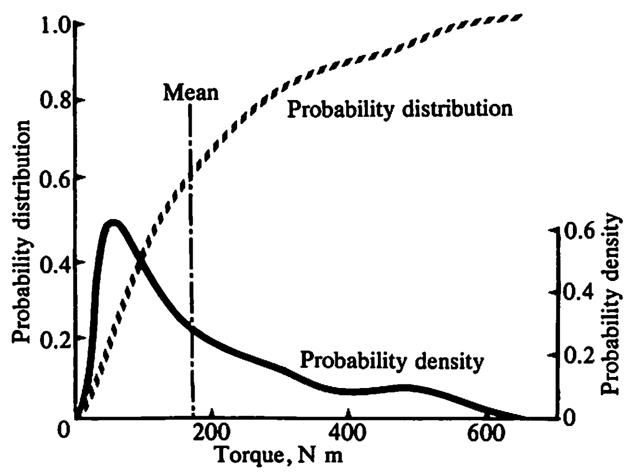


Fig 12 Baler C

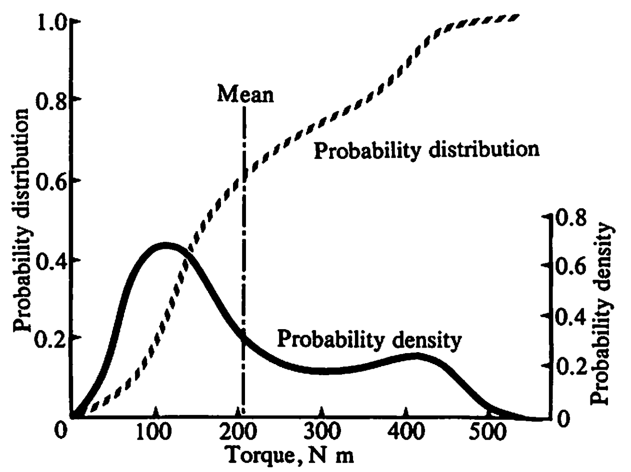


Table 2 Mean and maximum torques on some pto-driven machines

Machine	*Mean torque, Nm*	*(lb ft)*	*Max torque/ Mean torque*	*% time signal was above mean + 10%*	*% time signal was above mean + 50%*
Silage blower	393	(290)	1.9	42	7
Rotary mower A	296	(218)	1.6	45	2
Rotary mower B	146	(108)	2.4	41	17
Flail mower	339	(250)	1.5	28	0
Reciprocating mower	25	(19)	3.1	39	19
Mower conditioner	155	(114)	3.1	40	23
Forage harvester A	610	(450)	1.6	32	1
Forage harvester B	339	(250)	1.5	36	0
Forage harvester C	562	(415)	1.4	19	0
Baler A	271	(200)	2.8	36	23
Baler B	170	(125)	3.6	35	28
Baler C	203	(150)	2.6	35	24

torque values above the mean. These high torque values are believed to originate in the cutter-bar gearbox which contains a train of eleven gears, with small clearances between the gearbox and gears which are thought to have caused pressure surges as the gears pumped the lubricating oil.

The reciprocating mower, the mower conditioner and the three balers had higher maximum to mean torque ratios in the range 2.6–3.6. The reciprocating knife obviously generated the high peaks with the reciprocating mower, but although the mower conditioner had a similar cutting mechanism it is more likely that the highest torque peaks were caused by the irregular flow of grass through the conditioning rollers.

The baler ram action clearly caused high peak torques and the rapid rise and fall, to and from the high level required for the shearing and compressing actions, gave a bi-modal density curve, ie a greater probability of the torque occurring at two different levels. The probability density peak at the lower torque value is related to the smaller power requirement of the feeding operation which occurs during the return stroke of the ram. Baler B was older than the other two balers, and the ram knife was known to be blunt. This caused the operating torque to be higher than usual and increased the torque ratio, which was higher than those of the other two balers.

The power spectral density (PSD) graphs for the machines are shown in figures 13–24, and table 3 gives a summary of the main frequency peaks from the graphs compared with the estimated frequencies of various machine motions. Power spectral density peaks at 25 Hz were caused by mains frequency interference on the tape recording and should be ignored. With only one exception, the reciprocating mower, all the maximum power spectral density values occur at or below 5 Hz and no peaks are higher than 10% of the maximum at frequencies above 7 Hz. These low frequency peaks were associated with the mechanical operations in the balers and the mower conditioner. In the latter, the large torque variation at 4.5 Hz originated at the conditioning rollers, the crop being fed to them at this frequency, by the tine bars of the pick-up reel.

The sharp 5 Hz peak on the power spectral density graph for the silage blower suggests a mechanical origin. Torsional oscillation in the drive shafts between the tractor flywheel and the blower impeller assembly, appears the most likely cause. The maximum torque to mean torque ratio of this machine is also higher than would be expected from an impeller mechanism (see table 2).

The power spectral density graphs

Table 3 Frequency analysis of torques on pto-driven machines

Machine	*Frequencies of main PSD peaks, Hz*	*Mechanism frequencies, Hz*	
Silage blower	5	Impeller	100
Rotary mower A	2, 3.5, 17.5	Pto shaft	18
		Knives	104
Rotary mower B	2, 3.5, 17.5	Pto shaft	18
		Knives	97
Flail mower	1, 4.5, 6.5, 12.5	Pto shaft	13
		Flails	50
Reciprocating mower	9, 11.5, 16.5, 18, 33.5	Pto shaft	18
		Cutter bar	33
Mower conditioner	3.5, 4.5, 7, 8, 9, 18	Pick-up reel	4.5
		Pto shaft	18
		Cutter bar	25
Forage harvester A	0.5, 3.5, 20, 40, 43.5, 50	Pto shaft	18
		Cutter bar	20
		Cylinder knives	97
Forage harvester B	1.5	Pto shaft	18
		Flywheel knives	54
Forage harvester C	3	Pto shaft	18
		Flywheel knives	81
		Flails	96
Baler A	2, 3.5, 5.5, 18.5	Ram and feeder	1.8
		Ram and feeder	3.6
		Ram and feeder	5.4
		Pto shaft	18
Baler B	1, 2.5, 3.5, 5, 6	Ram and feeder	1.2
		Ram and feeder	2.4
		Ram and feeder	3.6
		Pto shaft	18
Baler C	1, 2, 3	Ram and feeder	1.1
		Ram and feeder	2.2
		Ram and feeder	3.3
		Pto shaft	18

PSD = Power spectral density

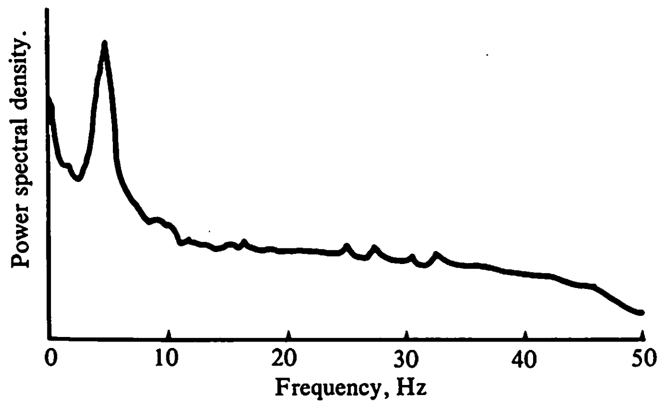


Fig 13 Silage blower

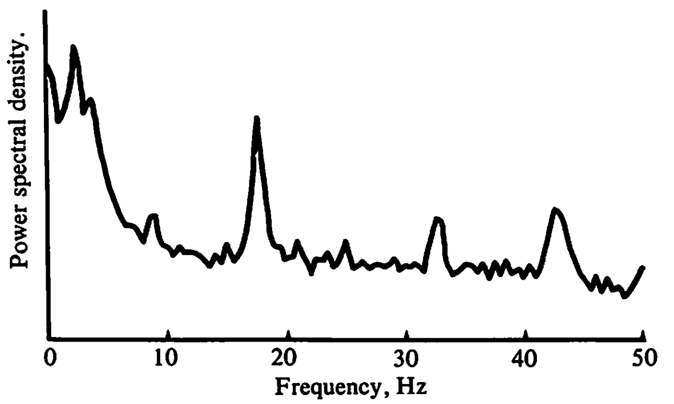


Fig 14 Rotary mower A

Fig 15 Rotary mower B

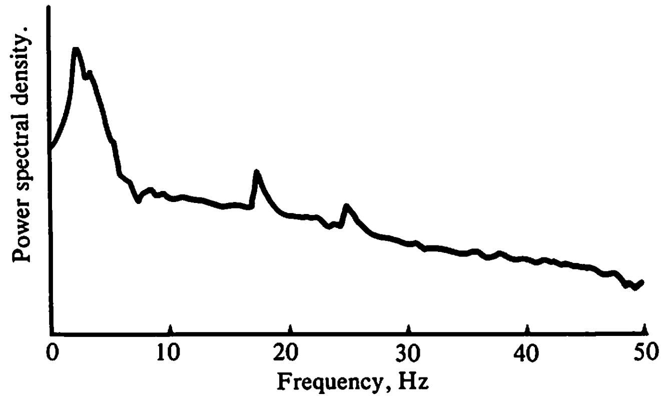
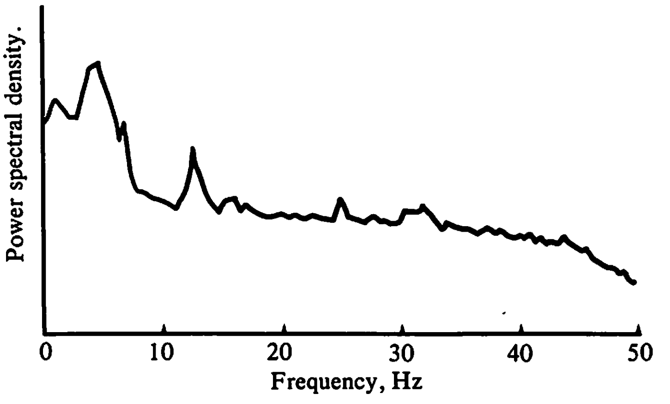


Fig 16 Flail mower



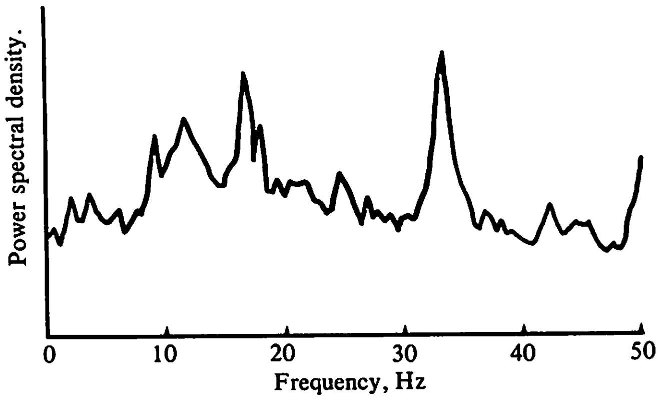


Fig 17 Reciprocating mower

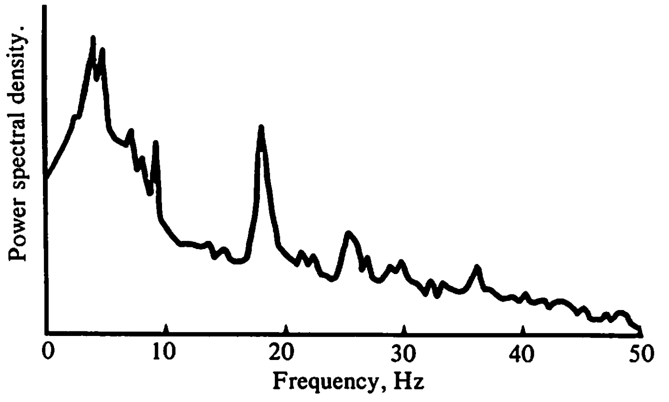


Fig 18 Mower conditioner

Fig 19 Forage harvester A

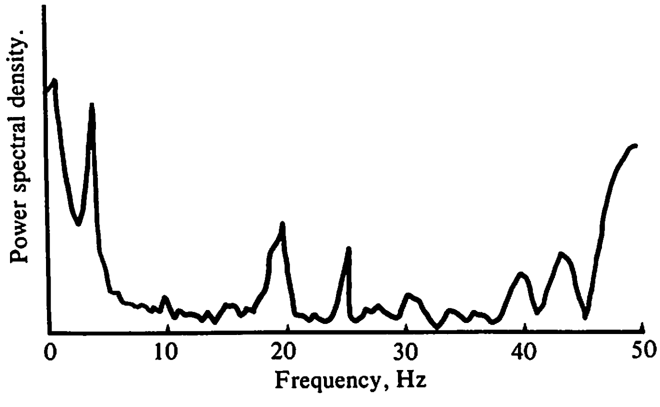
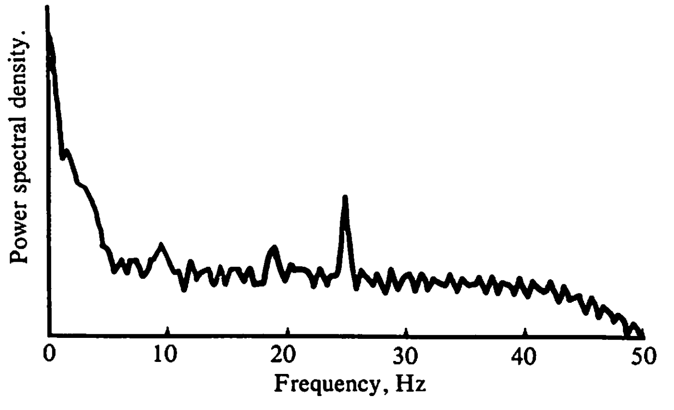
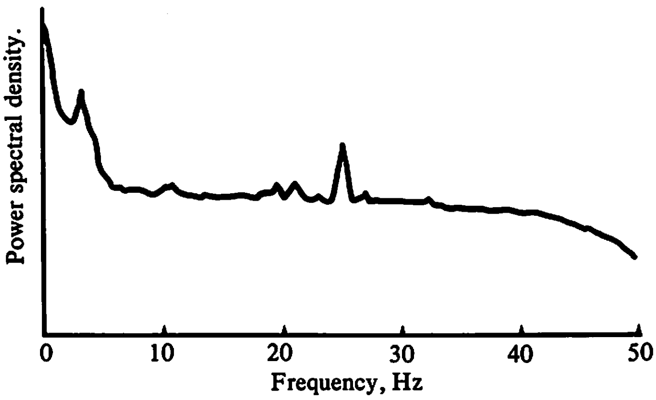


Fig 20 Forage harvester B





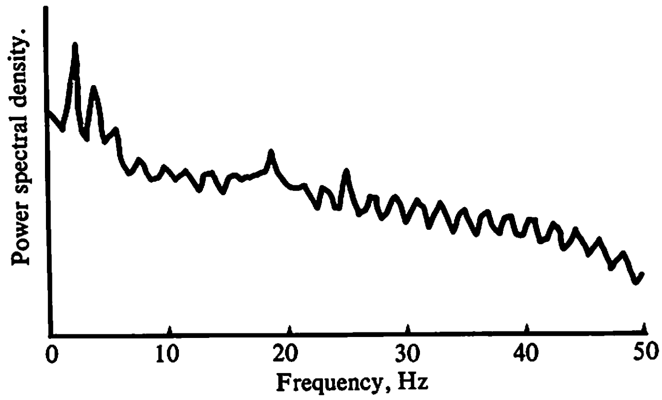
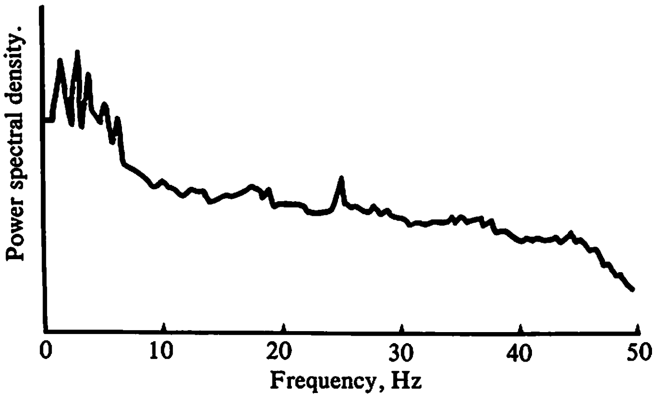
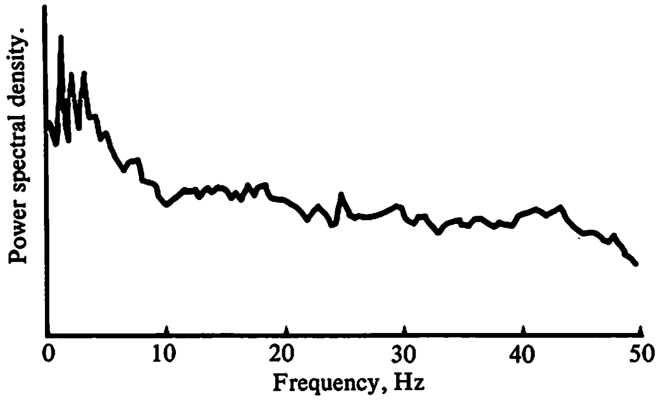


Fig 21 Forage harvester C
Fig 23 Baler B

Fig 22 Baler A
Fig 24 Baler C





for the balers all have large peaks at the main ram frequency with smaller peaks at two and three times this figure, caused by the operations of shearing and compression during the forward ram stroke and the packing action taking place during the return stroke.

The maximum power spectral density value for the reciprocating mower occurs at 33 Hz, showing a sharply defined peak. The knife speed is 33 cutting strokes/s, each stroke requiring a complete cycle of torque. Another power spectral density peak at half this frequency is associated with the same action. In all other machines there is a low frequency torque variation which does not peak at one well defined frequency and must be caused by changes in crop density or irregular flow of cut material.

Most machines also show a peak at approximately 18 Hz arising from angularity in the pto shaft, rotating at 540 rev/min, each revolution producing two cycles of torque fluctuation. The lower pto speed used with the flail mower (395 rev/min) produces a peak at 13 Hz.

This analysis of pto shaft torques shows that the most significant variations in torque occur at low frequencies. In most cases, a higher frequency torque fluctuation is produced by the joints in the pto shaft itself. The major power spectral density values occur below 5 Hz and with few exceptions are related to the processing functions of the machine.

As would be expected, rotating mechanisms produce a relatively smooth torque, but for design calculations a maximum to mean torque ratio of at least 1.5 should be assumed. In machines with reciprocating parts, eg balers, the main power requirement may be concentrated into a small part of the work cycle and the maximum to mean torque ratio should be assumed to be at least 3–3.5. Allowances should be made for extreme conditions and for the possibility that maximum torques will increase as wear takes place.

Future developments in tractors and pto-driven machines are all likely to reduce the fluctuations in load which occur and enable tractor engines to run continuously at closer to maximum power. Unlike the situation with draught implements, there are no advantages in forcing a pto driven machine to cope with large increases in load. From all aspects, it is better to control forward speed so as to keep an even load on the machine. In this way, the machine is likely to work more efficiently, as well as providing a more constant load on the engine. This is likely to be achieved in the future by separating the pto transmission from the ground drive system, with at least one of them being continuously variable, possibly automatically controlled by the torque.

5 Special requirements for transport operations

As mentioned previously, although there may be scope to reduce drastically the power requirement for many operations on the farm, the one which is always likely to remain is transport, unless vehicles can be at least partially replaced by conveyors. Power requirements for transport on the farm and the fluctuations in load which occur are likely to be very similar to those for other transport vehicles. Therefore, the engine requirements are also likely to be very similar. The main ways in which transport requirements on the farm differ from those elsewhere are the higher rolling resistances caused by travel over soft ground, the relatively short haul distances and the need to match closely the output of other equipment.

Farming has often been described as primarily a materials handling operation and, when one considers the quantities of materials which have to be moved, collected, stacked, stored and distributed in order to grow a crop or rear an animal, one can see the justification for this statement. To grow a hectare of cereals it is necessary to transport to the field and distribute approximately 160 kg of seed, 450 kg of fertiliser and a smaller quantity of chemicals. After harvest, approximately 6 tonnes of grain must be transported back to the buildings, processed and stored and a similar weight of straw either collected and transported or disposed of in some other way. For each hectare of grass 50 to 100 kg of fertiliser must be transported to the field and distributed and approximately 10 tonnes of hay or 25 tonnes of grass must be transported from the field, processed and stored.

By far the most common form of farm transport is the two-wheel unbalanced trailer of 5 to 10 tonne capacity. Coupled to a tractor by the hydraulic pick-up hitch and equipped with a hydraulic tipping ram operated from the tractor external hydraulic supply, this trailer has proved over many years to be a very versatile and relatively cheap vehicle. However, as with tractors, although there is always a place for the general purpose machine, there is also, on the larger farms and among contractors a demand for a more sophisticated machine which will perform specific tasks more efficiently. This has led to a steady increase in trailer capacity up to 15 or 20 tonnes and to the development of more sophisticated tipping arrangements, which have increased costs.

The most common materials requiring transport on the farm are seed, fertiliser, chemicals, cereals, sugar-beet, potatoes, grass, hay, straw, farmyard manure and slurry. With chemicals, farmyard manure and slurry, transport and distribution capabilities are usually combined in a machine designed specifically for handling one material. Handling of seed and fertiliser offers scope for a similar combination of the transport and sowing operations. The other materials are the products of harvesting and present different problems according to their nature and that of the harvesting operation. Cereals, sugar-beet and grass, probably require the most speed of transport since large quantities must be moved in a short time. Potatoes require the most care to avoid damage and hay and straw, normally being in bales, present problems of load stability and bulk.

The power required for farm transport depends on the payload, speed, steepness of slopes to be climbed and surface conditions. Payload and speed depends on the urgency of the operation, the capacity of the machinery at the loading and unloading ends of the journey, ie harvesting machines, processing plant such as driers and machinery for handling into store, and the number of transport vehicles available. Speed also depends on the surface roughness, the suspension provided for the operator and payload and the sensitivity of the payload to vibration and jolting.

Because of the urgency of the operation, the highest power requirements are likely to be for the transport of harvested crops to processing or store. The economics of matching the number and capacity of harvesting machines, the transport vehicles, processing plant and handling equipment at the store are complex and beyond the scope of this paper. It is necessary, therefore, to make some simplifying assumptions if any implications are to be drawn concerning the power required for transport. It will be assumed, therefore, that:—

1 the capacity of harvesting machines will continue to follow current trends,
2 the capacity of processing and handling equipment at the store can keep pace with that of harvesting machinery,
3 harvesting machines work continuously.

The power required for a transport vehicle operating on level ground is used entirely in overcoming rolling resistance. Additional power will be required when travelling uphill, but this will be compensated by a reduction in power required downhill. Since the transport vehicle makes round trips between harvester and store, the amount of uphill and downhill travel will be equal and, therefore, the effect of slopes on power requirement will be ignored. This introduces a significant error when the journey from field to store with the vehicle laden is uphill and the return journey unladen is downhill. This analysis must, however, be treated as a very broad generalisation and, therefore, such special cases must be treated separately.

The ability of the vehicle to climb slopes depends on its traction characteristics and the transmission ratios available. It is assumed that the vehicle has a low enough transmission ratio to climb all the uphill slopes on its journey, sufficient tractive capacity to avoid excessive wheel-slip and a sufficiently high speed to take advantage of the downhill slopes.

Therefore, the power required is given by:

$$P = c \times 10W \times V/3.6 = 2.8\ cWV$$

where: P = power, kW
c = coefficient of rolling resistance, rolling resistance/weight
W = total vehicle weight, tonnes
and V = forward speed, km/h.

If it is assumed that the vehicle unladen weight is equal to one half of the payload

$$P = 4.2\ c\ W_p V$$

where: W_p = payload, tonnes.

Therefore,

$$P = 8.4\ c\ W_p d/t$$

where: d = distance from harvester to store, km,
and t = total time for journey to store and back, h.

On the return journey from the store to the field, the vehicle is unladen and the gross weight is only $0.5\ W_p$. It is assumed, however, that the vehicle will not be able to increase its forward speed by a factor of 3 to take advantage of this and to use the full power available, although some increase in speed will probably be possible on the return journey.

It is assumed that the time taken to load and unload is negligible compared with the journey time. At present this is not normally true but it is likely to be at least partly compensated by the higher speed of the unladen vehicle on the return journey.

If the transport vehicle is to receive another payload as soon as it returns to the harvester and then again returns to the store, the payload divided by the journey time must equal the rate of harvesting.

Therefore,

$$P = 8.4\ c\ H\ d$$

where: H = rate of harvesting, t/h.

Thus, the power required for transport is dependent only on the rate of harvesting, the distance from harvester to store and the coefficient of rolling resistance of the ground surface. It may be provided by a relatively slow vehicle with a large payload, a fast vehicle with a proportionally smaller payload or a combination of two or more vehicles.

Considering operation of a transport vehicle on stubble taking grain from a combine harvester, a typical value of coefficient of rolling resistance would be 0.1. A typical rate of harvesting would be 12 t/h so that for a journey of 1 km to the store or drier the power required would be approximately 10 kW. The biggest combine harvesters in use with cutterbars over 5 m width are capable of an output of 24 t/h and would therefore require a 20 kW transport vehicle for a journey of 1 km on a typical surface. Cutterbar widths are unlikely to exceed much more than 5 m since even this width can only be used on relatively level land, due to the difficulty of keeping the cutterbar parallel to the ground on side-slopes. There may be scope in the future for increasing forward speed of combines but this will require considerably more development of automatic controls since present speeds are probably near the limit for satisfactory manual control. It appears, therefore, that the power required for transport of grain from combines is unlikely to exceed approximately 20 kW/km in the near future, unless radically different methods of harvesting grain are introduced.

The present rates of harvesting potatoes and sugar beet are approximately 7 t/h for the commonly used single-row machines and up to 14 t/h for the more advanced multi-row machines. The surfaces on which potatoes and sugar beet have to be transported are, however, softer than for cereals and, therefore, a rolling resistance coefficient of 0.2 would probably be more appropriate. Therefore, the power required for transport is likely to be approximately 12 kW/km for present machines and 24 kW/km for the future.

The rate of cutting grass for silage with a conventional trailed forage harvester is approximately 15 t/h and this rate is likely to double in the future. The ground surface over which these crops have to be transported are generally firmer than for either root crops or cereals so that a coefficient of rolling resistance of 0.05 is probably more appropriate. The power required for transport of grass for silage is, therefore currently approximately 6 kW/km and could be up to 12 kW/km in the future.

These power requirements are generalisations based on very broad assumptions and individual situations are likely to require widely different powers. However, they do confirm that transport is a relatively low power operation compared, for example, to heavy cultivations. They also suggest that for harvesting, grass is the least demanding of transport power and cereals the most demanding with root crops somewhere between.

It was stated above that the power necessary for transport vehicles to support a harvesting operation could be supplied either by a large slow vehicle, a small fast vehicle or a combination of vehicles. In general a single vehicle is likely to be the most economical because of its lower labour requirement. Other factors will limit maximum weight and maximum speed. In particular to achieve satisfactory acceleration and slope climbing speed, especially on the road, a power of at least 6 kW/tonne will probably be necessary. This means that current typical train weights of 10–15 tonnes require 60–90 kW and this is likely to rise to 150–180 kW in the future, which is far in excess of what is theoretically required.

6 Conclusions

In the short term, power requirements for farm operations are likely to continue to increase at the present rate because of the economic pressures to increase rates of work. In the longer term, however, there are possibilities that developments in field machinery may lead to drastic reductions in the power required for cultivations and harvesting operations. This could leave transport eventually as the highest power requirement on the farm. Again, in the short term, this could be very high, but theoretically could be much lower than at present.

Engines have to cope with fairly large fluctuations in load on many farm operations. This means that they are frequently operated well below their maximum power. Better torque back-up characteristics or fuel control would enable engines to cope with these fluctuations more effectively and thereby provide a higher mean output. However, future developments and, in particular, more and better automatic controls on tractors and machines are likely to reduce these fluctuations in load. This will result in a greater need for engines to run continuously at maximum power, under a nearly steady load. This will be further encouraged in the future by providing better noise isolation for the driver.

7 Acknowledgement

The measurement and analysis of torque variations on pto-driven machines was carried out by the author's colleague, Mr G Pearson.

8 References

ADAS (1972). Wheeled and tracklaying tractors — A joint ADAS/NIAE study of utilisation, performance and tyre and track costs. Farm Mechanisation Studies No 21.

Crolla D A (1975). The performance of off-road vehicles under fluctuating load conditions. Proc Instn Mech Engrs Conf on Off-Highway Vehicles, Tractors and Equipment, London. CP11, pp 91–99.

Crolla D A (1977). Theoretical analysis of inertia torque overloads when starting up pto-driven agricultural machinery. *J agric Engng Res,* **22**(2), 197–208.

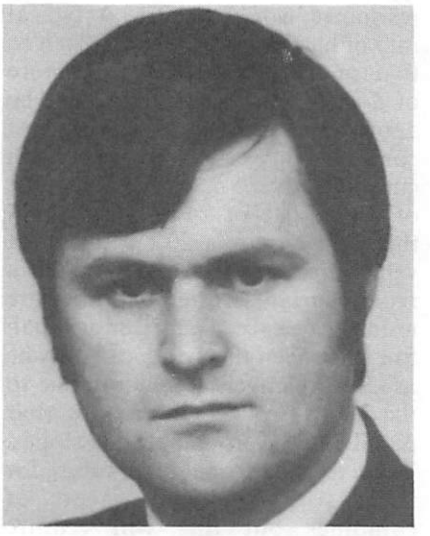
Dwyer M J (1978). Maximising agricultural tractor performance by matching weight, tyre size and speed to the power available. Proc 6th Int Conf, Int Soc Terrain-Vehicle Systems, Vienna. Vol 1, pp 479–499.

Gee-Clough D (1980). Selection of tyre sizes for agricultural vehicles. *J agric Engng Res,* **25** (3), 261–278.

Stansfield J R (1974). Fuel in British agriculture. Nat Inst agric Engng Report No. 13.

Internal combustion engines for future field machines

A R Chowings



Summary

THE work carried out on the farm is varied and yet the basic powered equipment is expected to carry out all these varied tasks. The engine is the heart of the equipment and this paper describes the trends that are expected over the next 20 years. These trends are mainly market led and are in the main evolutionary, although there are instances where advances in technology, particularly control electronics, can help to influence the design of machinery for the future. The effect of the ever changing fuel scenario is discussed and some solutions to the problems posed are proffered. The paper concludes that the compression ignition engine will remain the primary basic power source for the Agricultural Industry until the turn of the century but that engines will be refined in terms of basic fuel efficiency and in terms of matching to a given application requirement.

Product polarisation

THE trends of the Agricultural Industry are formulated by economic considerations as much as pure technological advances. Consequently, it is not surprising that the diesel engine manufacturer has a primarily reactive role to play in the industry. Some specific advances in technology on engines can influence the concept of capital equipment for the farming industry and some instances can be found later in this paper, but the supplier of the power unit for agricultural machinery must be able to provide the whole goods manufacturer with the right product for the job. To do this well, the power unit supplier must work closely with the whole goods manufacturer and, between them, anticipate the market requirements.

As stated earlier, this paper concentrates on the next 20 years and, although within this timescale there may be some move towards a change in traditional power units, the major power source will still be the compression ignition engine.

The requirement for power units can be split down into four basic groups:

- light duty;
- low cost;
- medium duty;
- heavy duty.

Each group has a specific set of requirements for the power unit, yet it is possible to satisfy the latter three groups from the same basic engine family.

Light duty

The light duty requirement has risen from two basic needs:

- the small 'market garden' tractor;
- specialised self-propelled equipment.

The key objectives for such an engine which has a power requirement in the 24–49 kW band can be summarised as follows:

- reliability;
- low cost;
- small package size.

These needs are best satisfied by a small direct injection diesel engine which probably has its ancestry in the automotive industry. This, in fact, is a case where the availability of product from the engine supplier may influence trends. Growth in this sector has been very slow in the past due to non availability of product, indirect injection diesels have economy and torque penalties whereas the derated 'tractor' diesel has cost and size penalties.

Figures 1 and 2 clearly illustrate the advantage the small direct injection engine has over its rivals in terms of fuel consumption compared with the traditional indirect injection engine and in terms of size when compared with a typical de-rated tractor engine of the same power. Additionally, its automotive ancestry can ensure economy of scale in manufacture and simple design; plus automotive industry style levels of automation can ensure very high levels reliability and adequate durability.

Low cost

There has always been the need for a low cost, no frills farm tractor for the Third World and, indeed, there is still a need for such a machine on many European farms. The power unit also needs to be low cost, no frills and the key objectives can be summarised as follows:

- power range 40/55 kW;
- reliable;
- low first cost;
- low cost of ownership;
- simple to operate and service.

The requirements of this sector are best served by a relatively conventional, four cylinder, naturally aspirated diesel engine of approximately four litres. The best design approach is to begin with a conservatively designed basic carcass of cylinder block and crankshaft from a more highly rated version of the same engine family and use cost-effective components on that carcass

---

Roy Chowings is a Project Manager in the Engineering Division of Perkins Engines Company, Peterborough.

This paper was presented at the East Midlands Branch Conference entitled: Power for Mechanised Farming in the 21st Century, held at Nottingham University on 27 September 1984.

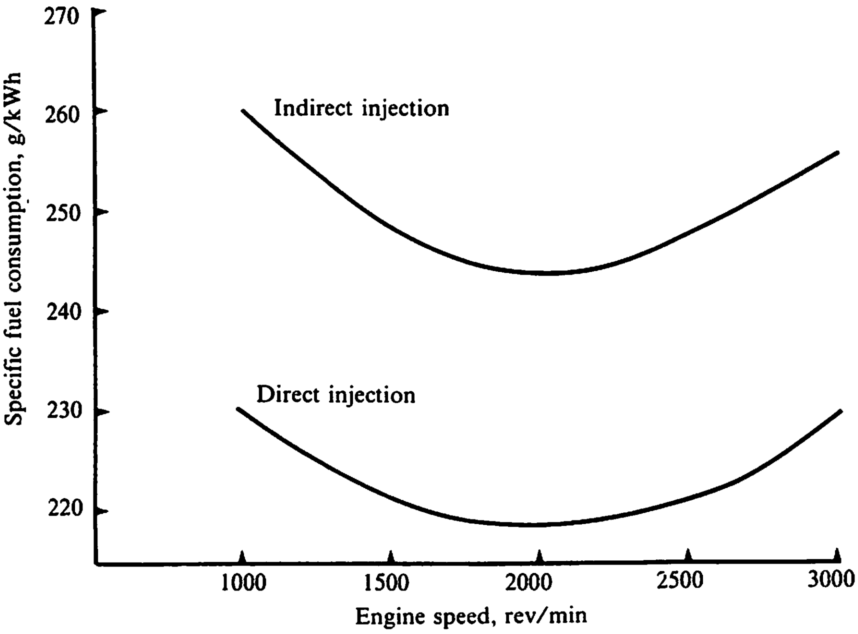
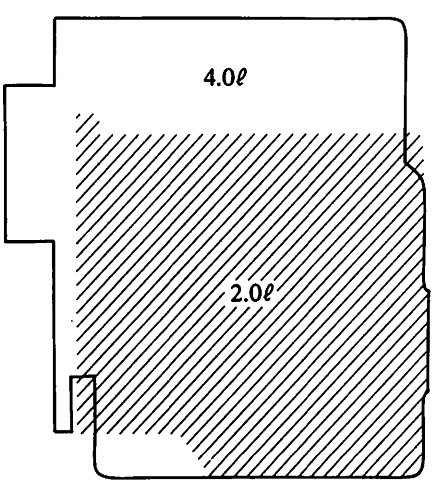


Fig 1 Fuel consumption comparison for direct and indirect injection engines, developing 40kW at 3,000 rev/min

ie pistons/rings, valves, fuel injection equipment etc to ensure that the cost targets are met, whilst achieving adequate durability levels. The use of a 'high' specification carcass gives the engine an element of over-design which, in turn, makes the engine tolerant to 'low skill' servicing and maintenance. This approach of conservative specific power outputs also makes the engine tolerant to the use of poor quality lubricants.

One additional feature that reduces the maintenance requirements, yet increases application flexibility, is to gear drive the engine water pump. Fig 3 shows a typical configuration of gear drive ancilliaries for the "low cost" tractor engine.

Fig 2 Basic size comparison between the smaller, 2 litre, direct injection engine and the larger, 4 litre, indirect injection engine, both producing 40 kW at 3000 and 2000 rev/min. respectively



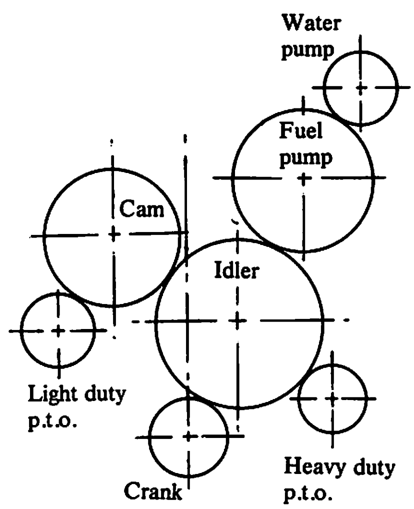
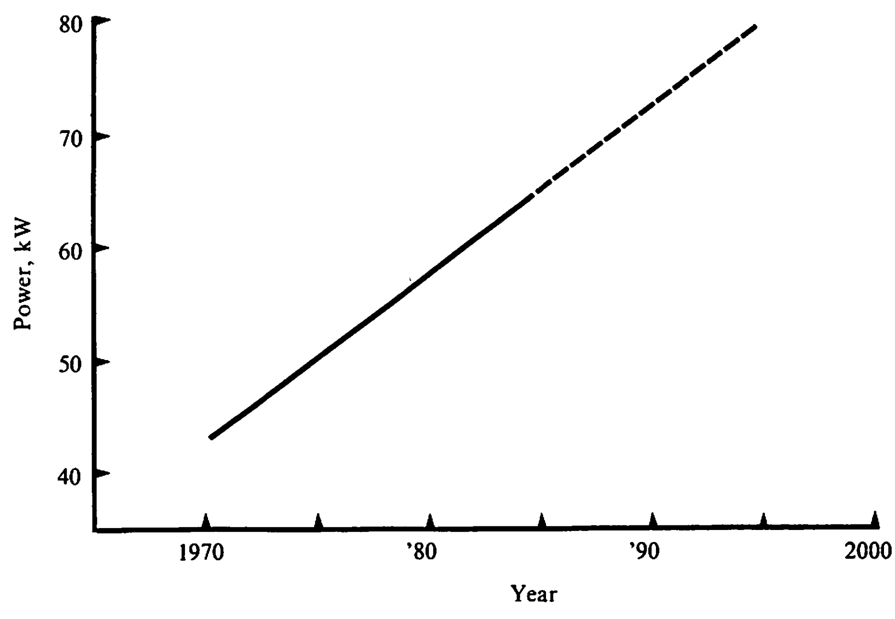


Fig 3 Typical gear train for ancillaries on a "low cost" tractor engine

Fig 4 Tractor power trends



Medium duty

For the engine manufacturer this is the most important sector as it represents the highest volume. The European tractor is essentially a medium duty application and fig 4 shows how the power requirements have grown over the past ten years. With the increasing use of four wheel drive tractors, there is no reason to suggest that the trend will change significantly over the next ten to twenty years.

The primary requirements for engines in this sector are as follows:

- power range 50/75 kW;
- reliable;
- durable;
- applications flexibility;
- fuel efficient.

This sector is also best served by a four cylinder, four litre, diesel engine in naturally aspirated and turbocharged form. Indeed, it is the turbocharged version that sets the basic design parameters for such an engine.

Figure 5 shows how the power output from typical four litre engines have increased in the past 15 years and how, with the advent of greater levels of turbocharging and even charge cooling, this trend could continue to the point at which the naturally aspirated, six cylinder, six litre member of the family could be displaced by the turbocharged four. The power/weight ratio naturally mirrors this trend.

The key elements for design of the modern engine are:

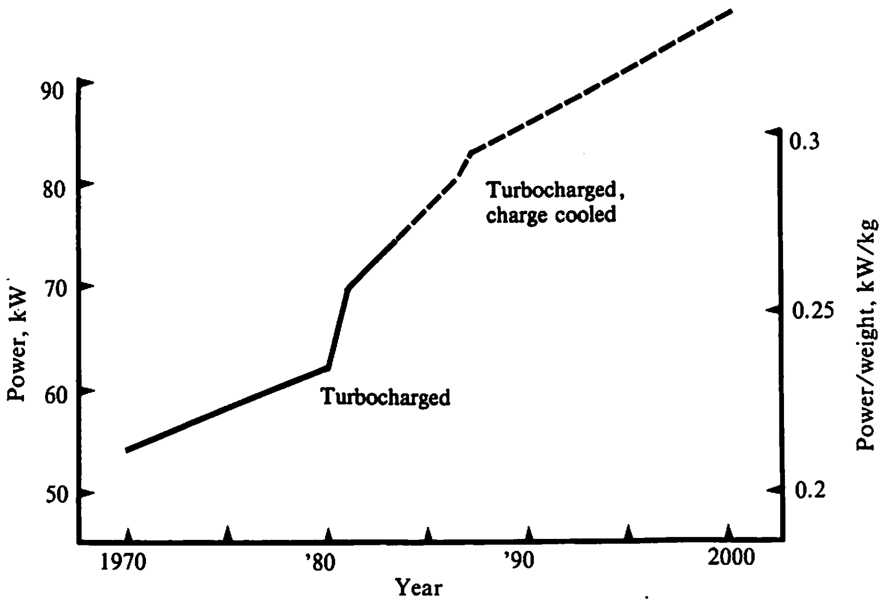


Fig 5 Power rating development of the four litre, four cylinder, diesel engine.

- the combustion process;
- the mechanical/thermal loading of the structure.

The parameters against which the combustion process must be developed are many and varied but the key objectives are:

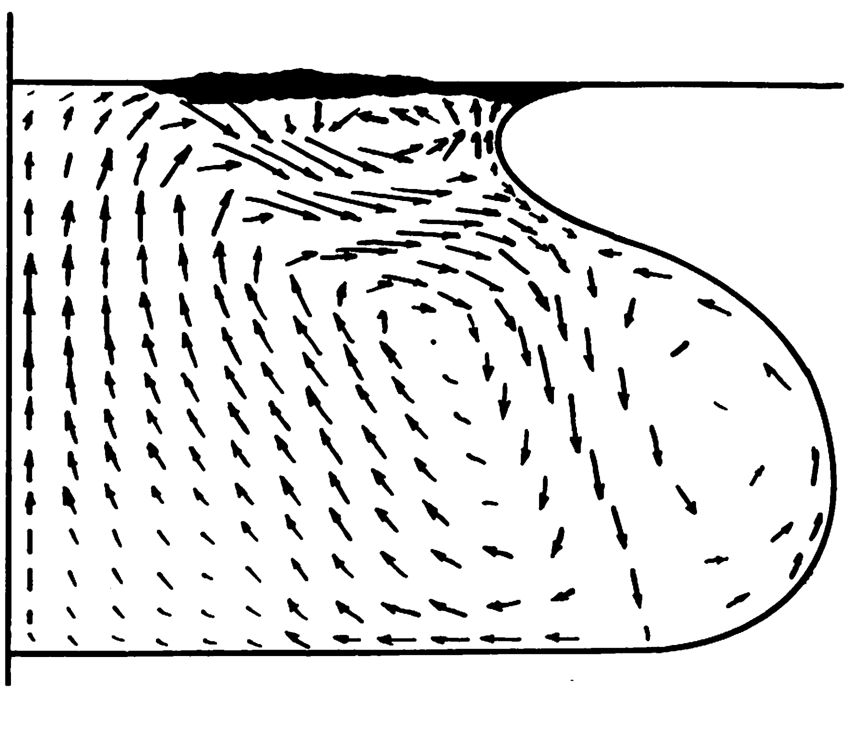
- greater fuel economy;
- reduced combustion noise;
- lower in-cylinder peak pressures;
- controlled emissions;
- greater tolerance to degraded and alternative fuels.

Not too many years ago, the approach to such a challenge would be to test many systems on a trial and error basis and hope that, after many wasted hours and dollars, an acceptable compromise could be found. In today's environment, such an approach is not acceptable and, although the final combustion chamber will always be a compromise, the method of selection is much more scientific. With something as sensitive as the combustion process, it is necessary to take a dual approach to development — theoretical and practical. By using such tools as the Air Motion Simulator (fig 6) and Laser Doppler Anemometry (fig 7), it is possible to select the wheat from the chaff before commencing the full development programme.

Having made the basic selection and drawn up a 'short list' by using the theoretical and practical 'high technology' approach, detailed testing can be undertaken to develop the chamber to a high level of tune to meet the key objectives. Chamber developments are underway which will yield significant performance improvements and exhibit the basic characteristics as shown in fig 8. The basic power and fuel consumption levels are 'state of the art' but, additionally, other characteristics are equally impressive and give the farmer the chance of a significantly improved environment (see table 1).

Having chosen the best combustion system, the characters of that system must then be used to produce mathematical models of the main engine structure to enable prediction of mechanical and thermal stresses to be calculated. Fig 9 shows the basic form of a fully interactive, 3D, finite element model of a typical, four litre, four cycle diesel. Use of such tools can enable the designer to make maximum use of new materials and processes to ensure that the basic engine structure is optimised at the design stage. Greater detail of the methods and application of the finite element method for diesel engine design can be found in a standard text (Haddad and Watson 1981).

Fig 6 Air motion simulator diagram with arrows indicating direction and the length of the lines proportional to velocity



Heavy duty

Having chosen to separate out medium and heavy duty, it is acknowledged that there is a considerable overlap between the two sectors. The engines being considered in the heavy duty sector are those required for the large, four wheel drive, tractors in Europe. The requirements put on the engine in the same sector in North America are similar, even though the power requirements are greater. Consequently, this paper will concentrate on the European heavy duty sector.

The primary requirements for the engines are:

- power range 80/125 kW;
- reliable;
- durable;

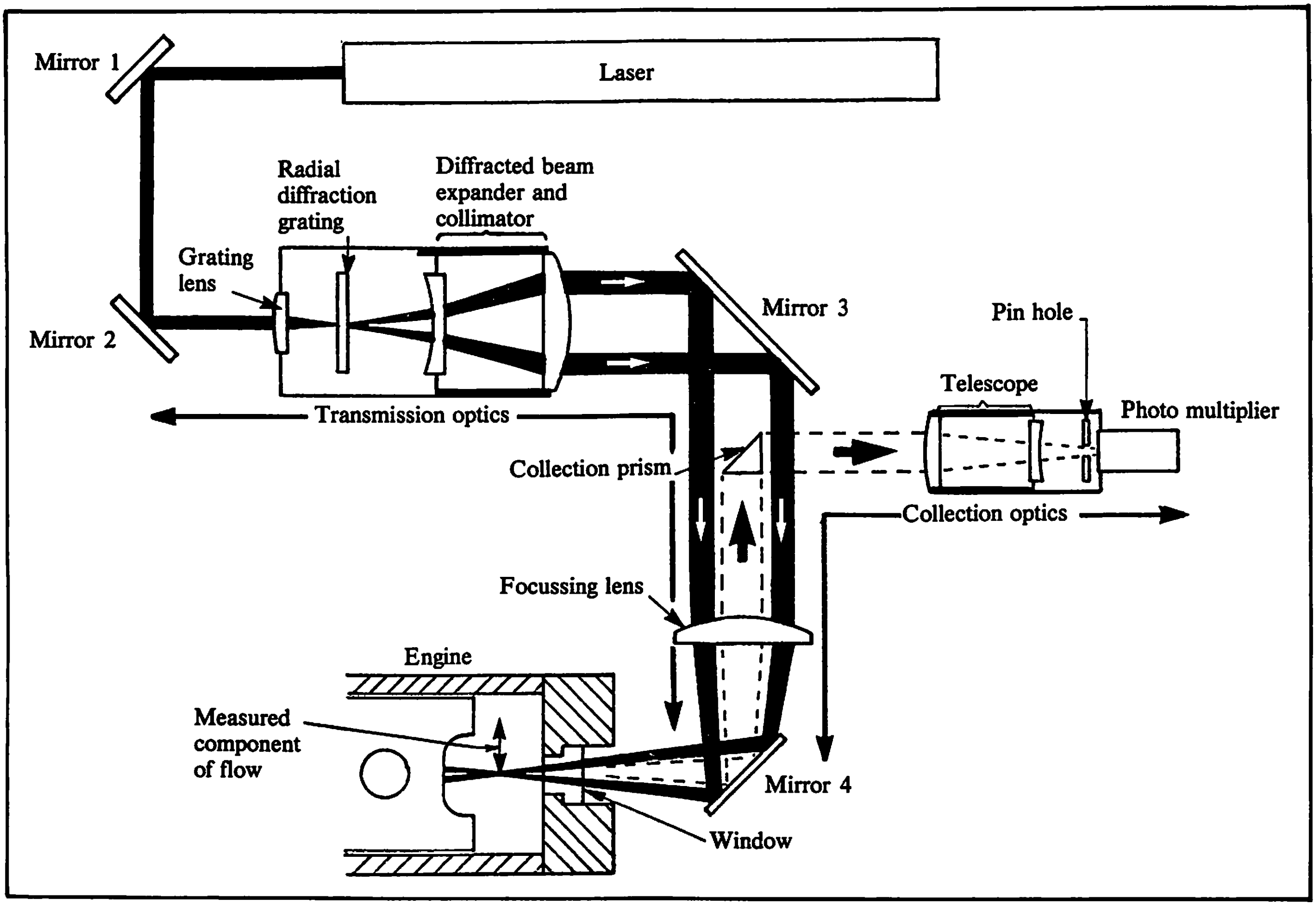


Fig 7 A schematic of laser doppler anemometer optics and engine combustion chamber

- high level of application sophistication;
- fuel efficient;
- environmentally acceptable.

The engine most likely to fill these requirements will be the six cylinder, turbocharged variant of the one litre/cylinder engine family. The development process will have been a concurrent exercise with the turbocharged, four cylinder engine that is specified for the medium duty sector and the basic achievements will be similar to that engine, although, in the main, the six cylinder will be approximately 2% more fuel efficient due to the economy of scale eg seven main bearings for six cylinders, compared with five main bearings for four cylinders.

The heavy duty tractor is a large investment; hence, it will be utilised to the full and utilisation of 2000 hours per year will not be abnormal. The design of the engine must take such factors into consideration. Cost is always a factor but, for this sector, reliability and durability take precedence. Hence, higher grade materials will be used.

The environmental acceptability is important, particularly for the operator. With the high utilisation factors, the operator will be sitting at the controls for many hours at a time and hence noise levels are particularly important. The engine will always be a source of noise, either directly or as an exciting force for the rest of the machine structure.

Fig 8 Typical performance characteristics after applying combustion technology to the design of a four litre, four cylinder, diesel engine

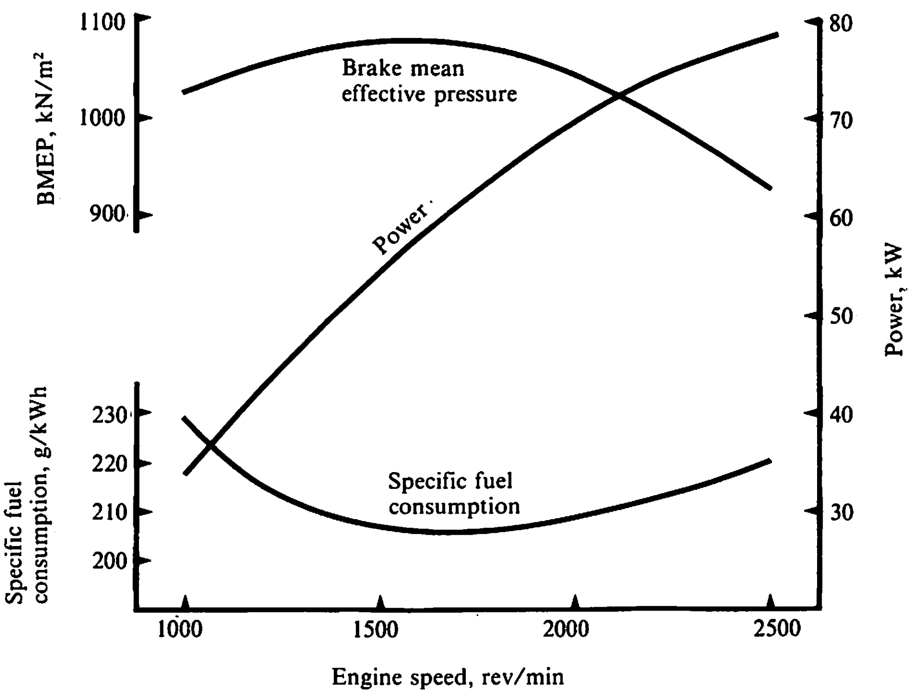
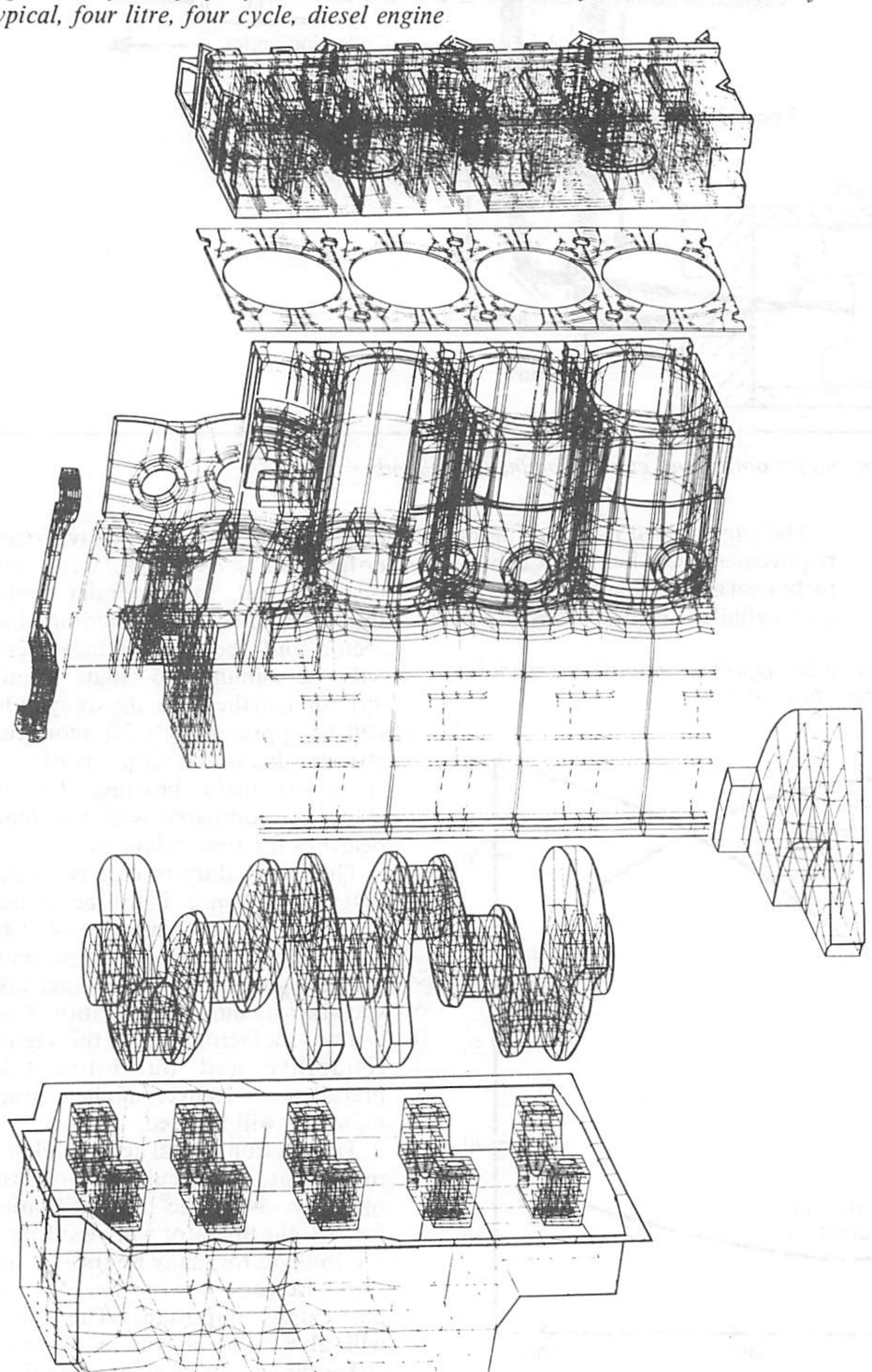


Table 1 Engine performance parameters

Rating	87 kW at 2400 rev/min	
Smoke	1.5 BSU (max torque — max speed)	
Emissions	NOx — 15 g/kWh	EEC test conditions
	HC — 1 g/kWh	EEC test conditions
	CO — 1.5 g/kWh	EEC test conditions
Peak cylinder pressure	12.4 MPa	
Combustion noise	89 dBA	

Significant advances in cab design, in particular, have taken some of the pressure off the power source itself but basic reductions in engine noise will be required for the future. The diesel engine is quieter than in the past but it is not silent and alternatives referred to later do show distinct advantages over the traditional diesel engine. However, in terms of overall suitability for farm machinery, the diesel engine is with us for many years to come and there are considerable advances that can be made to reduce engine noise. In most circumstances, the combustion process dominates the noise spectrum. The rate of pressure rise is the measurable parameter that correlates most closely with noise level; this correlation is demonstrated in fig 10. It is important, therefore, that rate of pressure rise is carefully controlled. Fig 11 shows how rate of pressure rise varied with injection timing and, clearly, a retarded system is the most desirable. Normally, retarding produces unacceptable smoke emission and fuel consumption but revisions to the combustion system can enable full advantage to be taken of the retardability without degrading smoke and fuel consumption (see fig 8).

Fig 9 Basic form of a fully interactive, three dimensional, finite element model of a typical, four litre, four cycle, diesel engine



Engine management

The current level of technology means that the efficiency of machine usage is almost totally related to the skill and experience of the machine operator. More effective use of capital equipment must be a high priority for the future and whilst operator training will help, the real opportunity is to harness advances in technology to improve machine utilisation.

The first stage to give the operator more objective data ie:

- true ground speed;
- instantaneous fuel consumption;
- percentage engine load.

Given this data, the operator can make the appropriate adjustments to improve the running condition of the machine. Developments are underway to provide this information and, without doubt, it will be available to the market place in the very near future.

The next, and more important phase, is to use this information on a closed loop for the control system of the engine ie the fuel injection pump. The fuel injection pump is a complex piece of hydraulic equipment, delivering fuel at pressures up to 50 MN/m^2. The fuel delivery curve is limited to the hydro-mechanical systems available and, hence, the delivery curve does not always match the demand curve. It is possible (although currently complex) to control the delivery curve electronically and, hence, provide total flexibility of delivery on demand.

There are a number of projects

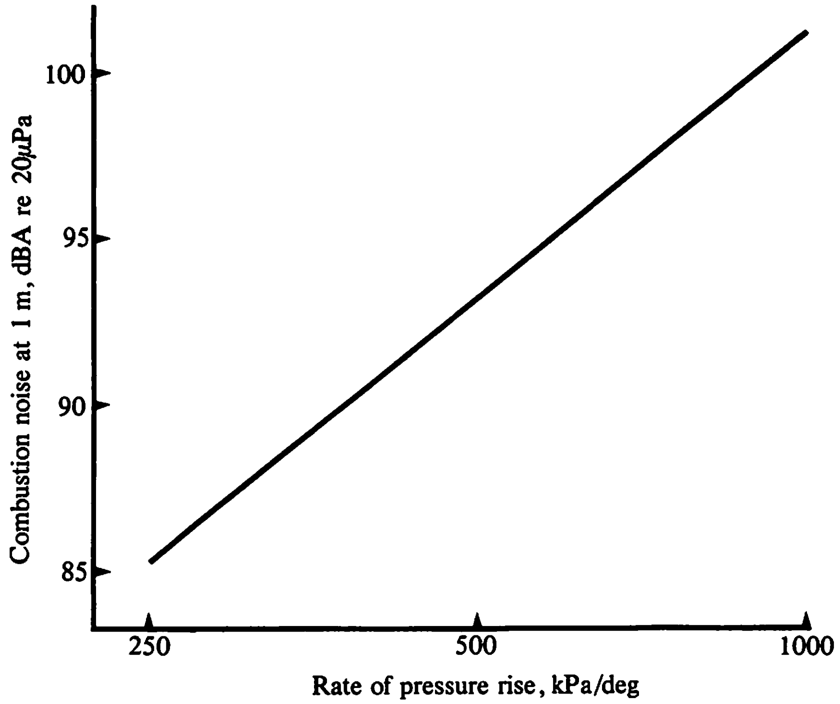


Fig 10 Correlation between the rate of pressure rise and combustion noise

underway within the engine and fuel injection equipment industries to fully develop the electronic fuel injection pump. There are some pumps currently available that boast a degree of electronic control but none can claim full authority control. Such pumps will be available within the next five years but, undoubtedly, will be specified against a very well researched cost versus benefits package. A typical circuit for such a pump is shown in fig 12.

The ability to trim the fuel delivery curve to any set of predetermined parameters means that the following benefits are available:

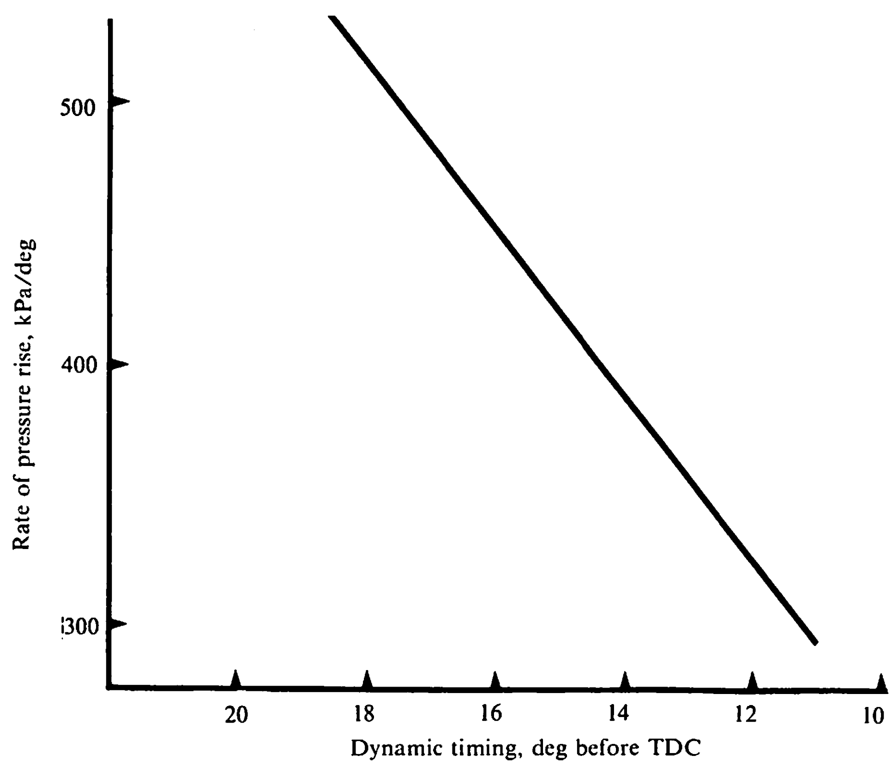
- improved control of emissions;
- superior 'in field' fuel consumption;
- increased tolerance to degraded and alternative fuels;
- diagnostic and monitoring capability.

Additionally, of course, the system provides the required interface with a closed loop, machine management package.

In the long term, it will be possible to 'dial a condition' by building in a number of basic demand/delivery conditions. A typical application could be in the heavy duty sector, where there could be obvious benefits from a 'high power' mode and a 'high economy' mode. The heavy duty tractor is a significant piece of capital equipment and, hence, it should spend the majority of its working life being used to its full potential, ie in 'high power' mode. However, there are times when the same machine may be required to carry out tasks that do not require the high power output. In this case, it would make sense to trim the engine operation to maximum economy by changing the injection timing plan for part load operation or by using a modification to the boost control system to allow the turbocharger to free-wheel and, hence, significantly reduce pumping losses at part load.

There are numerous possibilities for the use of such a powerful, yet flexible, control system and there are probably permutations that have yet to be considered. Electronic control of fuel injection equipment is probably the most significant technical advance that will come to the farm machinery power unit in the next 10 years.

Fig 11 The effect of injection timing on the rate of pressure rise



Alternative and degraded fuels

Currently, engines throughout the world run on crude oil derived, liquid fuels. In future, engines in different parts of the world may run on different fuels, where the local choice is determined by local circumstances.

Fuel derived from coal will be a major energy source of the future in many countries, as will liquified natural gas. In other areas, vegetable oil might be used where the climate and other conditions allow agricultural land to be diverted from food production to growing oil-bearing crops for industrial energy. Similar considerations apply to certain alcohols, which can be distilled from vegetable matter, and gases which can be derived from

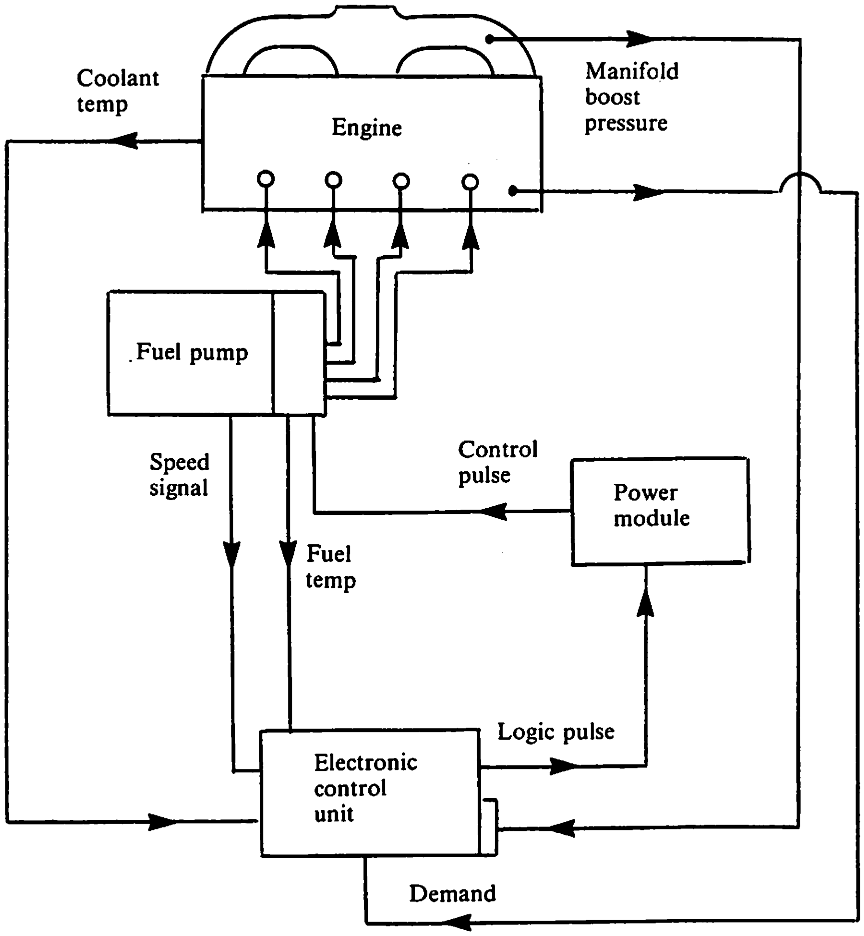


Fig 12 A micro-processor controlled fuel system

sources such as wood chips and coconut shells.

Political and economic considerations — such as a shortage of foreign currency or a desire for economic independence — will also affect the choice of fuel. So will environmental considerations — for example, objections to mining operations or concern about exhaust emissions from certain fuels and/or engine types.

To retain the economies of scale in engine production, to maintain an international engine building industry and to permit the movement of road transport across national and geographical boundaries, the successful engines of the future will have a multi-fuel capability. The diesel engine offers just this facility — the ability to burn a wide range of different fuels at acceptable levels of efficiency and with acceptable power outputs.

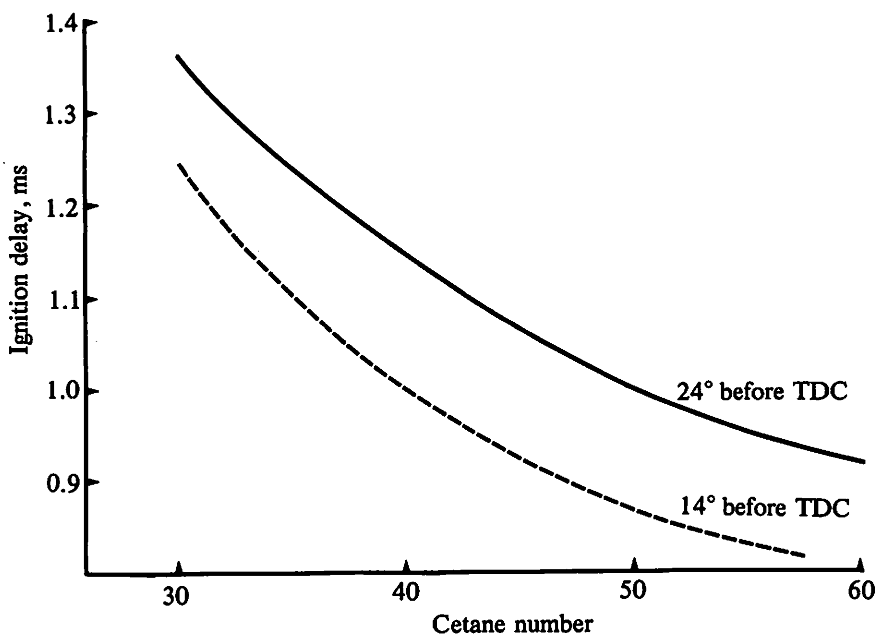
Already the range of fuels that the modern diesel engine will cope with is — of necessity — being extended. There has been an increasing trend in some parts of the world towards a degradation of the quality of diesel oil fuel, because of cost and supply shortages, energy conservation measures and different refinery investment and operating policies. This degradation of the fuel manifests itself in a lowering of the cetane number — a measure of the ability of the fuel to self-ignite under the compression-ignition conditions of the diesel engine cycle.

Low cetane number fuels can give rise to a number of problems in a diesel engine — high noise, excessive wear of pistons and other components, and poor cold-starting ability. British diesel fuel is usually maintained at cetane numbers of between 50 and 56 — yet in many parts of the world, engines are now required to run on fuels with cetane numbers as low as 37. At this low cetane number on standard combustion systems,. the fuel burns directly off the pistons, causing cavitation which leads to quite dramatic piston problems.

One method of coping with low cetane fuel is to retard the injection timing to reduce the delay period. Fig 13 shows the effect of cetane number on ignition delay and how, by retarding the timing 10°, the ignition delay can be 'corrected' to compensate for a 10 point drop in cetane number. This is yet further support for the retardable combustion process.

Alcohol fuels (ethanol and methanol) are becoming available from a number of sources and there is mounting pressure for these fuels to be used. Alcohol is best suited to the spark ignition engine and can be run in traditional engines with only minor modifications. Figure 14 shows the performance of a four litre, four cylinder, spark ignition engine which is running successfully on a sugar plantation in Africa and compares it with the equivalent diesel engine performance. It can be seen

Fig 13 The effect of cetane number on ignition delay



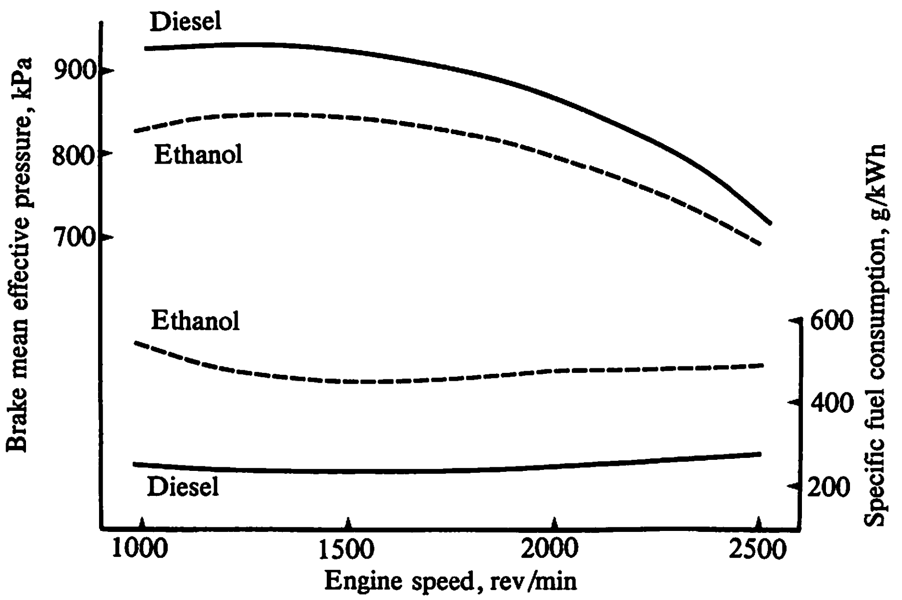


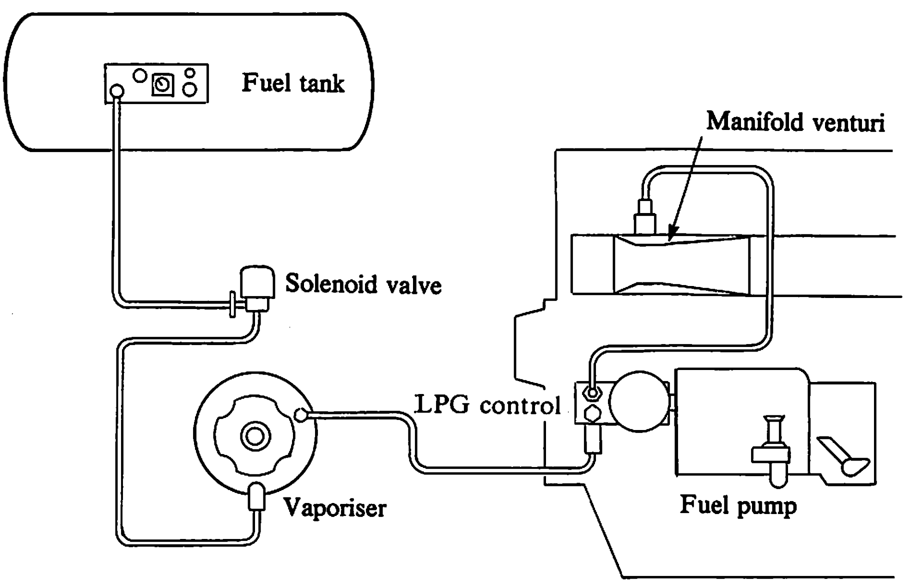
Fig 14 A comparison between the performance characteristics of a spark ignition and a compression ignition, four litre, four cylinder, engine running on ethanol and diesel, respectively

that there is a very wide difference in results. Hence, there is a strong desire to take advantage of the inherent efficiency of the compression ignition engine and use the alcohol fuel. Unfortunately, alcohol has a great affinity for water and, although dry ethanol can be blended with diesel fuel, its tendency to attract water (drawing it from the atmosphere) makes it unsuitable for a diesel extender.

Alcohols can be mixed with diesel oil when the mixture is in the form of an emulsion — ie the alcohol is held in suspension in the oil in tiny sub-micron sized droplets. Keeping the emulsion stable requires the addition of a third component — called a surfactant — and research is currently underway investigating the chemistry of various surfactants. Certain types have been identified which do maintain stable emulsions and engine durability tests are being carried out to evaluate the long term effects of using such a fuel mixture.

Problems associated with mixing two fuels can be overcome by introducing them into the engine cylinder separately — a principle known as dual fuelling. Although this approach is feasible, one difficulty still to be resolved is the need to accurately control the two fuel inputs together, while there could also be a problem with cold starting.

Fig 15 A liquid petroleum gas/diesel dual fuel system



Two systems of dual fuelling are currently under consideration — fumigation and dual injection.

In the fumigation system, a gaseous fuel or carburetted volatile liquid is introduced into the engine inlet manifold. Ignition of the two fuels takes place in the engine cylinder as the result of the diesel compression-ignition cycle. Fig 15 shows the fuel system for such an engine.

A dual injection system uses two completely separate fuel injection systems to introduce two fuels into the cylinder, either together or one after another (though both, of course, within the single compression/expansion cycle). A large quantity of the energy input to the engine can be provided by an alcohol substitute (typically up to 95 per cent), as this system is not 'knock limited'. The main objection to this technique is the necessity to duplicate the expensive fuel injection systems and hence the motivation for using the fuel must be high to overcome this cost penalty.

A further fuel source that is becoming available in isolated cases is vegetable oil — such as sunflower, peanut, soya bean, corn and palm — which have quite high cetane numbers and are good diesel fuels. They all, however, have a tendency to coke the fuel injection nozzles. Chemical modification of vegetable oils, aimed at reducing the molecular weight of one of the main components of the oil, is expected to overcome this problem and preliminary tests have already been carried out.

There is some optimism in the industry that the chemistry of the problem can be overcome. The vegetable oil issue is very much a local one which will be influenced by geographic and political considerations but it is an unsophisticated approach to the fuel problem that can be successful in a compression-ignition engine with no modification, merely increased maintenance.

Long term alternatives

It is difficult to predict the long term future but, over the next 20 years, the trend is definitely evolutionary rather than revolutionary. There are a number of alternatives to the internal combustion engine as we know it and it is likely that there may be special circumstances where these alternatives can be developed ie gas turbines for heavy trucks and some marine applications in the 400 kW range. However, most developments will be aimed at improving the efficiency of internal combustion engines and, as the compression-ignition engine already has a significant advantage over the spark-ignition engine, it is the compression ignition engine that will be the focus of attention.

The four main areas of attention in the quest for greater efficiency will be:

- improved air/fuel mixing;
- greater levels of turbocharging;
- reduced friction and parasitic losses;
- improved thermal insulation.

The first two of these are already a reality for many market sectors, although the agricultural industry has been the slowest to recognise the advantages of turbocharging. This reluctance has now been largely overcome, particularly in the heavy duty sector, and there is evidence of good user acceptance of turbocharged engines down to 60/70 kW. The trend will continue and turbocharged, charge cooled, four litre engines will soon displace the naturally aspirated, six litre engine. The advantages to the user are not only improved fuel efficiency but also lower first cost of the complete machine.

Converting fuel into useful work is the primary task of the engine designer and every kilowatt that can be saved in the mechanical conversion of energy is a corresponding increase in output and efficiency. Table 2 shows how the mechanical losses are made up in a typical tractor diesel engine. It can be seen that there is no single area of design that will have a dramatic effect on parasitic losses without hampering functional efficiency but attention to detail may yield small but significant savings of perhaps 3%. However, the cost impact may outway the advantage, particularly in the Agricultural sector where fuel cost is a small percentage of the overall operating cost. It is likely that these benefits will be pursued for the fuel efficiency gains in the sensitive sectors ie road transport, and that the benefits will quickly find their way into engines for farm machinery.

Table 2 Mechanical losses in a typical diesel engine for a tractor

Friction source	*Power loss, kW*
Pumping loss	7.9
Pistons/rings	4.1
Crankshafts/bearings	1.3
Fuel injection pump	0.7
Water pump	0.5
Oil pump	0.4

There has been much talk in the popular press on the subject of the 'ceramic engine' for the future. Some of the claims are difficult to substantiate and uneconomic to produce. There are, however, significant gains to be made in the selective use of ceramics. Before discussing this aspect of engine design, it is important to understand the energy balance of a typical naturally aspirated, one litre/cylinder, diesel engine. It can be seen from table 3 that the 'wasted' energy is dissipated roughly equally between cooling and exhaust systems. Moving to materials with high insulation properties, ie ceramics, in the combustion area does little other than change the balance. Whilst there may be some benefit in such a change for some specialised applications, the cost penalty of the ceramic coatings, etc far outweighs any improvement in engine performance. Hence, we are unlikely to see this technology applied to naturally aspirated engines.

Table 3 Energy balance for a diesel engine

Energy dissipation	*% of total*
Power	36
Exhaust	29
Coolant	25
Convection/radiation	10

If the ceramics are going to pay their way, then the extra energy in the exhaust must be used and so the turbocharged engine is a candidate for modification. With attention to detail, it is entirely possible that efficiency improvements in the order of 20/25% are achievable and a significant amount of development work is underway in the industry to turn ideas into economic reality.

There are other benefits to the application of ceramic technology to components in the combustion area, namely:

- reduced emission on 'start-up';
- potential for more severe/ turbulent combustion chamber design;
- weight saving on reciprocating components.

These benefits, combined with the basic efficiency improvement, will justify the resource that is required to develop the technology. There will inevitably be a cost penalty on the engine but the tangible benefits will more than compensate for this initial cost increase.

Conclusions

The diesel engine will continue to be the primary power source for the Agricultural Industry for the next 20 years. The major characteristics that will be required for the future are:

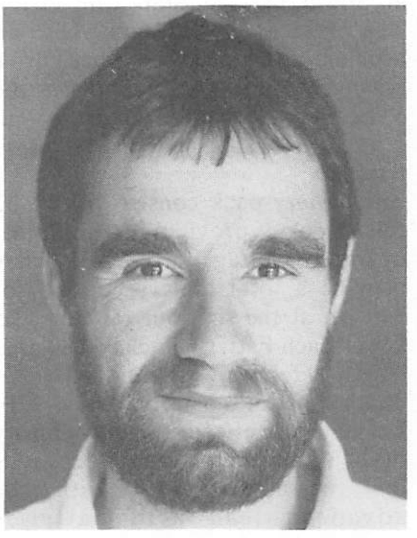
- greater levels of turbocharging;
- reduced parasitic losses;
- ability to run on degraded and alternative fuels;
- improved overall efficiency;
- greater standardisation of parts within the engine family concept;
- greater flexibility in fuel delivery to meet varying power demands.

Reference

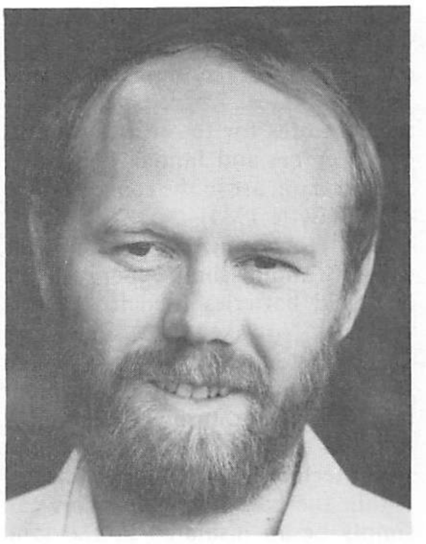
Haddad S, Watson N, Editors (1981). *Design and applications in diesel engineering.* Publ Ellis Harwood Ltd.

A battery powered tractor

R Alcock and L L Christianson



Ralph Alcock



Les Christianson

Introduction

Battery powered vehicles held a position of considerable prominence amongst automobiles at the turn of this century; indeed, a battery powered car held the world land speed record of 105 km/h in 1899 (Vincent 1984). The advent of the internal combustion engine, run on petroleum based fuels, saw the gradual demise of the battery powered vehicle. In evaluating the performance of a battery powered car for the Mercedes Company in 1914, the test engineer concluded: "the electromobile cannot compete, on a technical basis, with petroleum fuelled vehicles and can only be considered for specialised applications" (Riedler 1914). These remarks are equally applicable to the petroleum and battery powered vehicles of today. The battery powered automobile is unlikely to gain acceptance as long as the petroleum fuelled versions are able to provide a basis for comparison. Table 1 (Alcock 1983) provides further evidence of the limitations of the battery as an energy source for vehicle applications. Energy densities of some commonly used fuels are compared on the basis of their energy equivalency to 100 litres of petroleum. The efficiencies given represent those associated with the conversion of secondary energy forms into mechanical energy at the power unit. This table does not include any consideration of the efficiency of conversion and distribution of primary energy sources, nor does it include the efficiency of the vehicle transmission systems. Despite the better energy conversion efficiencies of battery powered systems, a large battery mass is required to provide a similar vehicle range.

In spite of these limitations, the battery powered vehicle has considerable potential for repetitive tasks carried out within some identifiable range of its recharging point. The most prolific use of electric vehicles for commercial applications is in England where approximately 35,000 electric milk floats are in daily service. In addition, a number of battery powered trucks are used for street cleaning, refuse collecting and the retail delivery of goods. In the US, the postal service has converted over 300 of its ¼ tonne delivery trucks to battery power and the coal mining industry has for some time used battery powered vehicles for scooping and hauling coal, as well as carrying personnel (Anon 1981).

The advantages of battery powered vehicles are that they are quieter, have no exhaust emissions, are mechanically simpler and can deal with short duration overloads more effectively than vehicles powered by internal combustion engines. Lucas Chloride has developed several electric systems for commercial applications. A Lucas vehicle with a payload rating of two tonnes uses a 420 Ah capacity traction battery operating at 160 V. The traction motor is separately excited with a rating of 50 kW. This vehicle has a gross weight of 6.6 tonnes, a maximum speed of 65 km/h and a range of 70 to 90 km. A one tonne payload vehicle developed by Lucas in conjunction with Bedford Commercial Vehicles Ltd has a 216 V traction motor with a 188 Ah battery capacity and a 40 kW drive motor. This vehicle has a gross weight of 3.5 tonnes, a maximum speed of 80 km/h and a range of 80 to 100 km (Anon 1983).

The diesel engine has become the most popular power source for

Ralph Alcock and Les Christianson are both employed by the Department of Agricultural Engineering, South Dakota State University, Brookings, SD57007-1496, USA.

They are joint leaders on a research project to design, build and test a battery powered tractor.

Table 1 Comparison of fuel energy densities

Fuel source	*Energy density, MJ/kg*	*Conversion efficiency assumed*	*Fuel mass equivalent to 100l petrol, kg*
Petroleum	44.2	0.20	74.1
Diesel	43.0	0.26	58.5
Lead-acid battery	0.086	0.504*	15,112
Advanced lead-acid battery	0.135	0.504*	5656–9627

**A battery charge-discharge efficiency of 0.7, a controller efficiency of 0.9 and an electric motor efficiency of 0.8 were assumed. These are cited as typical efficiencies by the respective manufacturers, viz: – General Battery Corporation, Reading, Pennsylvania; Cableform, Stockport, Cheshire; and General Electric Company, Erie, Pennsylvania.*

agricultural tractors. It provides some torque "back-up" with fall in engine speed, but its power output characteristic is not ideal. It also has disadvantages due to inherent noise levels and atmospheric pollution. The diesel powered tractor can also be difficult to start in cold weather which is particularly disadvantageous to operators in the north central United States where mean daily temperatures for the winter months of December and January, based on 30 year data, are in the range of -6 to -13°C (Lytle 1984)

Low temperatures will reduce the capacity and discharge energy of the lead-acid batteries used for electric vehicles. Nowak (1983) found an optimum temperature of 38°C and suggested a minimum ambient battery temperature of 25°C. A solution to this problem is to adopt some technique of thermal control within the battery region. This can simply be an insulated box around the batteries but it might also incorporate a heating system using a thermally controlled battery tray.

A battery powered tractor offers advantages in terms of noise and pollution. It also provides for the use of alternative fuels in the generation of electrical energy required to recharge the battery cells. A series wound dc traction motor is capable of overcoming overloads for short periods of time. The traction motor installed on an electric tractor developed at South Dakota State University can operate at 200% of rated power for a period of four minutes and at 150% of rated power for ten minutes. The low energy density of the battery means that this battery powered tractor is unsuited for extensive field work. However, there are many "chore-type" tasks to which the battery powered tractor is well suited. A study by Resen *et al* (1980) suggests that up to 50% of tasks on eastern South Dakota farms could be performed by a battery powered tractor. Similar projections were made for those farms in other parts of the US where smaller and more intensive farming systems are the norm. The battery powered tractor is suited to "chore-type" tasks such as hauling, scraping, feedlot operation, etc (Alcock *et al* 1981, Alcock and Calkins 1983). It is readily identifiable with those tasks which are associated with materials handling to and from the field, around the farmstead, and as an integral part of intensive systems of agricultural production.

The SDSU "Electric Choremaster" tractor

In September 1983, work on the design and construction of a battery powered tractor began in the Agricultural Engineering Department at South Dakota State University. The vehicle configuration is an articulated frame, four wheel drive arrangement and is based on the Versatile 150* utility tractor (fig 1).

Batteries

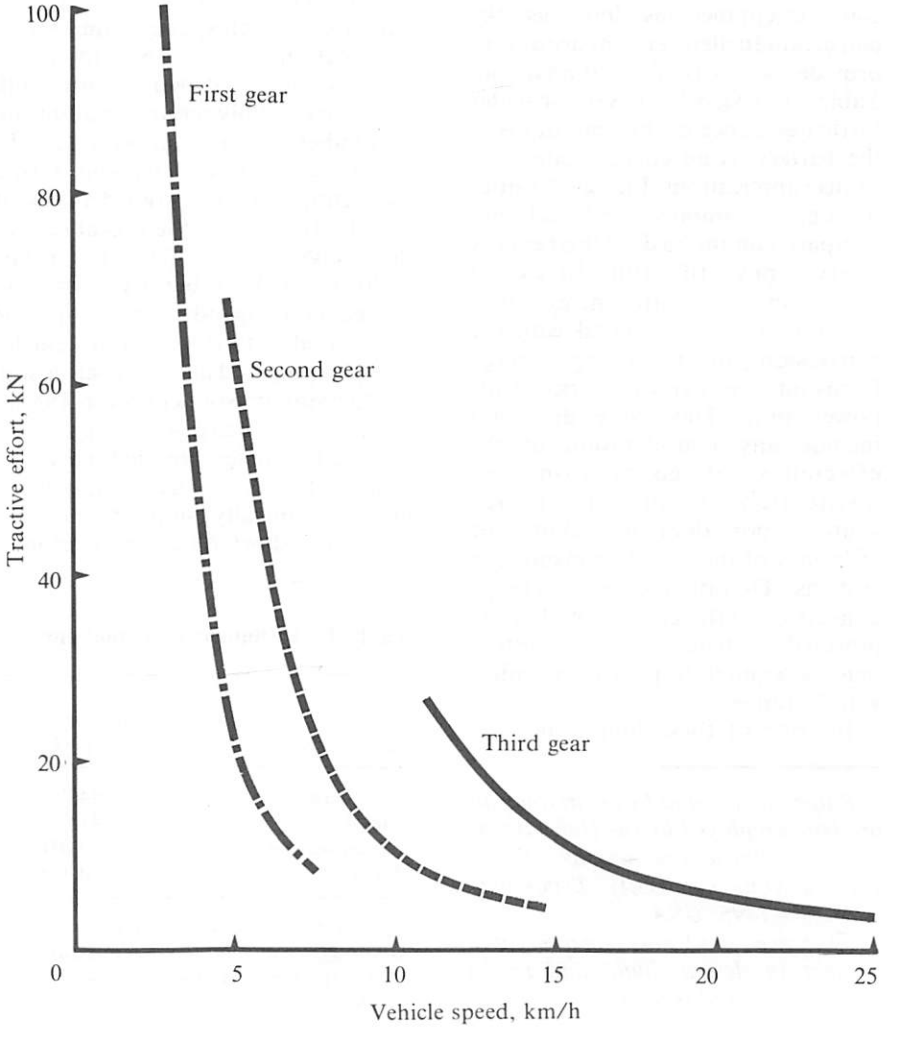
The battery pack consists of two 32 cell blocks, providing a nominal operating voltage of 128 V. They provide a total battery capacity of 340 Ah at the six hour rate, or 43.5 kWh. Each battery block is 0.89 m in length, 0.5 m in width and 0.59 m in depth. The total battery mass is 1914 kg, giving an effective energy density of 24 Wh/kg. This energy density is low when compared with the advanced lead acid batteries developed by Lucas Chloride, which have an effective energy density of 38 Wh/kg (Vincent 1984).

Fig 1 South Dakota State University battery powered tractor

Electric Motors

Two series wound dc motors were used, one for traction, and one for the pto and hydraulic pump. Both motors are protected by time-delay fuses and high speed cutout switches. The traction motor was wound to provide the torque characteristics required. The tractive effort versus speed curves for the vehicle are given

Fig 2 Tractive effort in relation to vehicle speed (battery powered tractor)



in fig 2 and the characteristics of the traction motor are shown in fig 3. The operating speed range of this motor is, for all practical purposes, between zero and 2750 rev/min and operation at speeds above 2750 rev/min is prevented by the "overspeed" switch. A speed control unit mounted in the tractor cab is used to provide infinite speed variation within the operating range. The traction motor has a one hour rating of 37 kW, and can also supply 81 kW for 3.3 minutes. Thermistors in the motor frames are used to control the operation of two small, twelve volt blowers for cooling both the traction and pto/hydraulic motors. The pto/hydraulic motor is rated at 17 kW for 1 hour and has overload characteristics similar to the traction motor. In the present vehicle, this motor drives a hydraulic pump for steering and hydraulics, as well as the power take-off shaft. The hydraulic pump is fitted with a priority valve to ensure oil supply to the steering rams. This arrangement is satisfactory for our current purposes of testing the vehicle; however, the installation of a third, fixed speed, motor to power the hydraulic pump independently of the power take-off shaft is being considered.

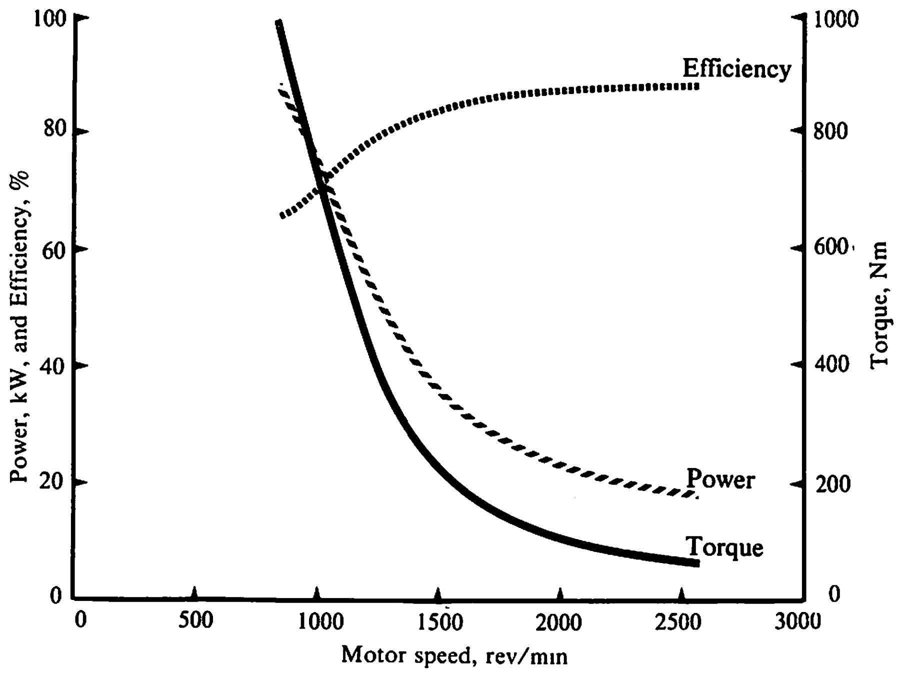


Fig 3 Electrical traction motor characteristics

Controllers

Speed control of the traction and pto/hydraulic motors is provided by two separate SCR (silicon controlled rectifier) controllers. The controller for the traction motor also has a "by-pass" contactor and a by-pass circuit for full speed operation. This arrangement avoids the energy drop across the controller at maximum speed of the traction motor. The controller for the traction motor can provide 265 A continuously (producing 34 kW) and 550 A for five minutes (providing 70 kW). The controller for the pto/hydraulic motor gives 250 A continuously (26 kW) and 475 A for five minutes (61 kW). Two lever actuated potentiometers positioned in the tractor cab enable the operator to independently adjust the speeds of each motor. A reversing switch, operated from a cam on the speed control lever, allows the operator to change the direction of the traction motor for quick and easy reversing of the tractor. The reverse mode can also be used to provide a braking effect against the direction of travel. Both motors used are sensitive to change in load, resulting in a reduction in motor speed as the load is increased, as shown in fig 3. This non-linear relationship between motor torque and speed is typical of that expected from a series wound, direct current electric motor. This characteristic is advantageous in terms of maintaining a constant power output, but small load changes will produce a significant drop in motor speed. This disadvantage has been countered by the installation of a feedback circuit that allows a set motor speed to be maintained. This was accomplished by varying the motor voltage, via the controller, in accordance with a change in output speed resulting from an applied load. The motor responds to a mean voltage which is determined by a combination of frequency and pulse width modulation by the controller.

Transmission

The output from the traction motor is connected to a three speed transfer box and then to the front and rear differentials. Power is transmitted from the differentials through reduction gear boxes mounted at each wheel. The overall gear ratios and associated speed ranges are given in table 2. In addition to the braking effect provided by the controller, a hydraulically operated caliper brake acts on the drive shaft to act as a parking-brake and to provide for emergency braking.

**Footnote. Reference to a manufacturer does not imply any endorsement of that company or its products by the Agricultural Engineering Department of South Dakota State University.*

Table 2 Tractor transmission ratios

Gear	*Overall ratio*	*Speed range, km/h*
1	72:1	0 - 8
2	36.4:1	0 - 16
3	17.67:1	0 - 24

Battery management

Instrumentation provided in the cab displays the state of key components. A voltmeter registers the battery voltage at the controller and ammeters display the current drawn for both the traction and pto/hydraulic motors. Also included are tachometers for each motor. An important item of instrumentation is the "fuel gauge" which gives the operator a useful indication of the state of charge of the battery. Initial battery condition is used as a reference point and from this value the watt-hour consumption is subtracted. When the battery has discharged to 20% of its rated capacity, an indicator light flashes on the "fuel gauge".

The battery condition is also checked from the electrolyte specific gravity readings. Specific gravity of the electrolyte in all of the cells is measured once per month. In addition, the specific gravity in two pilot cells, one in each battery block, is checked on a daily basis. The battery is re-charged when the battery capacity has been reduced to 20 percent of its nominal rating. Recharging takes from six to eight hours, depending on the discharge state of the battery.

Tractor performance characteristics

The Versatile 150 utility tractor uses a hydrostatic drive, in combination with a three speed transfer box to provide power to the drive wheels. Characteristics of this transmission system are illustrated in fig 4. The tractive effort in relation to speed curves shown for the three, transfer box, gear ratios provide the capability of obtaining a constant power output of 40 kW. The theoretical curve relating tractive effort and vehicle speed for a constant power output of 40 kW is shown in fig 5. The general shape of the curve in fig 2 is similar to that for the theoretical relationship (fig 5). The efficiency, output power and output torque characteristics for the hydrostatic drive found on the Verstaile 150 are given in fig 6.

The electric traction motor provides superior efficiency and a better torque characteristic. The torque improvement at low motor speeds is particularly evident and is perhaps the major consideration since the ability to cope with temporary overloads, rather than maintain a constant power output, is the major advantage of the electric tractor. Tests are currently being conducted to determine the energy efficiency of the electric powered tractor in comparison with a diesel tractor performing the same tasks. It is envisaged that the energy efficiency of the electric powered tractor will show a considerable improvement over that obtained for the diesel powered tractor. Tests will also be conducted to determine the operating range of the electric tractor. Computer modelling, in which the vehicle was repetitively sequenced through a fixed duty cycle until the available battery energy had been used, suggested that the vehicle will operate effectively for a period of four to six hours depending on the nature of the tasks. Pertinent dimensions of the electric tractor, including the static weight distribution, are given in table 3.

Fig 4 Tractive effort in relation to vehicle speed (Versatile tractor)

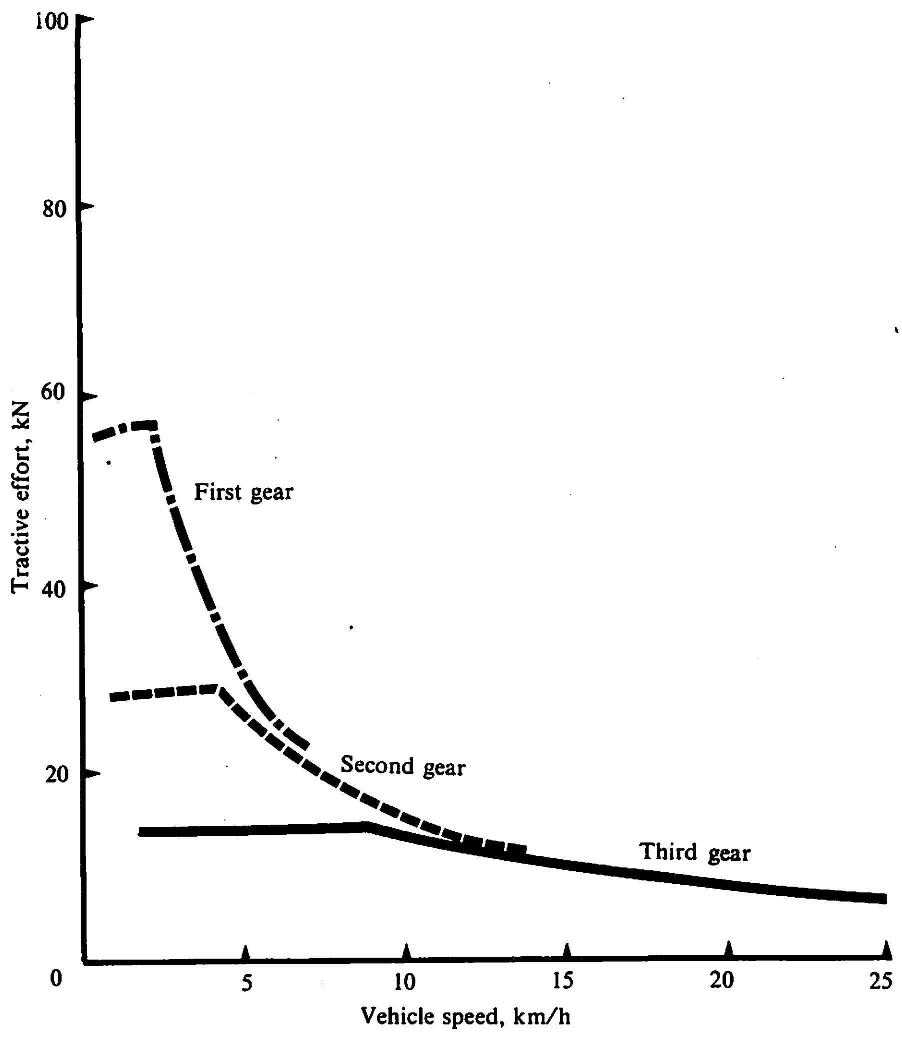


Table 3 Tractor dimensions

Wheelbase	2.03 m
Overall length	3.66 m
Overall height	2.90 m
Nominal turning radius	3.07 m
Tyre size	340 x 610 mm
Static weight on front (including loader)	24.197 kN
Static weight on rear	30.690 kN
Total static weight (including loader)	54.887 kN
Battery mass	1816 kg

Summary and conclusions

A battery powered tractor suitable for chore tasks has been constructed at the Agricultural Engineering Department of South Dakota State University, and is currently being tested to determine the efficiency of the charger and controller, the response of the control system and the effects of battery parameters, such as state-of-charge and electrolyte temperature, on the vehicle performance. The characteristics of the electric motor and controller, in conjunction with the three speed transfer box, provide the potential for a constant power output, with infinitely variable vehicle and pto speed control. The ability of the electric motors to cope with short duration overloads is seen as a unique advantage for the electric tractor. In addition, the vehicle operates with a relatively low noise level, and is virtually pollution free, making it suitable for operations within confined areas and near livestock. The electric tractor described is seen as also having potential for materials handling in the logging, mining and building industries since these load characteristics are well suited to its capabilities. This is important because it now seems appropriate to design mobile equipment which has applications for many industries and which is suited, or easily adapted to the needs of the agricultural industry.

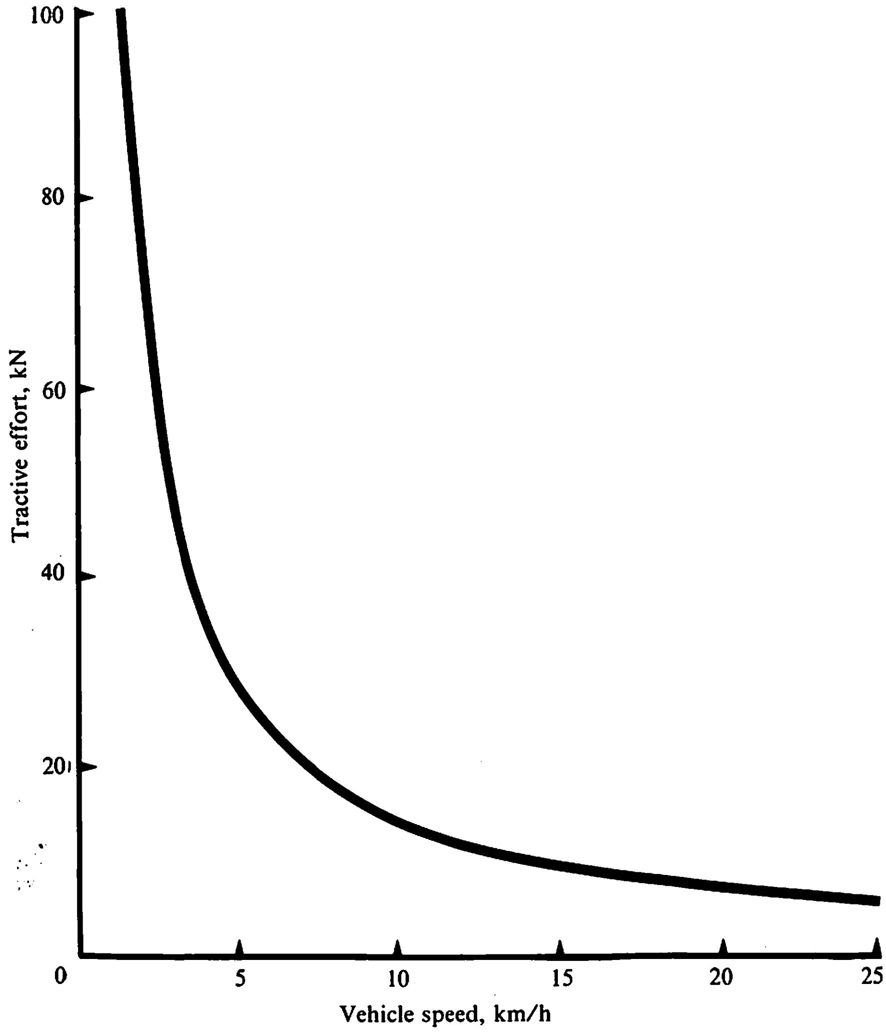


Fig 5 Theoretical curve for constant power output

Acknowledgements

The National Rural Electric Cooperative Association and the South Dakota Agricultural Experiment Station provided financial support for this project. The authors also wish to recognise the assistance of Professor Wayne Knaback and Dennis Helder of the Department of Electrical Engineering, as well as the students who contributed to various stages of this project.

References

Alcock R (1983). Battery powered vehicles for field work. *Trans Am Soc agric Engrs.* **26,** 10–13.

Alcock R, Buck N, Hughes H (1981). Electric vehicles: assessment of potential for South and Eastern United States farm operations. Paper No 81-1548. Am Soc agric Engrs.

Alcock R, Calkins P (1983). Linear programming models for assessing electric vehicle potential in agriculture. *Int J Energy Systems*, **3,** 6–10.

Anon (1981). Electric and Hybrid Vehicle Programme. 4th Annual Report to Congress for FY 1980, US Dept of Energy, Office of Transportation Programmes, DOE/CS-0/30/4.

Anon (1983). Lucas Chloride E V Systems. Lucas publ No 4135.

Lytle W (1984). Personal communication. Meteorologist, Agric Engng Dept, South Dakota State Univ.

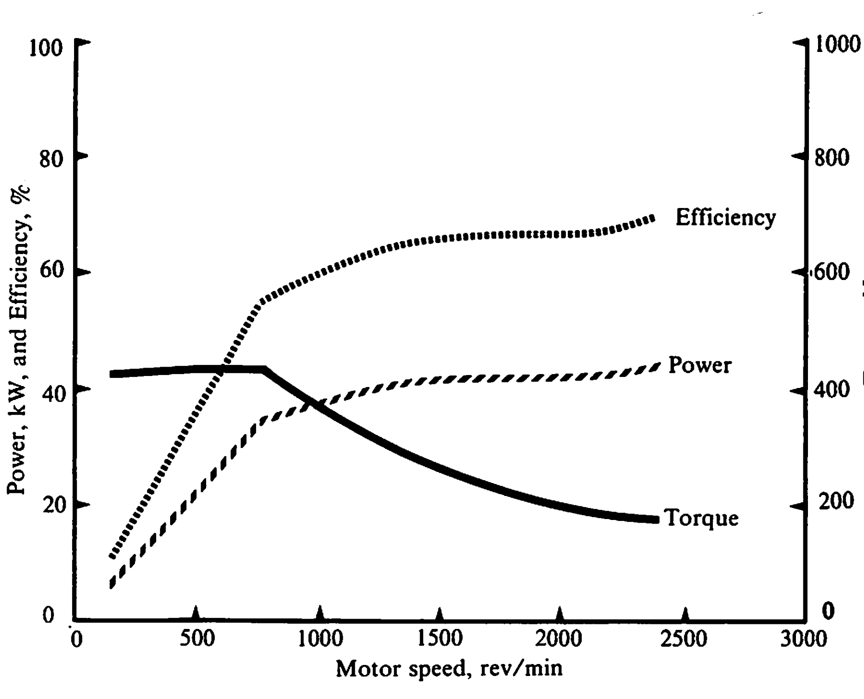
Nowak D K (1983). Methods to improve electric vehicle performance at low temperature based on an analysis of battery tests. Proc Electric Vehicle Council Expo '83, Paper No 8338, EVC 1111 19th Street, NW, Washington, DC 20036.

Riedler A (1914). The scientific determination of the merits of automobiles: report V, investigations of a Mercedes electromobile. General Oil Publ Co Ltd, Broad St, London. Republ 1951.

Resen M, Christianson L L, Healy, R (1980). Electric vehicles — assessment of potential as it relates to farm size. Paper NCR 80-201, Am Soc agric Engrs.

Vincent C A (1984). Battery research is back in business. *New Scientist,* 29 March, 34–39.

Fig 6 Diesel engine and hydrostatic transmission characteristics



Ergonomic workplace assessment with the aid of a computer program

D H A Zegers

Introduction

The activities of ergonomics are directed towards the improvement and/or designing of work situations in such a way that human capacities and limitations are being taken into account as far as possible. One part of ergonomics involves the assessment of work situations with special reference to human dimensions and the space occupied by man, or which he requires at a given workplace — the anthropometry. The present article deals in some detail with the use of the computer program ADAPS as an aid in the assessment of a workplace.

ADAPS

ADAPS is a package of an interactive-graphic computer program and stands for Anthropometric Design Assessment Program System; it is a software package developed by the Technical University at Delft (Technische Hogeschool, Delft) and acquired by the Instituut voor Mechanisatie, Arbeid en Gebouwen (IMAG) for agricultural application in workplace assessment and workplace design, with special reference to the specific agrarian user population. This means that this package can be adapted for the assessment of existing workplaces, for example, the assessment of the layout of tractor cabs. At the same time, the package can be employed in the assessment at the design stage of prototypes. Points requiring attention for redesigning may then be identified, so that modifications can be made at an early stage.

The ADAPS package consists of the following three computer programs:

Ir Didi Zegers is a research worker in ergonomics at the Instituut voor Mechanisatie, Arbeid en Gebouwen, 6700AA Wageningen, The Netherlands.

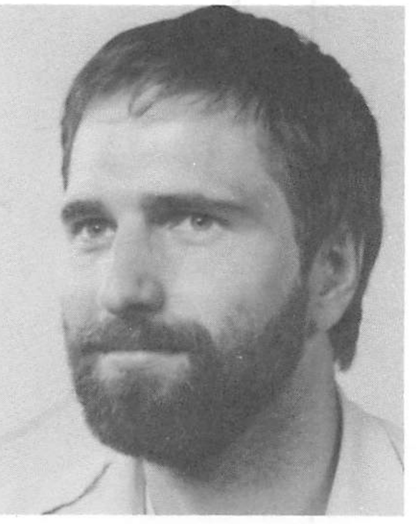
(a) DATA: an input program for the data of the anthropometric model;
(b) WPL: a program for processing workplace data and for displaying the latter graphically;
(c) MAN: the main program, in which the anthropometric model together with the diagram of the workplace can be displayed and manipulated on a graphics screen. There are many possibilities for viewing the whole from all possible viewpoints.

Each anthropometric model and workplace model has its own data base. While the main program is running, the data of the anthropometric model are interactively accessible for amendment and processing. Dimensions and attitudes of the model can also be put on the graphic display, for example, by a light spot indication, rotation of a control knob and introduction through a keyboard. Before the diagram of the workplace can be generated on to the screen, the ("draft") diagram must first be described in three-dimensional co-ordinates and fed into the data bank. In order to be able to assess a workplace, it must first be established which user population is represented by the anthropometric model (eg average height of the body and maximum deviation).

The anthropometric model is based on the description of the body structure, based on the functional system of limbs, which represents the geometry of movement of the human skeleton.

The system comprises five linearly ramified kinematic chains, consisting of non-deformable limbs, pivoting about centres of rotation or fulcrums (fig 1).

With respect to the system of limbs, 144 surface points have been defined, which fix the three-dimensional form of the body (fig 2).



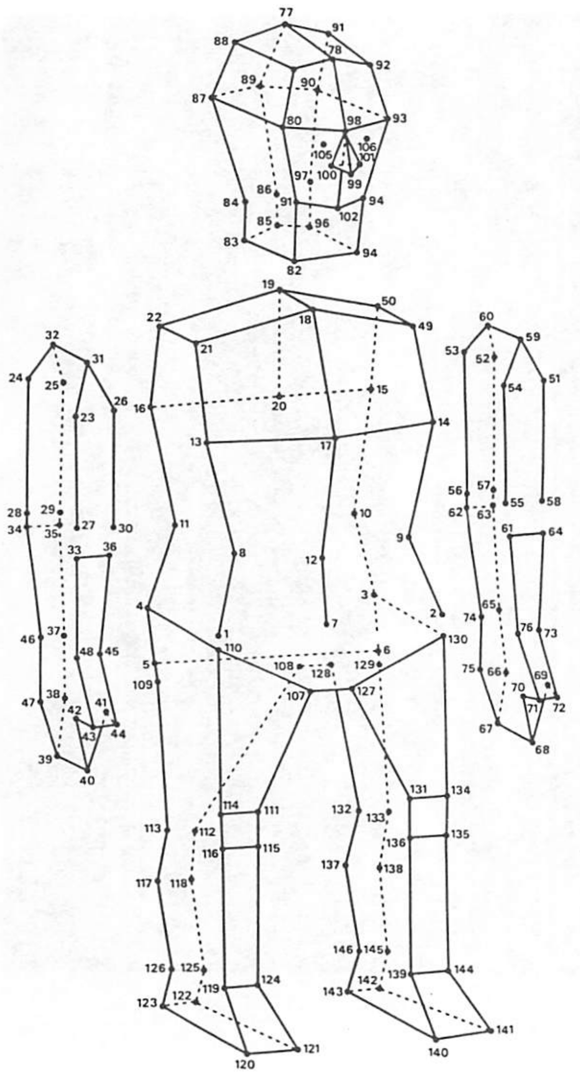
The body dimensions of the model can be varied in three different ways.

(1) The length of the limbs can be determined separately, as a result of which the proportions of the body can be varied.
(2) The positions of the surface points can be varied, this having the effect of changing the shape of the body.
(3) The whole body can be scaled on the basis of the body height. This enables one to start from a normal distribution, determined by the mean and standard deviation.

Computer program versus other aids

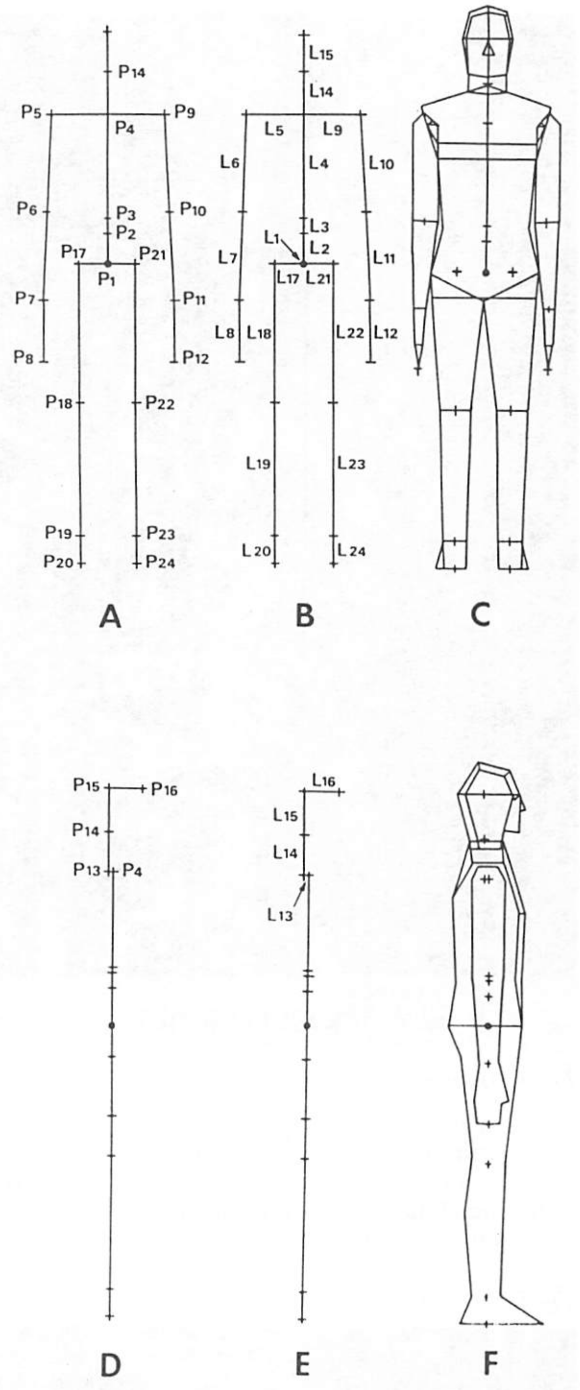
The use and benefit of working with a computer as a technique for ergonomic workplace assessment have to be weighed against traditional means of processing anthropometric data. Tables, graphs and nomograms can often not be used directly, but require interpretation, selection and reproduction in a more concrete form. In practice, some useful aids are being employed for this purpose (fig 3), such as

(1) dimensional drawings (Diffrient, *et al* 1981);
(2) stencils (Jenner *et al* 1982);
(3) two dimensional manikins.



Man 4

Fig 1 Structure of the limb system



Man 4

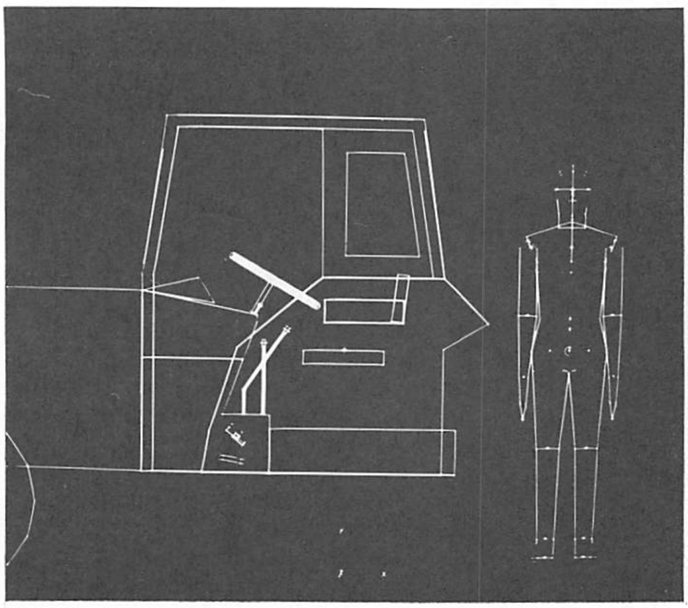


Fig 2 (above) Diagram of the anthropometric model

Fig 4 (left) Initial attitudes of the anthropometric and workplace models

These aids are simple and satisfactory in use, but are able to reproduce the human variety in sizes and attitudes only to a very limited extent. They are not suitable for the simulation of movment and the play of forces. Use of a computer has the following advantages:

(a) storage and processing of anthropometric and workplace data;

(b) visualisation of the anthropo-

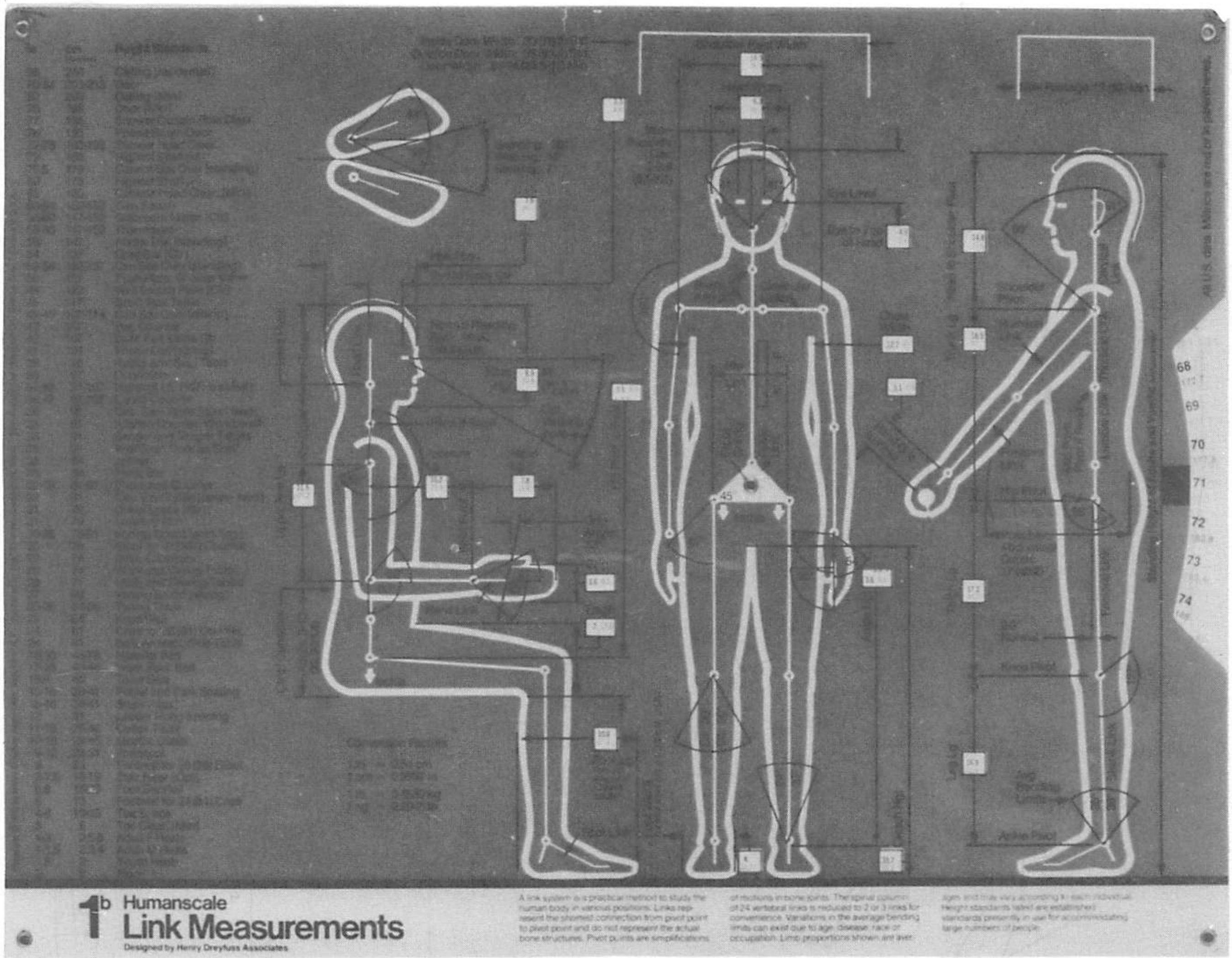


Fig 3 Anthropometric aids

metric model (shape of body, attitude) in the workplace model;

(c) simulation of movement and force transmission;

(d) flexibility: many alternatives can be tested in a short time (also at an early stage in the designing process).

Fig 5 Side view of the posture turning backwards

Practical example

The reproduction of a tractor (Ford 7000, see fig 5) was chosen as an example. Using a set of photographs of the real work situation, on the one hand, and a picture of the graphics screen, on the other, the agreements and differences were indicated. In reproducing an image of the tractor on the graphics screen, care must be taken to generate a realistic picture of the actual situation. A compromise must then be found between the degree of detail and clarity. The meticulous representation of excessive details of the workplace will reduce the clarity of the diagram and is not justified because of the lack of a 'hidden line' algorithm. Therefore, an optimal representation should be able to produce a different image for each workplace, depending on the need for detail.

Analysis of the layout of the workplace can be carried out in a number of stages.

Stage 1: First assessment of the entire space (see figures 5

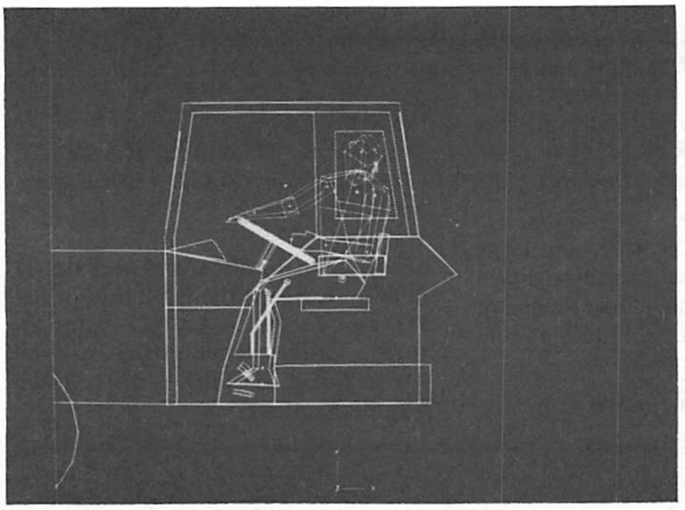


Fig 6 Side view of the anthropometric model in the posture turning backwards

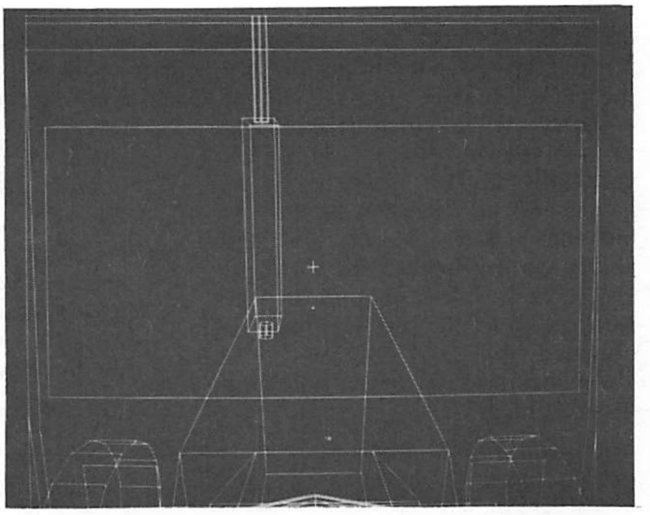


Fig 8 Field of vision generated by means of a computer program

and 6). At this stage, an overall impression is obtained of possible trouble spots, ie points requiring closer attention. For example, this may have something to do with the difficult accessibility of some controls, or restrictions of the field of vision (figs 7 and 8).

Stage 2: Points for attention identified in Stage 1 can be subsequently subjected to closer examination. For this purpose, only the relevant parts of the workplace need to be retained (see fig 9). At this stage, it is possible to investigate precisely what attitude is necessary to be able to operate given controls.

Stage 3: The desire may arise from Stage 2 to analyse the consequences of the layout of controls. By a simple operation, parts of the workplace can be displayed, added or removed rapidly. Using this mode of approximation, it is possible to produce a workplace that is optimal for the tractor driver.

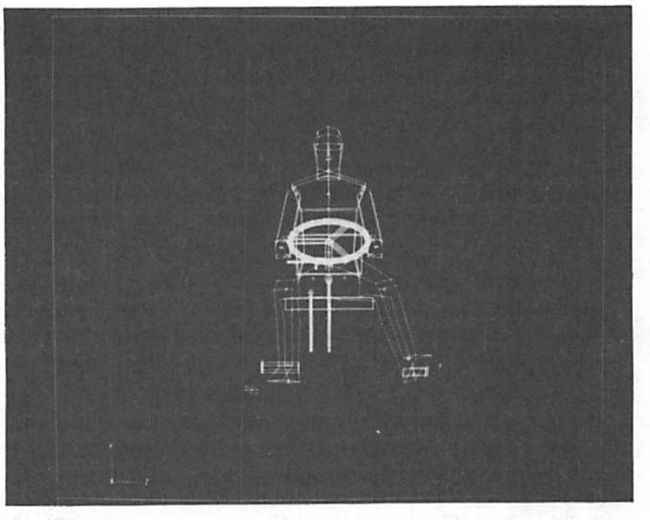


Fig 9 (right) Example of a detail of the workplace

Fig 7 (below) Photographic approximation of the field of view of the tractor driver

Discussion

With the aid of the example described above and the relevant photographs, it has been attempted to reproduce visually the differences and agreements between a photograph and a graphic representation of an existing workplace and attitudes.

These examples show that it is possible to produce realistic images by means of the graphics screen, with a specific choice of detail. In particular, the ability to assess the workplace interactively and three-dimensionally provides many more possibilities and a better insight into the workplace than when using other aids. Another advantage is the ability to vary the anthropometric model; variations in, for example, body height and postures can be quickly introduced and assessed. With the ability to reproduce the field of vision, a realistic picture of the workplace (with the controls) is obtained.

Against this there are the following disadvantages:

— operation of the ADAPS package makes minimum demands on the hardware (such as mini-computer with graphics screen plus accessories) and the software (such as FORTRAN compiler, GPGS graphics package and ADAPS).

— working with this package demands a certain familiarization period and a basic knowledge of working with computers and satellite equipment.

— the representation on the graphics screen remains in the form of a model.

References

Diffrient N, Tilley A R, Harman D, (1981). *Humanscal 1/2/3.* Mitt Press, Massachusetts.

Jenner R D, Kaufmann H, Schafer D (1982). Bosch-Arbeitshilfen fur die ergonomische Arbeitsplatzgestaltung; Zeichenschablonen für die menschliche Gestalt. Robert Bosch Gmbh, Stuttgart.

Book Reviews

Classic farm tractors

Michael Williams
Publisher: Blandford Press, Poole, Dorset, 1984. ISBN 0 7137 1421 2. £9.95.

THIS is the author's companion volume to *Great Tractors* (published in 1982 by Blandford Press) which was reviewed in THE AGRICULTURAL ENGINEER, Vol 37 No 4 1982. In this slightly shorter volume, the author has followed his previous style, providing thirty-one excellent quality colour plates of different tractors supported by black and white photographs, both new and old of the period. There is perhaps not quite the amazing variety of machines in this book compared with those shown in *Great Tractors,* but there is still a fascinating array of tractors covering about eighty years of tractor development from around 1900.

The black and white photographs are intriguing — showing as they do glimpses of the characters and machinery of a past era. For example, the man with cap, gloves and bow tie ploughing with his Allis-Chalmers General Purpose and "General Kitchener" driving his IH Mogul 8-16. With our improved concern about the safety of individuals, one might view with some trepidation the man and dog team operating a manual stump jump plough behind Kerosene-Annie and the individual, with daughter on knee, seated operating the levers of a cultivator pulled by the Ronaldson-Tippett.

Another message which comes over clearly in Mr. William's book is the ingenuity and inventiveness of designers who were often it seems far ahead of the engineering technology of their time. Can you really have a three-wheel tractor with each wheel having a different diameter? The Bull Tractor Company achieved this with great success even providing a means of levelling the tractor while ploughing and, as one photograph shows, a steering system which allowed the driver to work "hands off" for appreciable periods.

An example of "if you can't beat them, join them" was the Line-Drive. This quite unconventional tractor was a blatant attempt to prise the farmer away from his much beloved horse. Control was via two lines which operated a turntable upon which all the main components were situated. The Tom Thumb was also an unusual design, with traction provided through a single track. Outrider wheels balanced the whole thing, while turning was achieved by raising the front of the track off the ground.

It is soon apparent that this book does indeed provide a history of tractor design and development and shows us the pedigree of modern day tractors. Some of this pedigree is seen in the Wallis Cub Junior produced in 1913; here was the first design which made use of a rolled steel frame forming a rigid structure to which other components could be attached. We are also shown the forerunner of some of our present single pass systems, the Once-Over. This tractor had plough, rotary cultivator and soil injection system, the latter introducing carbon dioxide to promote the release of plant nutrients. An ingenious steering system was also employed which would literally turn circles round our present day tractors.

The author shows us that in 1922, International Harvester provided us with a vision of the future. Here we see the Farmall, the first really universal and versatile rowcrop tractor having a shape which is immediately familiar and which has lasted to the present day.

The first diesel engined tractor was introduced by Francesco Cassani in Italy in 1927. Cassani, at just 21, designed this engine himself along with more powerful engines for the Italian Navy and Air Force. In 1942, he formed the now familiar Same group of companies.

It is understandable that Fergusons' Black Tractor is covered in this volume as it was in *Great Tractors,* because of its significant role in tractor development. What is most depressing (or perhaps encouraging to the frustrated inventor!) is to learn how long it took for this ingenious system to be recognised for what it was.

The development of the tracked tractor is also followed, starting with the Bullock Creeping Grip! through the Clayton (with steering wheel) to the Caterpillar D2 and R2, the Fowler FD2 and the Howard Platypus. Mr Williams has cleverly picked out the Nebraska test reports for the Caterpillar tractors. These provide a very illuminating comparison between diesel, petrol and paraffin engines in the immediate pre-second world war period.

All in all, I think the author has provided a volume which gives a good balance of detail with interesting anecdote, sufficient for the enthusiast and easily readable by the layman, such as myself. I am also prompted to say "no self respecting present day tractor designer should be without this and Mr Williams' earlier volumes."

WCTC

Zeo-Agriculture: Use of Natural Zeolites in Agriculture and Aquaculture.

Editors: W G Pond and F A Mumpton. *Publisher:* Bowker Publishing Company, Essex 1984. ISBN 08 6531 6023. £43.50.

THIS is a collection of research and review papers presented at the Zeo-Agriculture '82 Conference held in Rochester, New York. The book opens with a broad review of the role or potential role of natural zeolites in agriculture and aquaculture and follows this up with a series of useful introductory papers on the nature, occurrence and properties of zeolites. The bulk of the book then deals with specific uses of zeolites in agronomy and horticulture, in animal science and nutrition, in aquaculture and in agricultural engineering, a coverage that is perhaps notable for breadth rather than depth. Nevertheless, this is entirely understandable in view of the fledgling state of this particular field of agricultural science.

Perhaps some readers may not be aware of what zeolites actually are and what is the basis of their claimed agricultural application. Zeolites are a group of natural hydrated alumino-silicate minerals which possess a number of unusual chemical and physical properties, particularly related to cation exchange, cation selectivity, gas adsorption and hydration. These properties may vary according to the particular zeolite mineral species involved and according to its particle size and shape, porosity, aggregate structure etc. Up until fairly recently, zeolites were known mainly as curiosities in the mineral collections of museums, but since the fifties it has become clear that zeolites occur in many sedimentary rocks in volcanic regions, often in the form of extensive high grade deposits. There is little likelihood of such deposits occurring in the UK, however. The basis of the alleged agricultural usefulness of these minerals is their cation exchange and adsorption properties. For example, in agronomy, zeolites have been used as slow-release ammonium and potassium fertilizers, as carriers for pesticides and as traps for heavy metals; in animal nutrition, they have been used as dietary supplements for poultry, swine and ruminants. They have been applied in the treatment of animal wastes to reduce malodour, to control the viscosity and nutrient retentivity of manure and to purify methane gas produced by anerobic digestion of excrement. In aquaculture, zeolites have been used to remove ammonia from culture waters and to produce oxygen-enriched waters. These are only some examples of the use of zeolites and, by any standards, we are obviously dealing with a material of exceptional versatility.

The question is, though, does zeolite treatment work? Even a casual perusal of the research papers in this volume rapidly leads one to the conclusion that the most appropriate verdict is the traditional Scottish "Not Proven". The only consistent feature of the results is their inconsistency. Thus, one group of researchers may show that zeolite applications result in increased crop yields or animal weight gains, whilst another group may conclude that such applications are totally ineffective. To be fair, this problem is fully recognised and discussed by the editors in their preface and in a final paper on future perspectives. One problem seems to be the general lack of an interdisciplinary approach in many studies, leading to poor experimental design. Nevertheless, despite these drawbacks, there are enough encouraging aspects of "zeo-agriculture" to suggest at least that research should be continued and perhaps extended. Indeed, in view of the food crisis presently enveloping many countries in the Third World, a crisis engendered to a large extent by problems of low soil fertility and limited animal protein supply, it becomes increasingly urgent to evaluate such novel approaches to agriculture as quickly as possible.

MJW

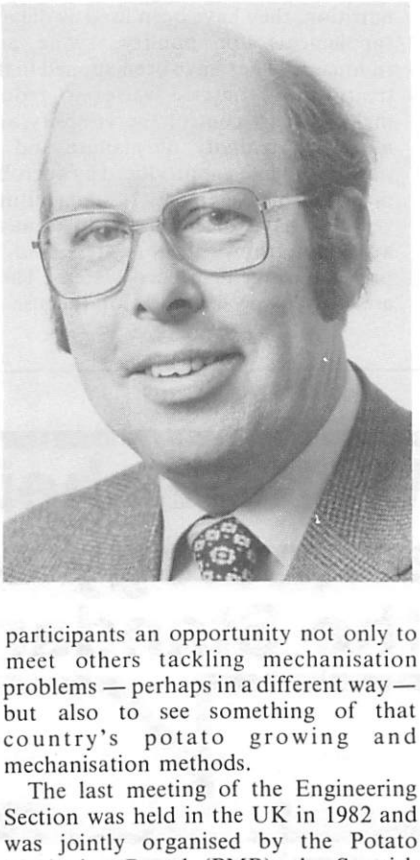
The Engineering Section of the European Association for Potato Research

D C McRae

THE European Association for Potato Research (EAPR) was formed in 1957. The principal aim in its construction is "to promote the exchange, between various countries, of scientific and general information relating to all phases of the potato industry and to encourage and assist international co-operation in the study of problems of common interest in this field". An important part of the constitution of EAPR was the provision for the creation of subject sections which concentrate on specific disciplines relevant to the potato crop. The Engineering Section is for those interested in the many aspects of potato crop mechanisation.

Triennial Conferences of EAPR have plenary meetings which cover topics of general importance and section meetings for more specific interests. The Engineering Section sessions are valuable not only to research engineers, but also to manufacturers and users of potato machinery. The meetings provide a forum for discussing interesting new trends in mechanisation. The Ninth Triennial Conference of EAPR held in Interläken in 1984 attracted 500 delegates and 100 accompanying persons from Europe and the USA.

Between triennial conferences, the Engineering Section meets in one of the European countries. This gives the participants an opportunity not only to meet others tackling mechanisation problems — perhaps in a different way — but also to see something of that country's potato growing and mechanisation methods.



The last meeting of the Engineering Section was held in the UK in 1982 and was jointly organised by the Potato Marketing Board (PMB), the Scottish Institute of Agricultural Engineering (SIAE) and the Edinburgh School of Agriculture. Participants attended the PMB Autumn Potato Harvesting Demonstration and then travelled to Scotland where a day conference was held at the SIAE. Speakers from Holland and West Germany gave papers on haulm pulling and potato harvester testing, respectively. UK speakers described the latest developments in stone windrowing techniques, potato damage during riddling and harvester design. The conference ended with a tour of the Scottish seed potato growing area which included an engineering works visit.

It is hoped to hold the next Engineering Section meeting which will be arranged along similar lines, at Hanover, West Germany in 1986. Anyone interested in attending will be most welcome and details will be published nearer the time.

Membership of EAPR whilst not a requirement for attending the conferences, it is to be commended because it supports an organisation which has done much to promote progress in research and development of the potato crop throughout Europe and in countries further afield. It has played a part in cementing good international relations and fostered collaboration between research workers in Europe — for instance in pooling knowledge of methods for testing and screening potatoes for mechanical damage. Membership application forms are available from the author. Even if membership is not sought, an expression of interest in the Engineering Section and suggestions for any conference topics or work of a collaborative nature between countries in the field of engineering for the potato crop would be valued. It would be particularly encouraging if engineers from firms manufacturing potato machinery in UK were to take more of an interest in the activities of EAPR. Meeting one's counterparts from other European countries at both triennial and section conferences is beneficial and can stimulate fresh ideas.

Douglas McRae is Head of the Potato Section of the Scottish Institute of Agricultural Engineering, Bush Estate, Penicuik, Midlothian EH26 0PH.

He was elected Chairman of the Engineering Section of the European Association for Potato Research in 1984.