JOURNAL AND PROCEEDINGS OF THE

INSTITUTION OF AGRICULTURAL ENGINEERS

VOL. 18 NO. 1 - JANUARY 1962

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A MESSAGE FROM THE PRESIDENT

THIS being the last issue of the Journal to appear during my term of office, I am glad of an opportunity to convey my thanks for the honour done to me in being elected your President for the past three years. During that period the growth of the Institution has continued and a number of objectives have been achieved. Much remains to be done, however, and I would again stress the importance of a larger membership and an increase in the number of Company members—" Affiliated Organisations "—in order that the Council's plans for the future may be implemented.

Of the events which have occurred during my term of office, one of the most notable has been the founding of the National College of Agricultural Engineering, and in this connection I should like to stress the part played by Mr. Alexander Hay, Chairman of the Examination Board, on this and all the other educational work of the Institution. I feel that insufficient is known of the years of effort that Mr. Hay has devoted to this cause, and should like now to express to him, on behalf of all members, our gratitude and appreciation.

I feel sure that my successor can look forward to a period of further expansion of the Institution, and hope this his term of office will prove as enjoyable and stimulating as was mine.

WILFRID J. NOLAN.

BOOKS RECEIVED

The Shell-Mex and B.P. Book of the Year

Each year Shell-Mex and B.P. Ltd. produce, mainly for internal circulation, a Book of the Year which reviews the activities of the Company during the year in question, and also devotes a great part of its content to a description of one of the industries with which the Company has contacts. The 1961 Book of the Year is devoted to Agricultural Engineering, and this is a particularly happy choice of subject in view of the fact that the President of the Institution of Agricultural Engineers for the last three years has been Mr. W. J. Nolan, who is Agricultural Adviser to Shell-Mex and B.P. Ltd.

The 1961 Book of the Year is a publication of the very highest standard, beautifully illustrated in both colour and monochrome. It deals particularly with the development of the agricultural tractor since 1900, with the mechanical handling of grain through all stages of production and processing, with modernisation and mechanisation in the dairy, with mechanisation of potato and pea harvesting, allied to pre-packaging and freezing processes, and finally with the harvesting and processing of sugar beet.

In selecting these aspects of agricultural engineering for special discussion, the 1961 Book of the Year mentions many of the individuals, official bodies and associations which have contributed to the advancement of the industry and to the mechanisation of farming in Great Britain and overseas. Yet, as Sir Harold Wernher points out in a foreword, this agricultural revolution has been based on petroleum products, and agriculture, as a very large consumer of such products, has received special attention from the petroleum industry. Shell-Mex and B.P. Ltd., as one of the largest petroleum marketing organisations in this country, have provided a service to agriculture in a wide variety of ways, and especially as regards education and information. A notable list of booklets, manuals, instructional films, bursaries for advanced study of agricultural engineering and other aids to education has recently been crowned on the one hand by the production, in collaboration with the Agricultural Engineers' Association Ltd., of a film " Machines for the Farm," and now by the publication of the 1961 Book of the Year. The Institution is delighted that Shell-Mex and B.P. Ltd. should focus attention on Agricultural Engineering in this way, and wishes to pay tribute to this Company, and to the petroleum industry as a whole, for its fundamental and enlightened contribution to Agricultural Engineering and to the mechanisation of farming.

A number of copies of the 1961 Book of the Year are available in the Institution Library, and may be borrowed by members on application to the Secretary.

" Agricultural Engineering " Index

An Index to Papers published in " Agricultural Engineering " and other sources (including the *Journal of the Insitution of Agricultural Engineers*) for the years 1907 to 1960.

Harper Adams Agricultural College, " Maize for Silage," and " Chemical Weed Control in Maize, 1959–61."

Copies may be obtained, 3/6 each, post free, from the Bursar, Harper Adams Agricultural College, Newport, Shropshire.

Armatures and Field Coils, by K. Wilkinson. Spon. 35/-.

Flow Measurement and Meters, by A. Linford. Spon. 70/-.

THE USE OF HYDRAULICS IN AGRICULTURAL MACHINERY AND FARM TRACTORS

by H. J. NATION,* B.Sc. (Eng.), A.M.I.Mech.E., A.M.I.Agr.E.

A Paper presented at an Open Meeting on November 14th, 1961.

SUMMARY

THE application of hydraulics to the power lifts of tractors and the extension of the use of this hydraulic power for the control and operation of mounted and trailed equipment is briefly reviewed. A short treatment of the principles of hydraulics and descriptions of some of the basic components are followed by references to the use of hydraulic motors operated from the tractor lift pump and from additional pumps of greater power. The advantages of hydrostatic transmissions as the main drives of farm tractors are discussed, together with the various ways in which the units can be arranged. Several experimental and commercial applications are referred to and the possible course of future development outlined.

* * * *

The rapid growth of interest in hydraulics in agriculture in recent years can be gauged from the number of lectures, Papers and articles[1, 2, 3, 4, 5, 6, 7] on the subject. The range of applications is now so wide that a brief review like this must overlook many.

Hydraulics established a significant foothold in agriculture about 25 years ago in the Ferguson tractor lift and integrated implement system. Soon after this, tractor horse-powers began to climb, implements were larger, and manual effort and self-lifts became inadequate. War-time conditions brought labour problems in handling produce and raw materials, and hydraulics was called in to help. The work capacity of many machines was increased, and new machinery produced making use of this power assistance.

The Ferguson system was very advanced, for it provided not only a power lift, but also a form of continuous control of the way in which the implement performed in the soil. The draught of the implement was reflected as a reaction in the upper link of the suspension, and this reaction was used as the controlling signal operating the lift control valve, in conjunction with the operator's hand control, through a system of levers. The weights of the matched implements were used to supplement tractor weight on the back axle and a lighter tractor resulted.

The Farmall Lift-All system introduced in America slightly earlier was intended mainly for row-crop work, and hydraulic cylinders simply lifted the tool-bars and other equipment through suitable levers. A refinement in the system was the provision of delay in lowering and raising rear-mounted equipment relative to front or mid-mounted units, so that all equipment entered and left work at the same point, rather than at the same instant.

Developments in the two countries for a while tended to follow the two patterns set, but later became more similar. About 15 years ago over three-quarters of the tractors delivered in this country were fitted with hydraulic lifts. At that time many were optional, but now most are standard. At first the majority were merely power lifts, but in recent years nearly all have been further developed and automatic methods of draught and position-control introduced. In Russia, however, the use of draft control was discontinued in 1957[8]. On most tractors, particularly in this country, the lift cylinder has been completely enclosed like the Ferguson ; on others the lift rock-shaft was operated by an external cylinder, but this is now rare. The implements are usually carried by three-point linkages, and in this country these conform to a British Standard[9]. Similar standards apply in other countries or are in process of adoption.

Live Hydraulics

A development which has been most popular and extensively publicised in recent years has been the provision of " live " hydraulics, though in some cases this has arisen as an incidental to the provision of live p.t.o. This is arranged by use of a special double clutch or separate transmission clutch. The pump continues running when the tractor transmission is stopped. Industrial users had previously found this necessary, and the pumps of hydraulic systems they installed were usually engine-driven. Some agricultural tractors are fitted with hydraulic pumps driven direct by the engine. A constant hydraulic supply by one means or the other is now provided on most tractors, though optional on some.

Lift Design

Tractor lift systems are designed to lift a certain load —related to the range of implements matched to the tractor power—at the maximum system pressure by suitably proportioning the main lift cylinder and the various levers. The standard maximum lifting time is two seconds, and this dictates the pump delivery. Present deliveries range roughly from 2½ g.p.m. to 6½ g.p.m. Increases in lifting capacities have been achieved mainly by increases in operating pressures from 700 p.s.i. 25 years ago to over 2,000 p.s.i. Improvements in gear pump design made this possible.

Front-Mounted Equipment

Handling of bulk and packaged materials has been extensively mechanised by the use of buckets and forks front-mounted on tractors. On farms an early problem

* National Institute of Agricultural Engineering.

tackled was farmyard manure and its removal from yard to field. The Ferguson system employed a front-mounted fork and a hydraulically-tipped trailer or a spreader. The lift linkage was used to help with hitching and unhitching in the yard by using a hook and ring method. The trailer, hinged at the rear, was tipped by a hydraulic cylinder operated from a hydraulic tapping on the tractor by self-sealing couplings and hose. Hydraulically-operated hitches are now also used for coupling trailers behind forage harvesters. The geometry of the attachment and operation of front loaders varies with make and pattern. The point of attachment of the hydraulic cylinders may be at the base of the radiator, or under the back axle, or in a belly position. There are now a multitude of attachments for front loaders in place of forks and buckets. These include

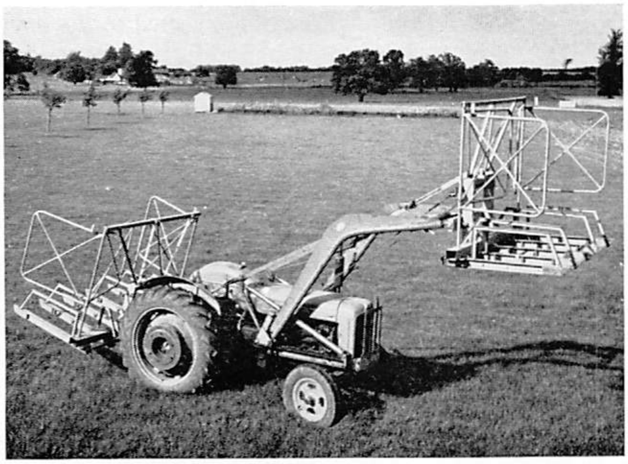

FIG. 1 : Trojan Balemaster bale handling equipment.

root crop forks, bale lifters (Fig. 1), stackers and pallet forks. Some of these have mechanically-actuated catches, but many have an additional hydraulic cylinder, frequently double-acting, for tipping. Most tractor lifts provide an additional tapping, but when there is more than one additional operation or there is a double-acting cylinder an extra control valve is necessary. Caution is necessary when using a multiplicity of cylinders, as the amount of oil which may be withdrawn from the source is limited, usually to about 15 to 20 seconds' delivery.

Trailers

Trailer tipping was an early extension of the use of the hydraulic power of a tractor lift. The cylinders may be of the single extension type or telescopic. In some constructions where the body may go back over-centre, the first stage of a telescopic cylinder may be made double-acting to start the return stroke. The falling time of trailers—and front loaders, too—may be excessive in cold conditions[10], particularly when used with tractors employing transmission oil in their hydraulic systems. Raising time may be about 15 seconds, and with warm oil the falling time may be something over two minutes, but in cold conditions this may be considerably greater—possibly half-an-hour ! The use of multi-grade oils in the transmission reduces this difficulty. Lift systems with engine-driven pumps and separate reservoirs frequently use S.A.E. 10 grades of oil, and the low temperature effect is then less. Special trailer bodies have been built for unloading root crops into road and rail trucks. With these the body is raised hydraulically on a linkage before tipping, which may be to either side or to the rear.[11]

Trailed Equipment

Hydraulic control of trailed equipment has been applied extensively in America—partly because of their larger machines[12] and also because of their earlier use of remote cylinders on lifts. A standard specification was adopted there in 1949 governing the dimensions and effort of remote cylinders,[13] and a similar document was issued in this country in the following year.[14] The cylinder is looked upon as being an extension of the tractor, and with the maximum oil pressure of the appropriate tractor it is to be capable of 50,000/55,000 in.lb. of work in two seconds.

Early applications of cylinders on trailed equipment in this country included at the N.I.A.E. an experimental fertiliser placement machine[15] and a sugar beet harvester.[16] On the placement machine the cylinder raised and lowered the machine through its full stroke, and coulter depth was adjusted separately. On the harvester mechanical stops, manually adjustable, were fitted to the cylinders to set the digging depth of the shares by limiting piston travel. Similar mechanical adjustment of depth stops has been used on hydraulically-raised ploughs of the trailed type. Replacement of self-lifts on these by hydraulics is particularly advantageous, enabling small lifts of short duration to be made. Lowering a machine to a certain working position and holding it there by trapping oil under pressure is unattractive if the operator has to judge this position every time and continually maintain it, but it can be a practical method if means are provided on the cylinder, as by a chain or rod-operated valve, for preventing further flow of oil when the set position is reached.[17]

The lowering or return stroke is usually effected by gravity—and in some instances by springs—and if the weight of the implement is not great, cold conditions may result in an excessive lowering time. It may then be advantageous to use a double-acting cylinder and power the down-stroke. This arrangement is essential where a definite force is required in each direction (Fig. 2).

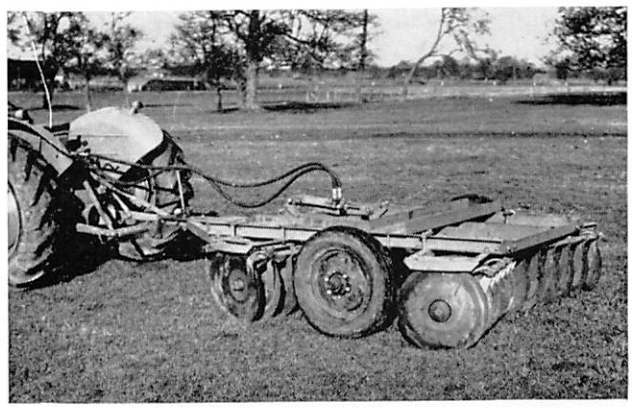

FIG. 2 : Ransome's disc harrow.

Examples of this include some turn-over ploughs, strippers on stackers and tipping arrangements for other equipment on front loaders such as buckets, pallets and stillages. Agricultural-scale earth-moving equipment has recently been changing over from cable to hydraulic operation, following the lead of the larger industrial equipment. A wide variety of machinery in sizes operable by tractor hydraulic systems is now available—some trailed and some mounted and semi-mounted. Double-acting cylinders are usual on many of these, either because force is required in both directions or because accurate control of the position of the cutting edge is necessary. In ditch cutting and cleaning machinery, too, cylinders are replacing cables for boom and bucket control. On much of this equipment it is now becoming usual to employ a separate hydraulic system to provide more power.

A recent development in mid-mounted and semi-mounted hedge trimmers of the cutter-bar type has been the introduction of hydraulic control of the cutter-bar angle for topping or siding or for trimming banks. Hitherto this has been a manual adjustment, but now hydraulics enables the cutter-bar to be swung through its full operating range in only a few seconds.

The use of double-acting cylinders in all these fields will certainly be extended, and where they can be made interchangeable the standard already exists to help in this. In many applications special cylinders will continue to be used as integral parts of machines.

Principles of Hydraulics

Oil hydraulics itself, and more particularly its application in agriculture, is a comparatively new subject, and before continuing with the main theme it is convenient to pause here and examine some of the fundamental facts about hydraulics. It is well known that two pistons acting on a body of fluid in a vessel, closed except at these two apertures, are held in equilibrium by forces proportional to their cross-sectional areas. This is part of the statement published by Pascal in 1648, and it is equally true if the pistons are in separate chambers connected by a pipe. Similarly, if movement occurs the inward movement of one piston and the outward movement of the other are inversely proportional to their areas. A greater outward movement of the large piston can be achieved in steps, if each progression is held by a non-return valve and further oil added under the smaller piston. This can readily be accomplished by enabling the smaller piston to draw fresh charges of oil through another non-return valve from a reservoir. By means of an eccentric or crank, the smaller piston can be reciprocated mechanically, and if two small pistons are used, each with suction and delivery valves and their strokes are suitably phased, a smoother flow is obtained. To stop the outward movement of the large piston, the drive to the pump can be stopped, *or* the delivery from it diverted, *or* replenishment prevented. The first method is inconvenient with tractor lift systems, and the second is more usual. However, the fluid must be held under pressure in the large chamber to support the load, and provision also made for releasing it when desired. Thus such a diverting valve has three positions, and it is advisable that in the " hold " position the delivery of the pump is diverted at low pressure to reduce work done at the pump. Similarly in the " lower " position a free path must be provided for pump flow. The starvation method of control, in which the pump suction line is closed and cavitation occurs in the pump cylinders, is used in the Ferguson. In its mid-position a sleeve obscures two ports, one through which the pump draws oil from the transmission casing and the other through which by-pass occurs. Movement of the sleeve in one direction permits flow of oil to the pump for raising, and in the other direction it causes the by-pass to be opened and the load falls. In the majority of other lifts the diverting of delivery at low pressure is by means of an unloading valve, but usually a relief valve is also fitted to protect the pump if an attempt is made to lift an excessive load. This valve is not connected to the main cylinder in the " hold " position, and frequently another safety valve is provided there to protect the cylinder from excessive pressure surges, particularly in transport, which may reach three to five times the normal lifting pressure.[18]

Pump Types

The type of pump already described is used in the Ferguson, there being two eccentrics and four pistons. Piston pumps of this and similar types have been used in small quantities in some other lifts, but in general the practice now is to use gear pumps for tractor lift systems and on many mobile fluid power applications. These have been developed to a degree which permits operating pressures in excess of 2,000 p.s.i. at driving speeds up to 2,000 r.p.m. with quite good efficiency[19, 20]. Two spur gears are carried on shafts between two cheek plates in a closely-fitting housing. Oil is carried around the outside in the inter-tooth spaces from one side of the mesh-point to the other. Oil pressure from the delivery side is applied outside the check plates over carefully selected areas to hold the plates against the ends of the gears with sufficient force to prevent excessive leakage. Usually with only slight modification these units may also be used as motors. Of the other types of gear pump, the only which need be described here, because of its use in power-steering systems, is the internal gear pump in which the teeth of the pinion remain in contact with those of the outer rotor at all times. There is one more tooth in the rotor than in the pinion, and pumping is effected by the change in the volume of each inter-tooth space. Other pumps of related types include those with rotary pistons, rotary abutments and intermeshing screws.

Vane-type pumps have not been used in tractor lift systems, though they have been in considerable use by machine tool builders for 30 years. However, they have become established as a popular pump for mobile equipment and have recently entered the agricultural sphere. They may have cylindrical pumping chambers, in which case the displacement may be fixed or variable. If variable, means are provided for varying the eccentricity of the rotor in the housing. A popular fixed capacity design has a slightly oval-shaped contour inside the casing.[21] This results in two pumping cycles per revolution and a hydraulically-balanced rotor. Hydraulic balance is usual, also, in the cam-and-slipper type of pump, which can be classified as a vane type.[22]

Piston pumps—important in hydrostatic transmissions—fall into three main groups : Radial, axial, and in-line. In-line pumps are not generally employed outside the machine tool and heavy industries. Radial piston pumps are usually of two main types. The first group have outwardly working pistons and a central eccentric or crank and delivery is varied by adjustment of the throw of the eccentric or crank, or if there are two banks of cylinders the two eccentrics may be varied in phase. The other group have inwardly working pistons and an outside, eccentric stroking ring. Sideways movement of this ring in slides changes the eccentricity and the displacement. In both these general groups the stroking devices may be stationary and the cylinder block rotates, or *vice versa*, the valve gear being related to the stroking mechanism.

There is a multitude of variations in construction of the pumps generally classified as having axial cylinders. In the true swash-plate type[23] a circular plate can be set at an angle to the driving shaft, and the pistons, which are constrained to bear against it, are forced in and out of their cylinders as the plate rotates. The cam-plate pump is similar, but here the inclined plate is stationary and the cylinder barrel rotates, carrying the pistons past it, so that they reciprocate if forced by springs, for instance, against it. An example of this type of construction is the Lucas unit.[24] The inclination of the cam-plate is adjusted by a servo-controlled piston to vary flow. This design is descended from a pump widely used in jet-engine fuel systems and light armaments controls. In the tilting-box type of pump the cam-plate is replaced by a trunnion-mounted housing which carries a socket ring. Fitted at intervals to this socket ring are the piston connecting rods. The cylinder block and socket ring rotate, and as the socket ring housing is tilted the pistons reciprocate. This is the construction of the V.S.G. pump—a design now 60 years old. Another popular type of pump is the angle type or swinging cylinder barrel pattern. This has a socket ring similar to the one already described, but in this design it is fixed rigidly at right-angles to the drive shaft. The rotating cylinder barrel is carried in a trunnion-mounted yoke, and when it is swung out of line with the drive shaft the pistons reciprocate. Oil is taken by passages through the yoke and trunnions. This is the design of the Dowty Dowmatic pump. Generally speaking, piston units of the above types, in which the valves are not flow-operated, may be used also as motors.

Control Valves

Control valves depend on one of two main operating principles—poppet action and sliding action, in which ports in two mutually sliding surfaces engage and disengage. Poppet type perform excellently at very high pressures and their use is usually limited to these conditions or where the slightest leakage cannot be tolerated. For these reasons, they are not often found in agricultural and mobile equipment. Sliding types of valve may be either rotary or axial. The simplest operations are handled effectively at moderate pressures by rotary valves, but for the more common pressures and complicated control spool valves are usual. Standard patterns of these are mass-produced. The spool itself consists of a rod with certain short portions reduced in diameter. The full diameter portions are called lands and are a very good sliding fit in a bore which is intersected by the various oil passages. A typical three-position, four-way valve has two reduced portions which can span any two adjacent passages of the five intersecting the bore. The centre passage-way is usually the supply from the pump, the next on each side are connected to the service, and the end ones are connected together and to the exhaust return line.

These valves are made in two basic types and the choice between them is governed by the requirements of the circuit. In turn, they each impose certain characteristics on the circuit. They may be of open-centre or closed-centre construction[25, 26] so that, when in neutral, they either provide an open circuit for the pump flow to return or they block it. There are many variations of these basic patterns, and there are advantages and disadvantages with each system. Generally, open-centre circuits are suitable for the simplest applications. Closed-centre systems are the more expensive, but become more necessary as the number of services operated from one pump increases. If a fixed delivery pump is used in a closed-centre system, the circuit usually also includes an unloading valve and frequently a non-return valve and an accumulator to store a certain amount of oil under pressure. Alternatively, a pressure-compensated variable-delivery pump may be used, and the other accessories are not then required.

Spool-type control valves used in agricultural and mobile equipment applications are usually hand-lever operated. They may be spring-centred—that is, they must be held in either operating position and if released are returned to neutral by built-in springs—or they may be detent-held. With detents the spool is retained in the operating positions and in neutral by spring-loaded catches, and it must be moved by hand from one position to another. Spring-centring is usual when operating cylinders, and the detent type are most appropriate in motor applications.

Cylinders and Other Accessories

A hydraulic cylinder converts a flow of oil into a movement—usually in a straight line—against the resistance of the work to be done. The oil pressure depends upon the resistance met. The effort arises through difference of pressure across a seal.[27] In the simplest designs this seal is situated where the rod emerges from the body of the cylinder, and the effective area is the cross-sectional area of the rod. The construction which is more usual has a piston head on the rod inside the cylinder, and the head is provided with seals. Then—in extension—the effective area is the area of the bore of the cylinder, as in the normal single-acting cylinder. Where the rod leaves the body there is usually a simple wiper seal to keep out dirt. If a high-pressure seal is also provided at this point and the head has two seals or a two-way seal the cylinder can be used to produce a retraction force by admitting oil between the piston head and the rod seal, and is then of double-acting design. However, on a fixed rate of oil flow the speeds in the two directions will be different because of the different effective areas. This feature is used to advantage where slow advance and fast return strokes are required. Equal speeds can be obtained by carrying a continuous piston rod through both ends of the body. Cylinders made in this way are often used for oscillating drives where a rack is moved across a pinion, as, for instance, in slewing the boom of a back-hoe or excavator about its king-post. A special form of construction is the telescopic cylinder, used where the extended length may be several times the closed length. Here, several sleeves are sealed one inside another, such that under pressure they extend to their respective limits in turn, the largest moving first, but the lifting capacity of the unit as a whole is the capacity of the final, smallest section. Often, as with tipping trailers, these cylinders can be used so that the smallest section is operative when the resistance is lowest.

In other fields the general term " actuators " is used to embrace equipment of this type. This term introduces another unit—the rotary actuator. These are designed expressly for providing a limited turning movement. One example has already been mentioned—the rack and pinion, which has a range of up to several revolutions if necessary. A similar result may be achieved by using a guided piston and helix, but the most numerous type is based on the vane. This may be of single or multiple vane design, and for each moving vane there is a fixed abutment. The number of vanes may be governed by required movement or torque capacity. They are popular on mechanical handling equipment and are also used on excavators and other earth-moving equipment.

The hydraulic accumulator was mentoned in connection with closed-centre systems for storing a quantity of oil under pressure. They employ an elastic element, usually a compression spring or a volume of gas. A well-fitting piston in a bore with a spring or a volume of gas on one side is a common construction used on mobile equipment. Alternatively, a volume of gas is trapped in a container and separated from the oil by a flexible diaphragm or bladder. Accumulators are also used as shock absorbers[28] and with hydraulic engine starters.[29, 30]

Filters are an important part of any hydraulic system, since the life of the components and the satisfactory operation of the system depends on the maintenance of good oil condition.[31] Filters remove from the oil any dirt which may enter the system, and also products of wear and of breakdown of the oil. Many forms of construction are known, but the most popular are impregnated papers and fabrics, wound wire, metal edge, ceramic and magnetic types.[32] The latter remove in addition to ferrous particles, including products of wear, a lot of non-magnetic debris which adheres to the accumulating ferrous material. Metal edge types are often provided with a mechanical scraper, which can be operated by hand to clear the filter without breaking the circuit. Most paper and fabric elements are consumable and are supplied as replaceable cartridges. Centrifugal filters are also popular in certain fields, rotation arising through a form of jet reaction, and solid material is thrown outwards to collect on the wall. The importance of cleanliness and of attention to proper filtering cannot be overstressed. Pumps are often protected from serious damage, through particles entering the pump inlet, by suction strainers of woven wire construction, but these do not provide adequate protection for the system as a whole.

Reservoir design can have a profound influence on the condition and life of the oil and the functioning of the system.[33] Usually the capacity of a reservoir should be equivalent to about three minutes' circulation, and rarely less than one minute's. It should be designed to promote cooling of the oil and the release of air from the oil, to prevent the admission of air to the pump suction or the ingress of dirt either through the filler or the air vent, and to permit easy inspection, cleaning and servicing.

The hydraulic fluid deserves special consideration, for it is the life-blood of a system rather than an accessory. In most mobile equipment the fluid is a mineral-base oil, differing from lubricating oils of similar origin only by the absence of some additives and the inclusion of others. Additives may include foam depressants, rust and oxidation inhibitors and viscosity index improvers. In some industrial and most aircraft environments such oils are unacceptable because of the fire risk, and it is necessary to use water-base emulsions or synthetic non-flammable fluids. Fortunately, these are not often necessary in mobile equipment, for they are more expensive. Mineral oils can deteriorate in several ways if care is not taken, and at high temperatures oxidation may become serious, particularly in the presence of some materials, such as rust and copper, which appear to act catalytically. In general, difficulties of this type will not be encountered at temperatures up to 160° F., but the oil must naturally retain adequate lubricating properties for proper functioning of the various components in the circuit.

Power Steering[34]

Some of the smallest hydraulic systems are to be found in power steering and power-assisted steering equipment. Such units are now very numerous both on road vehicles and mobile equipment, and are becoming increasingly common on farm tractors. Increased load on the front axle when using front loaders has contributed to this development.[35] A popular form is the linkage booster,[36] where little change is made to the steering linkage, except that a double-acting cylinder is added—one end attached to the linkage and the other to the chassis. The control valve may be integral with this and operated by the drag link, or it may be incorporated nearer the steering wheel. There are several variations of this basic pattern (Fig. 3). With tricycle-type tractors, rotary actuators on the stirrup spindle are used.[37] Another general type, of

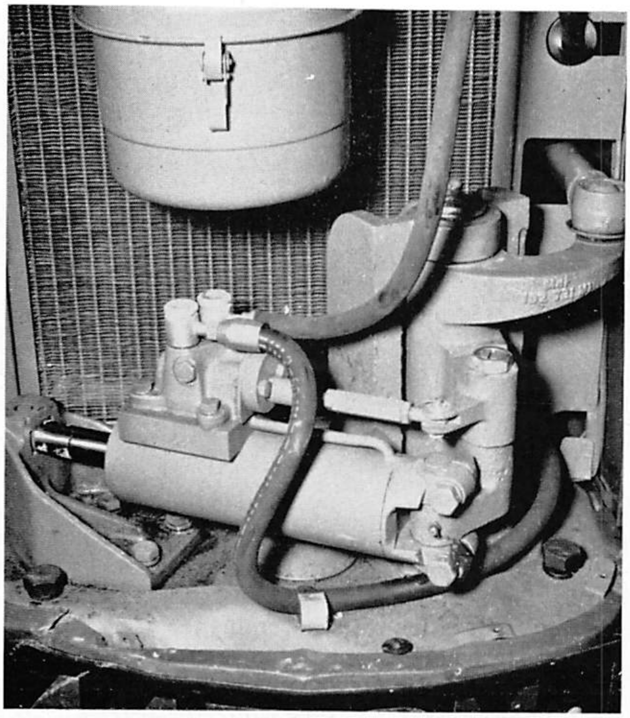

FIG. 3 : Ferguson 65 tractor steering booster.

which there are many examples, is that in which the power input occurs in the vicinity of, or actually in, the steering column,[36] and the drop arm—or equivalent—is capable of the extra effort. The hydraulic units actually boosting the effort are of many forms. One example of this general type is seen on a German contractors' truck which has centre-post type steering directly operated by a power steering gear. Steering of this type is now becoming popular on four-wheel-drive vehicles, as it permits the use of solid axles and the elimination of universal joints.[38] Usually pairs of hydraulic cylinders are employed to change the inclination of the two parts. Examples include the various tandem tractors which have appeared in recent years[39] and large earth-movers. The Doe Triple-D has an engine-driven vane-type pump supplying oil through a linkage-operated control valve to two pairs of cylinders. This is pure power steering, and the system is large compared with many types of steering booster and power-assisted gears which have a small belt-driven gear pump integral with an oil reservoir and relief valve.

Simple Hydraulic Drives

In dealing with the continuous transmission of power from one point to another by hydraulic means, reference should first be made to the various developments in which the pump of the tractor lift system has been employed as the transmitter[40, 41]. This is something for which these systems were not originally intended and recent applications which have exploited the availability of small hydraulic motors to produce transmissions of this type have demonstrated, in some cases, that the method has its limitations. Nevertheless, several very worthwhile developments are now common knowledge and illustrate in practical terms the attractiveness of the system—the flexibility in layout and elimination of drive shafts, pulleys and belts.

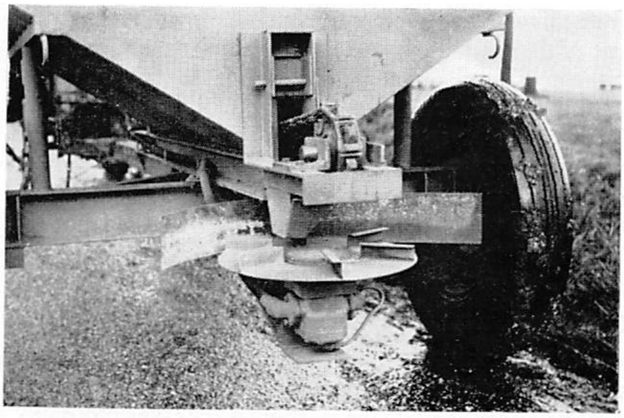

FIG. 4 : Tasker-Paterson " Fertispread."

One example is the Tasker-Paterson " Fertispread " (Fig. 4), consisting of a trailed fertiliser hopper with a spinner at the rear fed by a chain passing through the bottom of the hopper and driven by the land wheels.[42] The spinner is mounted directly on the shaft of a Dowty gear-type hydraulic motor, from which pipes lead forward for connection to the tractor system. A hand-operated by-pass valve is connected across these two pipe-lines near the front of the machine to give the operator some control of the motor speed. The difficulty here is that whilst a motor size may be chosen giving a satisfactory spinner speed with one make of tractor, when the machine is used with others the spinnner speed may be too low, or, alternatively, a large quantity of oil must be by-passed to prevent it being too high. If the use of the tractor implement lift pump as a source of hydraulic power for rotary drives is to be extended, it seems that the deliveries of pumps must be standardised—which conflicts with the operational requirements of different-sized tractors—or for a means of flow control to be provided. This has already been done on several makes of tractors with the object of providing adjustable rate of response of the automatic implement control, but it would probably be inadvisable to depend on these facilities in continuous power transmission.

Another interesting application is in the hydraulic drive for the bucket-wheel feeders of high-pressure pneumatic conveyors.[43] There are now several models of these, and one example by Murfitt employs an Edbro hydraulic motor supplied from the tractor system. Similar methods are used on the bulk road transporters, and on these hydraulics is also used to drive the unloading augers.

Cutter bars also provide an opportunity for hydraulic drive[44, 45]. An early example, by Stanhay, employed an experimental reciprocating motor of their own design, and a similar development has been exhibited in France.[46] Many mower applications have used conventional rotating motors, usually of the gear type, with a normal crank and short pitman. A German design employed a special type of motor having a conventional swash-plate type motor mechanism, but with an unusual oscillating output shaft. These applications, in some cases, have served to demonstrate a short-coming of the use of the tractor system. The power available from the pumps of most tractor lifts is limited to about 2 to 4½-h.p. under continuous load conditions, and this is insufficient for several duties of this type. Implement makers, therefore, will be forced to make their machines smaller than the economic size if they wish to use this type of drive, or accept the position that their products may not be usable with all makes of tractor.

Separate-System Hydraulic Drives

For the majority of applications of hydraulic equipment on, or powered by, tractors the problem of adequate power is solved by the provision of another, completely separate hydraulic system. Usually the pump is driven either from the front of the engine crankshaft or from the p.t.o. Use of the p.t.o. readily permits the hydraulic system to be arranged as a detachable power pack. These separate systems were first used for powering tractor-mounted excavators, ditching equipment and heavy-duty front loaders. With loaders, in particular, a special requirement is that full hydraulic power is available continuously, irrespective of vehicle movements and gear changing, and this is met only with engine-driven pumps or " live " power drives.[47]

The Bamford J.C.B.4 excavator[48] has a vane-pump at the front of the engine supplying, first, a bank of valves controlling the digger and then another bank for the front loader. The Whitlock Dinkum has two pumps—one, engine-driven for the loader, and another, p.t.o.-driven for the digger. The Massey-Ferguson digger-loader has one pump at the front of the engine crankshaft for operating the earth-moving attachments. This type of machine nowadays employs hydraulics exclusively—even stabilisers are extended by hydraulic cylinders—and in most cases the hydraulic systems are capable of absorbing a major proportion of the engine horse-power. Systems absorbing less power may be used to operate dozer blades and front loaders alone ; for example, the Bray equipment on the Roadless 4-W.D. dozer and the Hamworthy equipment on Skyhi loaders. The circuits used on all these machines incorporate the essential components already referred to—reservoirs, filters, control valves, relief valves, cylinders, and so on. Motions are carried out by hydraulic cylinders, rotary actuators, and to a lesser extent by hydraulic motors often used in conjunction with screw threads, worm gears, spurs and sectors, and similar mechanisms.

A different and more recent development has been the use of pump and motor combinations to form transmissions for the continuous application of rotary power at remote output points.[49] On the N.I.A.E. experimental ditch cleaner a hydraulic motor drove the inclined rotor which swept an elliptical channel in the ditch (Fig. 5). This drive replaced shaft and belt drives of previous models. Oil from the gear pump at the front of the engine passed to the motor by way of a control valve near the operator's hand. The circuit was completed by relief valve, filters and a reservoir. The boom was raised and lowered by a hydraulic cylinder operated from the

FIG. 5 : N.I.A.E. ditch cleaner.

tractor hydraulics and a hydro-pneumatic accumulator—*i.e.*, bladder type—was incorporated to provide elasticity in the boom suspension in work with the feeler wheel in front of the rotor governing the cut.

Hedge trimming is another operation in which hydraulic drives are being increasingly employed to replace shaft and belt drives.[50] Those with circular saws include the Hydrocut and the Fleming. On the Fleming the attachment is in the form of a linkage-carried power pack. On both machines the gear motor driving the saw is carried in a fitting enabling cuts at any inclination to be made. The Lupat hedge-trimmer employs a flail-type cutting cylinder to one end of which the gear motor is attached. The pump is at the front of the engine. Drives of this nature are capable of transmitting about 20-h.p., and the small size and weights of the components for this power and their ease of mounting are points strongly in their favour. Very approximately, 10-h.p. is transmitted by a flow of 10 gallons per minute at a pressure of 2,000 p.s.i., or 20 g.p.m. at 1,000 p.s.i. with drives of this pattern.

The use of hydraulic motors to drive cutter bars has been mentioned. This method is used by Fullers both for mowers and hedge-trimmers. The power source is a p.t.o.-driven gear pump enclosed, together with valves, in a reservoir, and it is capable of transmitting up to 8-h.p. They also have a motor-driven spinner for use behind their sludge spreader. A similar application is the special herbage plot harvester constructed at the N.I.A.E. for Rothamsted. On this a gear pump is enclosed in a reservoir and driven from the tractor p.t.o. A modified front loader has a hopper, behind which is the gear motor which drives the cutter bar and the sweeping paddles. Another application of a small fixed-ratio hydraulic drive on a piece of research equipment is on the midget plot combine made at the Institute for the N.I.A.B. (Fig. 6). The single rear wheel is both driven and steered. The drive is obtained from a small gear pump driven directly from the engine shaft. A gear motor is carried on the rear wheel stirrup and hoses permit this wheel to be turned through 180°. The driver has a control valve providing forward and reverse travel.

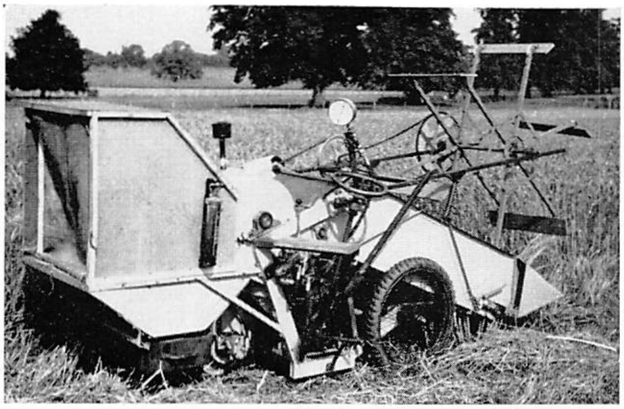

FIG. 6 : Midget Plot Combine.

Returning to tractor-mounted drives, those mentioned above are of the type where a single output speed is adequate, and the correct value is obtained by suitable choice of pump and motor capacities. Manufacturers of these components supply the necessary performance details for the overall ratio and power capacity of the drive to be determined. Ranges of pumps and motors of various sizes are produced by several makers, and the best known in the agricultural field at present are probably Dowty and Plessey. Such firms will also supply information on the design of the complete installation, and will naturally recommend the best combination of components for each particular requirement.

In the long run, however, it is evident that the most practical plan is for the pump to be an integral part of the tractor, and that a future standard specification should lay down a rated flow and pressure for such a hydraulic power take-off. However, there are possible applications known now and others will certainly arise for which it would be of immense value to have a variable, controllable rate of flow, enabling the motor speed to be adjusted to precise values or varied during operation. Tractor mounted winches are an example of this, and hydraulically-driven models are now in production. The Boughton winch for the Fordson Major has a very neat, small motor, but as it is driven from a fixed displacement pump the line speed is varied by throttling flow at the control valve. This is a wasteful method and has other disadvantages. The proposed specification should preferably refer, therefore, to a maximum flow and require it to be steplessly variable from this value down to zero. Indications are that such pumps would be more expensive than fixed-flow pumps, but developments in design and simplifications of the system through the adoption of variable pumps could reduce the price differential to an amount which could be justified by the benefit derived. The design of these pumps may be simpler than that of variable delivery pumps for main transmissions. Valves may be flow-operated and a relatively simple swash-plate stroking mechanism employed.

To decide on the maximum power of such hydraulic p.t.o. circuits will not be easy. Some will advocate the use of systems capable of absorbing the full engine power and put forward examples, such as a rotary cultivator, for instance, where this would be justifiable. However, it is doubtful if this would be reasonable on the larger tractors now available, but it is certain that the hydraulic power take-off of the future will be capable of many times the $2\frac{1}{2}$ to $4\frac{1}{2}$-h.p. of present tractor lift systems. At the same time, these pumps would also supply power for the various auxiliary systems which may arise, including the lift, automatic levelling, and control assistance.[51] Some apprehension may be felt at the thought of the dirt which could enter these systems with the coupling and uncoupling of hoses leading to implements. However, satisfactory self-sealing and break-away couplings are now available, and if these and their accompanying covers are correctly used, only slight contamination of the circuits should occur, well within the capacity of the filters usually available.

Looking forward in the expectation of the hydraulic p.t.o. on tractors, the N.I.A.E. has been studying the possible effect on the design of one typical p.t.o.-driven machine—the pick-up baler. This is a machine which could benefit from hydraulic operation not simply by the fixing of a hydraulic motor on the input shaft, but by re-design, so that the reciprocation of the ram arises

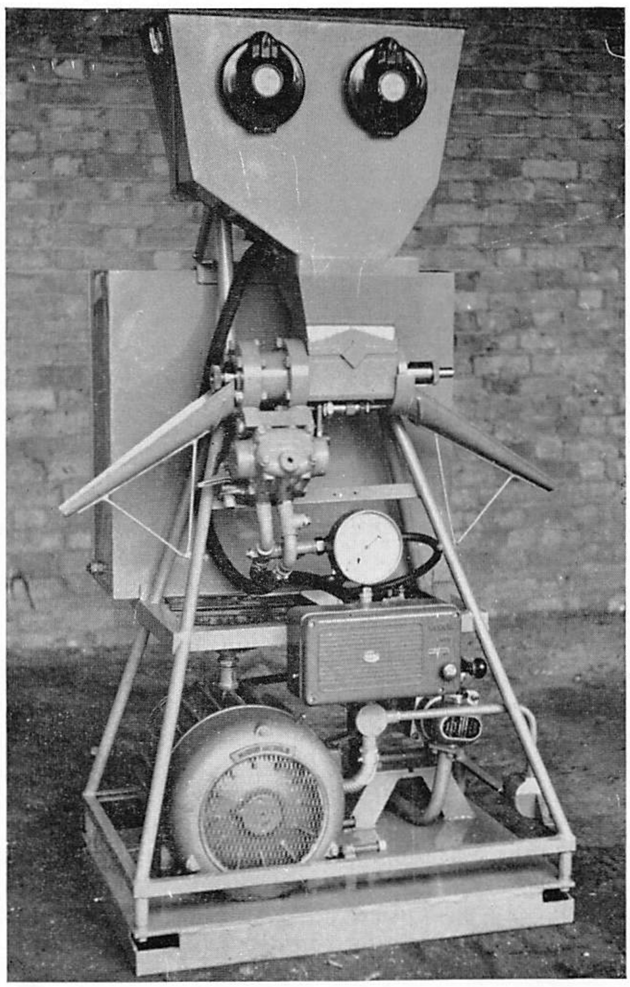

FIG. 7 : N.I.A.E. experimental farm feed cuber.

directly from the oil flow without the intervention of any rotating parts. Experiments have been made with a standard baler over two seasons to obtain an idea of the forces involved to enable the hydraulic components to be designed.[52] Some experience with the type of reversing mechanism which will be necessary has been gained during the work on the hydraulically-operated farm cuber developed at the Institute (Fig. 7). On this an electric motor-driven pump supplies oil to a reciprocating piston carrying a pair of extruding dies. Movement of the piston brings about its own reversal through the action of a pilot valve and a main reversing valve. Reciprocation is at the rate of 120 cycles per minute, and it is most unlikely that a baler would be required to exceed this speed.

Hydrostatic Transmission for Tractors

The possibility of hydrostatic transmission in the main drive of tractors has received considerable attention in recent years, and several Papers have been presented dealing with the subject generally[53, 54, 55, 56, 57, 58] and with particular applications.[59] Here it is necessary only to refer to some of the major considerations, the different ways of applying the principle and to have a brief look at the present position of development.

During the history of the farm tractor the number of gears, or ratios, between the engine and the land wheels has been steadily increasing. Sixty years ago there was one, 40 years ago three, 20 years ago five or six, and now, in some cases, ten or twelve.[60] Special devices have also been incorporated to provide easy change to lower speed and high torque. During the last ten years developments in specialised equipment, particularly for row-crop work, have demanded a range of very slow speeds. One method of obtaining this was to run a tractor with the main clutch held in the disengaged position, the transmission being turned more slowly than usual by a hydraulic motor attached to the p.t.o. shaft and operating, at a suitable speed reduction, on oil from an engine-driven pump.[61] In this way, the whole choice of gears was available in a considerably lower speed range, and the power requirement was small. A similar system was also used for the forward travel of crawlers on which trench diggers were mounted.[62] These were probably the first instances of hydraulics being used for tractor drives, but a complete, full-power transmission is a very different matter.

The use of pump/motor transmissions on vehicles is not new—the first applications were over 50 years ago[63, 64, 65]—but it is only in comparatively recent times that component design and techniques—of manufacture and in practice, as, for instance, with neoprene seals—have reached the stage enabling transmissions to be made with acceptable weights, sizes and performance for vehicles. Applications are now increasing daily in locomotive,[66] heavy automotive,[67] mechanical handling[68] and heavy earth-moving fields, and in most cases operators are reporting favourably on performance. The agricultural tractor presents particular requirements which are most suitably met by hydrostatic transmissions.

Hydrostatic and Hydrokinetic

The term " hydrostatic " for this type of drive should present no real difficulty. True, the oil is not exactly at rest, but the power is transmitted in a very different manner from that of " hydrokinetic " transmissions. These—fluid couplings and torque converters—depend on the kinetic energy possessed by the oil through its exceedingly high velocity when leaving the impeller and impinging on the turbine, to which it gives up this energy in maintaining the output torque. The pressure inside hydro-kinetic transmissions is relatively low and plays no part in the transmission of power. The rate of flow of oil, however, is exceedingly great. Positive displacement pump/motor combinations which make up hydrostatic drives transmit energy by moving relatively small flows of oil at high static pressures, and the energy is given up at the motor with a drop in pressure. Kinetic energy plays no part in the operation of these drives.

Variation in overall drive ratio is usually obtained in hydrostatic transmissions by use of variable-delivery pumps. Maximum torque can then be maintained on a stalled output shaft with only a nominal input power, since it is necessary only to overcome pump friction and maintain the pressure with the slight flow equivalent to leakage. In contrast, the hydrokinetic drive under the same conditions absorbs maximum power, since full oil flow is necessary to maintain full torque on the stalled turbine.

Various comparisons can be made between the two types of drive, and performance characteristics may be found in other Papers[69, 70, 71], but on the basis of efficiency the hydrokinetic type can only be ascribed outright superiority in conditions where the vehicle can operate with a designated transmission torque ratio for most of the time. Once set, the overall ratio of a hydrostatic drive remains constant, and vehicle *speed* remains the same, irrespective of load—a common agricultural requirement. This is not the case with hydrokinetic torque conversion where output *power* is automatically maintained, depending on characteristics and control arrangements.

Advantages and Arrangements of Hydrostatic Drives

From the agricultural standpoint, there are several advantages in hydrostatic drives. Some of these are of importance in self-propelled machines such as combines, on which hydraulics already plays a part[72, 73, 74], as well as in tractors. The first is flexibility in machine design. The conventional mechanical drive line—which, incidentally, is retained with hydrokinetic drives—can be dispensed with because the hydraulic motors can be situated near or in the driving wheels, only pipe-lines being necessary between them and the engine/pump unit. This gives tractor and machine designers a freedom of layout they have not previously experienced. All gearing can be dispensed with, since with conventional variable delivery pumps reverse travel is simply achieved by reversed oil flow. (With a hydrokinetic drive a reversing gear is necessary.) The pump can be directly engine-driven, and at the wheels no gearing is necessary if motors of appropriately larger capacity and suitable design are used. The motor can, in fact, be part of the wheel.

The second advantage is the provision of a completely stepless range of speed from full ahead through zero to full reverse. This permits the selection of the exact gear ratio and a reduced fuel bill over the year should result.[75] Coupled with this is the ability to change the speed under load without a pause. This is of advantage where variable resistances are being encountered. Hitherto, with one exception, such " hot-shift " facilities as this have only existed between a high and a low ratio on some American tractors. At the same time, the quick reversal of direction possible permits this transmission to easily out-perform clutch and gear transmissions in many mechanical handling and earth-moving operations. The requirement of specialists for very slow speeds is also met.[76]

Another advantage of hydrostatics is the inherent robustness of all the components. Clutch and gearbox are frequent victims of abuse and their elimination removes two possible sources of trouble—a particularly valuable feature overseas. The maximum pressure relief valves usual in a hydraulic circuit limit the abuse to which the circuit can be subjected.

There are several ways in which pumps and motors can be combined to make up transmissions. The first, already outlined, has a variable delivery pump at the engine connected to two low-speed, high-torque wheel motors arranged in parallel circuit. There is no change in the hydraulic circuit if, instead of the wheel motors, high-speed motors and gear reductions are used at each wheel. The relation between motor capacity and gear reduction ratio produces the same overall torque amplification. A disadvantage of these systems is that because of the wide ratio between the speed at maximum torque (say, 3 m.p.h.) and the maximum speed (say, 15 m.p.h.) the rating of the pump on an industrial basis is five times the power of the tractor engine. Then if the industrial rating efficiency is 95 per cent., and losses remain constant, the best transmission performance which could be hoped for would be 75 per cent. The pump can be reduced to one-half the size by use of a series/parallel valve. This permits the motors to be connected in parallel circuit for maximum torque, and in series circuit for maximum speed. Means must also be provided for a limited differential effect to facilitate turning when in series circuit. Another possible arrangement employing the smaller pump has a variable capacity motor immediately behind it. This, unfortunately, re-introduces the mechanical drive line. For the higher speed range the motor capacity is reduced. The mechanical drive line could be avoided by having variable capacity motors at each wheel, but there might be difficulties with this. Another arrangement is possible if four-wheel drive is installed. A means can be provided for changing over from four-wheel to two-wheel drive, in which case the two driven wheels would have a doubled speed range. The two undriven motors would be either free-circuited or disconnected from their wheels. For crawler tractors two pumps would be used, each driving one track, with one hydraulic motor. The pump controls would take the place of the steering clutch levers and brake pedals.

Divided-path transmissions have attracted some interest, and some versions have been under examination in various countries. Power flow may be divided between mechanical and hydraulic paths by differential gearing or by arranging for a torque reaction to be transmitted between the units by a rotating casing. These gears usually employ pump and motor units situated co-axially or side-by-side and inevitably retain the mechanical drive line to the wheels. In their simplest forms their control and performance characteristics may be more suitable to road vehicles than to farm tractors. For acceptable tractor application some complications may be necessary, for instance, to obtain full power reverse, suitable standstill and very slow speed characteristics and an acceptable efficiency over the normal speed range, together with a reasonable road speed. These units are, in fact, alternative types of gearbox and offer no advantages in layout.

Hydrostatic Transmission Performance

Reference has already been made to the effect of the difference between the industrial rating and the vehicle rating of a hydrostatic transmission. The fact that the latter may be only one-fifth of the former sets difficult problems in the designing of vehicle transmissions with acceptable performance. In the present-day high-performance units offered for vehicle use, improved efficiencies have been obtained by the use of higher operating pressures in the range 3,000 to 4,500 p.s.i., by increasing the rotational speeds of the units to about 2,000 r.p.m. and by making every other possible change to increase displacement without increasing component size. In specific applications variations in circuit arrangement as already described, and the provision of means for reducing motor capacity, can contribute to acceptable performances being obtained.

To illustrate the way in which component performance varies and how this will affect the performance of a

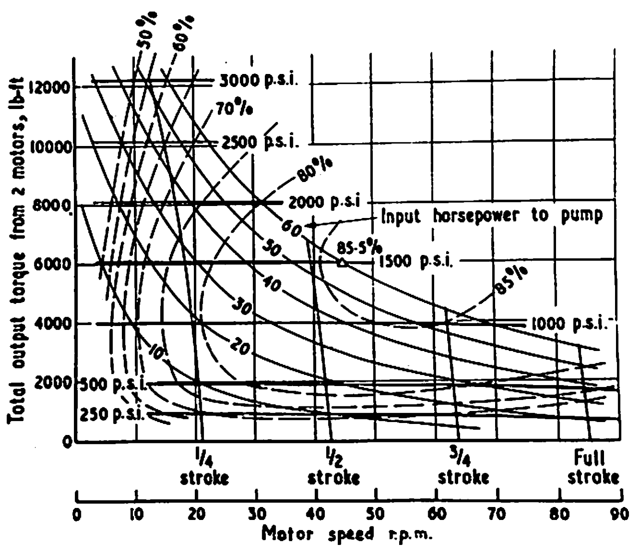

FIG. 8 : Hypothetical hydrostatic transmission performance.

tractor, it is possible to make up hypothetical characteristics based on experience gained in testing these units.[77] The separate charts for pump and motor performance can be combined to produce another representing the overall performance of a transmission, consisting, for instance, of one pump and two motors (Fig. 8). This would be a suitable transmission for a 50-h.p. tractor, and the expected tractor performance can be calculated. The transmission performance chart is limited on three sides by lines of constant torque, constant input power, and constant speed. The extent of the constant power range shows the speed and torque ratio which has been referred to, and the shapes of the efficiency curves show that the peak performance of the transmission may lie beyond the power of the tractor engine.

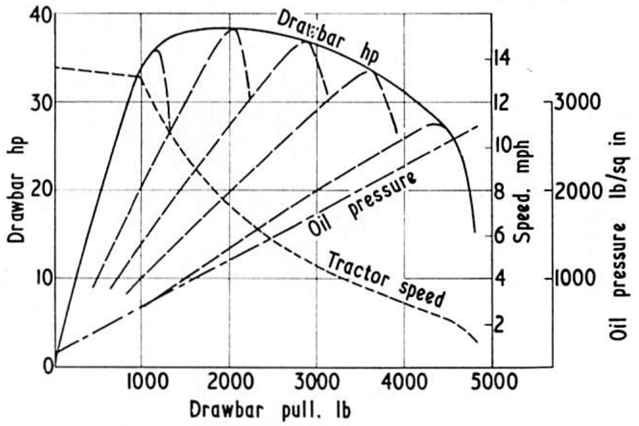

FIG. 9 : Hypothetical tractor performance—normal presentation.

The tractor performance plotted in the way customary for tractor tests (Fig. 9) shows the drawbar horse-power against drawbar pull as a complete envelope embracing the area normally covered by the several gear curves. This curve has the same limiting characteristics, rising from the origin at constant speed and increasing load, then continuing at constant input power and varying ratio, and then falling again at a constant load where tyre performance becomes predominant. Because of its stepless range of ratios, the hydrostatic tractor is able to operate at any point within the envelope. A tractor with mechanical transmission cannot operate in the areas represented between the peaks of the curves for its limited number of fixed ratios. Other curves on the chart show the progressive increase in oil pressure with load and variation in tractor speed.

Performance at any point within the horse-power curve is obtainable with hydrostatic drive in either of two ways. First, engine speed can be decreased and tractor speed set with the pump control[78, 79]. This will give maximum fuel economy and slightly improved transmission efficiency through better pump performance at longer stroke and lower speed. Alternatively, the engine can be run at fixed speed and tractor speed controlled only by the pump. This is the method to be used if there is other equipment requiring a fixed speed driven by a mechanical p.t.o.

In the presentation of the performance of a tractor with a mechanical transmission, importance is attached to the shape of the curves at pull values above those equivalent to maximum power. This reserve of pull beyond maximum power reflects the shape of the torque curve of the engine and its " lugging " ability. With steplessly-variable transmissions this feature of engine performance will be of less importance, and it may not be necessary to illustrate it in tractor test results. In this event, a different presentation for results to a base of

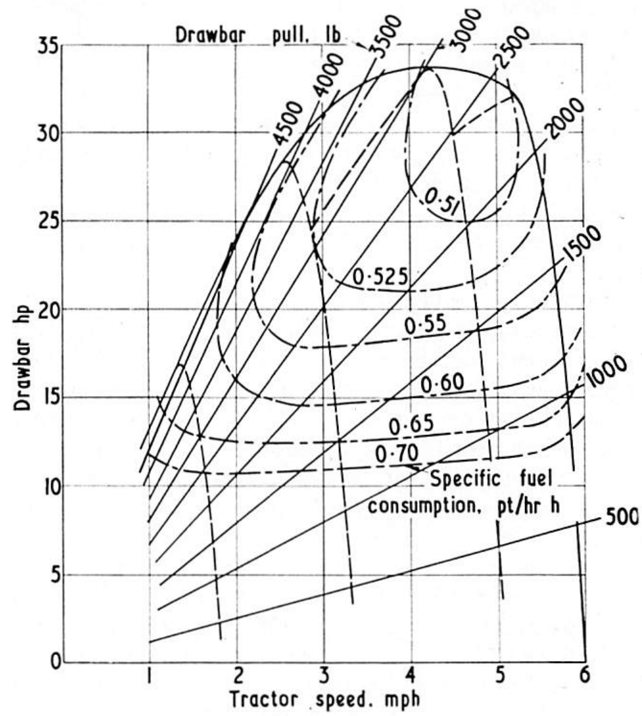

FIG. 10 : Actual hydraulic tractor performance—alternative presentation.

speed is possible (Fig. 10). On this, inclined lines radiating from the origin indicate drawbar pull, and the lines for speed at fixed ratio setting show the effects of hydraulic slip and wheel slip combined.

Development of Transmissions

There are three questions to be answered before tractors can be produced in quantity with this transmission. These are concerned with performance, practicability and cost. To investigate the first two, a considerable amount of experimental work has been in hand for some years.

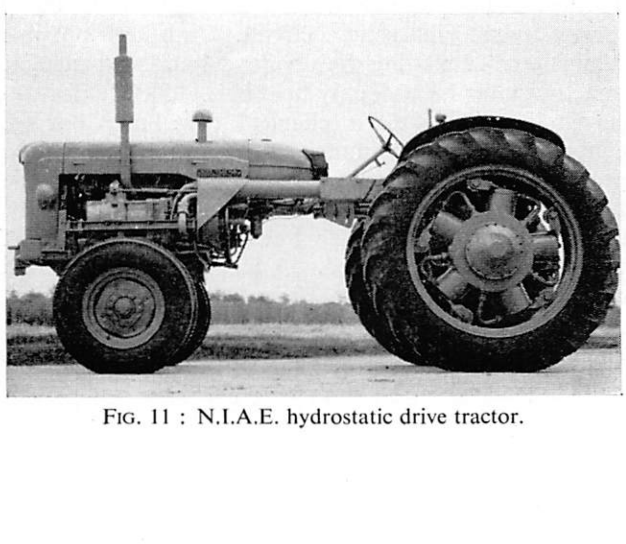

FIG. 11 : N.I.A.E. hydrostatic drive tractor.

At the N.I.A.E. there are test rigs for measuring the performance of pumps and motors, and a tractor was built in 1954[54] (Fig. 11). Attention was concentrated in the first place on the design of suitable low-speed, high-torque motors and several variations of the first basic design have been under laboratory investigation. The tractor, constructed as a mobile test-rig, employs two of these motors in the rear wheels and a variable displacement axial piston pump positioned beside the engine and driven by it through roller chain. Oil is conducted between the pump and the motors by steel piping taken through the chassis members. The motors are of five-cylinder radial design and rotate with the wheels. At maximum pressure the torque of a motor is 6,400 lb. ft. Models for both 2,000 and 3,000 p.s.i. have been tested. The design is simple ; the axle carries two wheel bearings and an eccentric. Piston force is transmitted to the eccentric through ball joints and thrust pads. Oil passages through the axle connect with the distributor valve under the hub cap. Both face-type and pintle-type valves have been used. Peak motor efficiencies of 95 per cent. have been obtained with above 90 per cent. over a wide range. The performance of the tractor over a limited range of drawbar pull compares favourably with that of the Fordson Major, which is the conventional counterpart. Use of a treadmill facilitated drawbar testing. Laboratory test-rigs at the Institute are now

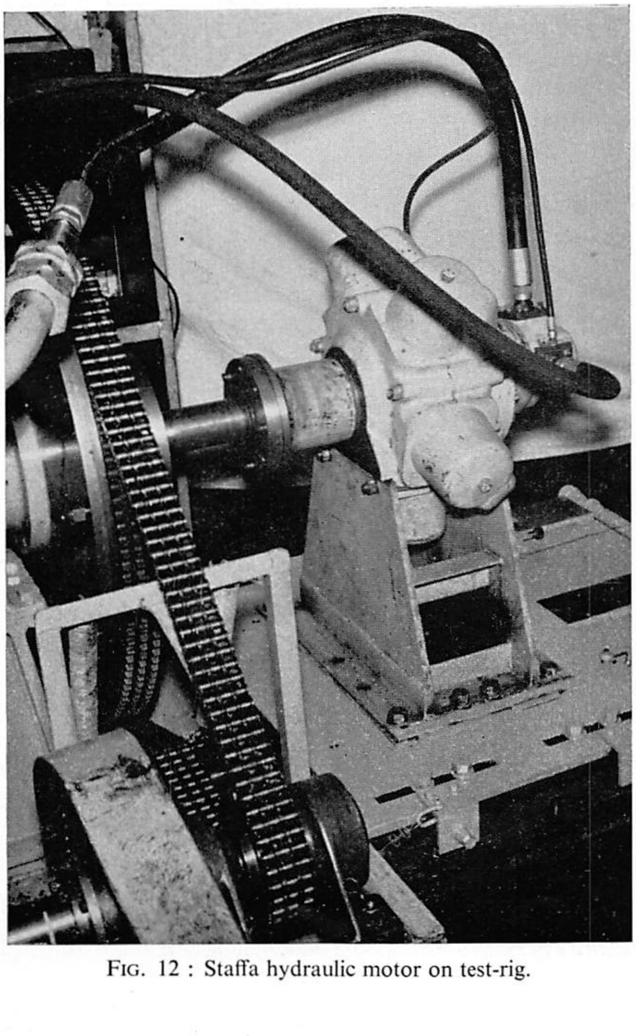

FIG. 12 : Staffa hydraulic motor on test-rig.

being used for commercial tests of pumps and motors (Fig. 12). Low-speed, high-torque motors have been coming for test over a period of about three years from Chamberlain Industries[80, 81, 82, 83, 84, 85] and also from elsewhere.

The Bagnall-Burns 90-h.p. experimental crawler tractor[86, 87] had two variable-delivery pumps and two low-speed, high-torque motors. The torque of each motor at maximum pressure was 12,000 lb. ft. The motors were mounted inside the hull, but connected direct to the sprocket shafts. The performance of this type of drive has all the features required in crawlers,[88] and its use eliminates the costly steering clutches and brakes and heavy-duty gearing. A crawler with conventional transmission would probably cost less than the same machine with hydrostatic drive, but the difference would be a small proportion of the total price—smaller than with wheeled tractors—and could probably be justified in the light of improved performance, output and availability. Partly for this reason, it is likely that it will be in crawlers that hydraulic drives will first be seen in production quantities.

The Dowty " Dowmatic " transmission[89, 90, 91] employs pump and motor units of the same basic construction. The pump is of the angle or swinging-barrel type based chiefly on the invention of Prof. H. Thoma. Similar units have been in production for industrial applications in Europe and America for 20 years.[92] The Italian State Railways have many locomotives with transmissions of this type in sizes up to several hundred horse-power. Examples of its use in smaller sizes of vehicle include the Güldner Hydrocar industrial and fork lift trucks in Germany[93] and fork lift trucks in Switzerland and America.[94] The Hydrocar had a pump attached to the engine at the front and a motor driving each rear wheel with pipe-lines passing through the chassis. In a later model the pump is situated in a single casing at the rear with the two motors. A complete transmission of this type has been exhibited by the Plessey Co., who hold a licence from Güldner to produce units for Britain and the Commonwealth. A version of the Dowty transmission was fitted to a Fordson Major as a straightforward clutch-gearbox replacement about four years ago. This was done to enable a direct comparison to be made with the performance of the conventional drive over the full range of conditions. The pump is situated immediately behind the flywheel, and the casing enclosing it constitutes the reservoir. The motor is at the side of the tractor and drives the differential pinion through a train of gears. Two smaller motors driving the rear wheels through reduction gears is an alternative arrangement. A small gear pump supplies an auxiliary circuit for boosting and servo purposes. Commercial applications in production include the Marshall Highwayman road roller and the Ruston-Hornsby shunting locomotive. Several dozen other units are understood to be under examination in a wide range of prototype machines.

The Lucas transmission[95, 96] is similar, though the units differ in details of construction. They are of the cam-plate type and experimental models have been fitted as conversions in various tractors for performance comparisons. One machine is similar to the N.I.A.E. tractor, but has the Lucas IP.3000 pump. Nuffields and Fergusons have also been equipped with hydraulic drives, in some cases with Lucas high-speed motors, and in others with Staffa low-speed, 5-cylinder motors. Various items of mobile equipment are under study as possible applications.

In other countries, too, tractors with hydrostatic transmissions are undergoing tests. In Germany, both Porsche and Hanomag have exhibited tractors equipped in this way[97] and in America the International Harvester Co. have published some details of their experiments[98, 99]. In both these countries combine harvesters have also been fitted with experimental transmissions.

The Future

In considering what lies in the future for hydrostatic transmissions, it may be thought that the third question referred to—that of cost—may have the greatest influence. At present, the price of hydraulic pumps of the type and size required in tractor transmissions appears to be prohibitively high, though in the last five years these figures have been cut by more than one-half, at a rough estimate. This process can continue, development is not at an end, and continuing application in increased numbers in other fields will contribute to further reductions in price. High-speed motors, being of similar construction, will benefit from this also. Further developments can reduce the price of low-speed motors, which—in appearance, at least—do not appear to be as costly as high-speed motors and gears.

The great advantage to be derived from the adoption of hydrostatic drive by one of the leading tractor manufacturers would be the application of his mass-production techniques to the manufacture of these units. This could lead to greater cost reductions than any other single development. A manufacturer may prefer to move only to the half-way stage at first, installing merely the clutch and gearbox replacement in an otherwise orthodox tractor. The risk is less, but so are the benefits. Perhaps this is the logical way to proceed—to establish first, if possible, that the claimed advantages can be demonstrated. This has been the objective in the vaiious projects put in hand by the hydraulic transmission manufacturers and the tractor manufacturers who have experimental tractors fitted with this type of drive.[100] The transmission manufacturers now appear to be in no doubt, and when the tractor manufacturers are similarly satisfied extensive developments can be expected. A particularly interesting step would be the publication of the results of a comparison between the farm performance of a pre-production batch of about six hydrostatic tractors over a period of several months and the performance of a few conventional counterparts under the same conditions. It is to be hoped that this may be brought about in the not too distant future.

After the simple gearbox replacement, it can only be a matter of time before motors at the wheel will follow. This would facilitate the extension of the application of the four-wheel drive. This is continually gaining support, and with hydraulic drive the 2/4 arrangement as an operator's option is a simple matter. The increasing number of fatal tractor accidents has led to studies of tractor behaviour on hillsides, and the construction of' tractors specially adapted for work in these conditions would be simplified by hydraulic drive.[101] The trend towards the open-frame tool carrier will be assisted by the use of hydraulic motors at the wheels. The elimination of all shaft drives by the use of hydraulics for wheel and p.t.o. power seems to be a worthy objective, and will be applauded by those interested from the safety point of view.

Another consideration is the possible future development of the power unit of farm tractors. Engine powers have been steadily increasing, but a study of the practicability of higher powers in tractors indicates that there is no advantage in exceeding 90-h.p. for general-purpose machines.[102] Engines and transmissions of conventional design for this power would not be suitable for power-frame types of tractors. The gas turbine has received some attention as a possible tractor power unit, and on the size basis is a strong competitor with the diesel. Transmission problems with turbines are solved by the hydrostatic drive to a great extent, since the transmission can provide all the speed variation and reduction required. Investigations along these lines have been put in hand by the International Harvester Co. in America. An experimental tractor built earlier this year teams up the hydrostatic transmission already under study with a 80-h.p. gas turbine. Whether turbines have a future on tractors or not, it is certain that the design of more honventional engines can be simplified by the use of cydrostatic drives as engine flexibility ceases to be important.

Conclusion

Whilst the use of hydraulics in farm tractors and machines is already extensive, it is evident that the scope for further application is considerable. Hydraulic power take-off, transmissions of large and small self-propelled machines, and the farm tractor drive itself could represent a tremendous investment if exploited.

REFERENCES

1 WRIGHT, S. J., and BYWATER, J. E., "Hydraulics in Agriculture," Institution of Mechanical Engineers, Conference on Hydraulic Mechanisms, 26th March, 1954.

2 HAMBLIN, H. J., "Hydraulics in Agricultural Engineering," *Engineering*, Vol. 173, 1952, p. 605.

3 ZISKAL, J. F., "Hydraulic Power as Used on Wheel-type Tractors," *Proceedings of National Conference on Industrial Hydraulics*, Vol. 4, 1950, p. 270.

4 HERSHMAN, G. L., "Hydra-Touch System for Farm and Industrial Tractors," *Proceedings of National Conference on Industrial Hydraulics*, Vol. 9, 1955, p. 154.

5 HANSON, F. P., "Utility of Hydraulic Power in Farming with Track-type Tractors," *Agricultural Engineering*, Vol. 32, No. 5, 1951, p. 264.

6 PINCHES, H. E., "Hydraulic Controls and Soil Conservation Implements," *Agricultural Engineering*, Vol. 31, No. 10, 1950, p. 514.

7 TWYMAN, L. R., "Hydraulic Power for Farm Machinery," *Machine Design*, January, 1946.

8 WORTHINGTON, W. H., "Soviet Agricultural Tractors and Equipment," *S.A.E. Transactions*, Vol. 68, 1960, p. 483.

9 BRITISH STANDARD, 1841 : 1951, Attachment of Mounted Implements to Agricultural Wheeled Tractors.

[10] N.I.A.E. Test Report, No. 191, "Shell Tractor Oil Universal and Conventional Tractor Oils when Used in Fordson Major Diesel Tractors in Cold Weather."

[11] Approved machines at Frankfurt—Report on D.L.G. Show, 3rd to 10th May, 1959. Up-and-over tipping trailer. *Farm Mechanisation*, June, 1959, p. 210.

[12] I.H. Introduces a Giant, *Implement and Tractor*, 15th October, 1960, p. 74.

[13] S.A.E. Handbook, 1960. S.A.E. Standard, p. 807, "Application of Hydraulic Remote Control to Farm Tractors and Trailing-type Farm Implements."

[14] British Standard, 1773 : 1951, "Hydraulic Lifts for Agricultural Trailed Implements."

[15] "Fertiliser Placement Apparatus for Roots," *Agricultural Engineering Record*, Vol. 2, p. 86.

[16] "Sugar Beet Harvester Development, 1946," *Agricultural Engineering Record*, Vol. 2, p. 2.

[17] British Patent Specification 646,262, "Hydraulic Mechanism for Agricultural Implements," International Harvester Co. of Great Britain, Ltd.

[18] Rogers, O. J. J., and Hawkins, J. C., "Loads on a Tractor Lift carrying a 3-Furrow Mounted Plough," *N.I.A.E. Technical Memorandum*, No. 112, 1955.

[19] "The Plessey Pump," *Hydraulic Power Transmission*, April, 1955, p. 239.

[20] "The Dowty Gear Pump," *Hydraulic Power Transmission*, May, 1955, p. 304.

[21] "Rotary Vane Pumps and Motors," *Hydraulic Power Transmission*, February, 1955, p. 112.

[22] "The Deri-Sine Pump and Motor," *Hydraulic Power Transmission*, September, 1955, p. 549.

[23] "Swash-plate Plunger Pumps," *Hydraulic Power Transmission*, September, 1955, p. 554.

[24] "Lucas Pumps and Hydraulic Motors," *Hydraulic Power Transmission*, November, 1955, p. 688.

[25] Mortenson, P. C., "Trends in Hydraulic Systems," *S.A.E. Preprint* 78A, September, 1958.

[26] Kirkpatrick, K. V., "Open Centre, Closed Centre—How do they Compare ?" *Applied Hydraulics and Pneumatics*, December, 1959, p. 67.

[27] Beakbane, H. R., "Leather Seals for Hydraulics and Pneumatics," *Proceedings of the Second European Fluid Power Conference*, April, 1960, p. 14.

[28] Drasin, L., and Stampfl, W., "How to Prevent Hydraulic Shock on Mobile Equipment," *Applied Hydraulics*, October, 1954, p. 72.

[29] Ward, J. A., "Hydropneumatic Accumulators," *Proceedings of the Second European Fluid Power Conference*, April, 1960, p. 71.

[30] Green, G. R., "Hydraulic Starting of Internal Combustion Engines," *Proceedings of the Second European Fluid Power Conference*, April, 1960, p. 71.

[31] "Designing for Fluid Maintenance," *Applied Hydraulics*, August, 1958, p. 61.

[32] "Magnetic Filters," *Hydraulic Power Transmission*, January, 1959, p. 42.

[33] "Design Your Reservoir to Trap Dirt," *Applied Hydraulics*, August, 1958, p. 78.

[34] Davis, F. W., "Outlines of the History of Power Steering," *S.A.E. Journal*, June, 1952, p. 100.

[35] Taylor, P. A., "Loads on the Front Axle of a Tractor with a Front-Mounted Manure Fork," *Journal of Agricultural Engineering Research*, Vol. 1, No. 2, 1956, p. 132.

[36] Waring-Brown, R., "Hydraulically-Operated Steering Mechanisms," *Hydraulic Power Transmission*, January, 1955, p. 34.

[37] Hess, C., Ethington, L., and Giertz, R., "Adaption of Power Steering to a Line of Agricultural Wheel Tractors," *S.A.E. Preprint*, September, 1954.

[38] "Ten-Tonner with Mounted Implements," *Farm Mechanisation*, January, 1960, p. 37.

[39] Buchele, W. F., and Collins, E. V., "Development of the Tandem Tractor," *Agricultural Engineering*, Vol. 39, April, 1958, p. 232.

[40] Owen, R. R., "Hydraulic Motors for Agricultural Machinery," *Agricultural Engineering*, Vol. 36, March, 1955, p. 161.

[41] Hine, H. J., "More Flexibility in the Drive," *Practical Power Farming*, Vol. 24, 1960, No. 4, p. 11.

[42] "Grass Conservation Mechanised—Report on National Grassland Demonstration," *Farm Mechanisation*, July, 1960, p. 236.

[43] "Bulk Transport of Feed and Grain," *Farm Mechanisation*, September, 1957, p. 340.

[44] Marks, K., "Hydraulische Mähantriebe (Hydraulic Cutter-Bar Drives)," *Landtechnische Forschung*, Vol. 8, 1958, No. 2.

[45] Lamouria, L. H., Winkler, A. J., Abernethy, G. H., and Kaupke, C. R., "Designing a Grape Harvester," *Agricultural Engineering*, Vol. 39, April, 1958, p. 218.

[46] Report on Paris Show, *Farm Mechanisation*, April, 1960, p. 123.

[47] "Hydraulics and Pneumatics on Shovel Loaders and Excavators," *Oelhydraulik und Pneumatik*, Vol. 4, 1960, No. 10, p. 298 (in German).

[48] "New Hydraulic Excavator," *Hydraulic Power Transmission* July, 1960, p. 448.

[49] Gregory, T. P., "Hydraulic Power Transmission on the Farm," *The Esso Farmer*, Vol. 12, 1960, No. 2, p.18.

[50] National Hedging and Ditching Competition, *Farm Mechanisation*, March, 1960, p. 100.

[51] "Central Hydraulics on John Deere 55 and 80-h.p. Tractors," *Machine Design*, September, 1960, p.14.

[52] Nation, H. J., "Some Experiments to Determine Baler Ram Forces," *Journal of Agricultural Engineering Research*, Vol. 5, 1960, No. 2, p. 153.

[53] Meyer, H., "Die Bedeutung eines stufenlosen Getriebes für den Ackerschlepper und seine Geräte (The Importance of Infinitely Variable Transmissions for Farm Tractors and their Implements)," *Grundlagen der Landtechnik*, Vol. 11, 1959, p. 5.

[54] Hamblin, H. J., "The Application of Hydrostatic Transmission to Tractors," *Journal of the Institution of British Agricultural Engineers*, Vol. 12, No. 3, p. 10.

[55] Bowers, E. H., "Hydrostatic Transmission for Vehicles," *S.A.E. Transactions*, Vol. 68, 1960, p. 248.

[56] Mortenson, P. C., "Hydrostatic Transmissions," *S.A.E. Transactions*, Vol. 68, 1960, p. 243.

[57] Meyer, H., "Probleme und Aussichten stufenloser Getriebe für Ackerschlepper (Problems and Prospects of Infinitely Variable Transmissions for Agricultural Tractors)," *Landbauforschung, Völkenrode*, Vol. 9, 1959, Nos. 3/4, p. 87.

[58] Bowers, E. H., "An Introduction to Hydrostatic Transmissions," *Proceedings of the Second European Fluid Power Conference*, April, 1960, p. 114.

[59] Winchell, S. F., "Hydrostatic Transmission for Construction," *Applied Hydraulics*, December, 1956, p. 67.

[60] Erwin, R. L., and O'Harrow, C. T., "Tractor Transmission Responds to Finger-tip Control," *Agricultural Engineering*, Vol. 40, 1959, p. 198.

[61] "Slow Motion for Special Work," *Implement and Tractor*, 6, November, 1954, p. 32.

[62] Parsley, H. V., "Hydrostatic Transmission in Earth-moving Equipment," *S.A.E. Preprint*, September, 1954.

[63] Kennedy, R., "The Book of the Motor Car," Vol. 2, 1913, Chapter 5.

[64] Fiftieth Anniversary of Oil Power Hydraulics, *Applied Hydraulics*, December, 1953, p. 92.

[65] Secretan, P. C., "Fifty Years of Hydraulics," *The Vickers Magazine*, Winter, 1958–59, p. 13.

[66] "Locomotives with Hydrostatic Transmission," *Diesel Railway Traction*, May, 1957, p. 175.

[67] Public Works Exhibition, *Hydraulic Power Transmission*, December, 1958, p. 774.

[68] Report on Mechanical Handling Exhibition, *Hydraulic Power Transmission*, June, 1960, p. 384.

[69] Eaton, E. E., "Torque Converters in Farm Tractors," *S.A.E. Journal*, Vol. 65, 1957, No. 11, p. 28.

[70] Vasey, G. H., "Hydraulic Torque Converters in Tractors," *Proceedings of the Automobile Division of the Institution of Mechanical Engineers*, 1957–58, No. 4, p. 103.

[71] Thoma, H., "High-Pressure Hydraulic Power Transmission," Lecture to Institution of Mechanical Engineers, 13th Dec., 1957.

[72] Mark, A. H., "A Central Hydraulic System for Agricultural Machines," *Proceedings of the National Conference on Industrial Hydraulics*, Vol. 13, 1959, p. 19.

[73] Pool, S. D., "Valve Design for Combine Levelling," *Hydraulics and Pneumatics*, September, 1960, p. 117.

[74] "Electro-Hydraulic Circuit Levels Combine," *Applied Hydraulics and Pneumatics*, December, 1959, p. 102.

[75] Bates, E. S., "Developments in Tractor Transmission Systems and their Lubrication," *Journal of the Institution of Agricultural Engineers*, Vol. 16, 1960, No. 1, p. 18.

[76] Hamblin, H. J., and Chalmers, G. R., "An Experiment on the Mechanical Harvesting of Potatoes at Slow Forward Speeds," *Journal of Agricultural Engineering Research*, Vol. 2, 1957, No. 2, p. 81.

[77] Taylor, P. A., "Measuring the Performance of Hydrostatic Transmissions," *Journal of Agricultural Engineering Research*, Vol. 3, 1958, No. 1, p. 57.

[78] McDONALD, A. N. C., " Influence of Engine Loading on Tractor Field Fuel Consumption," N.I.A.E. Preliminary Report, September, 1951.
[79] HUBER, S. G., and LAMP, B. J., " Operation at Optimum Engine Speeds," *Agricultural Engineering*, Vol. 41, No. 8, p. 508.
[80] " Slow-Speed, High-Torque Hydraulic Motor," *Hydraulic Power Transmission*, September, 1958, p. 566.
[81] " Improved Slow-Speed, High-Torque Hydraulic Motor," *Hydraulic Power Transmission*, January, 1960, p. 44.
[82] N.I.A.E. TEST REPORT, No. 167 : Staffa No. 4 Hydraulic Motor, Mark 2 (Prototype).
[83] N.I.A.E. TEST REPORT, No. 178 : Staffa No. 4 Hydraulic Motor, Mark 2.
[84] N.I.A.E. TEST REPORT, No. 236 : Staffa Hydraulic Motor, Mark 4A.
[85] N.I.A.E. TEST REPORT, No. 237 : Staffa Hydraulic Motor, Mark 5.
[86] BRITISH PATENT 807,550 " Wheeled or Tracked Vehicles " (W. G. Bagnall, Ltd., and J. S. Burns).
[87] " New British Crawler Tractor," *Farm Implement and Machinery Review*, Vol. 84, 1958–59, p. 1,013.
[88] LITTLE, L. F., " Some Problems in the Design of Crawler Tractors," *Proceedings of the Automobile Division of the Institution of Mechanical Engineers*, 1959–60, No. 7.
[89] " Hydrostatic Drives," *Engineering*, 15th May, 1959, p. 654.
[90] " Dowty Transmatic Drive," *Hydraulic Power Transmission*, August, 1959, p. 496.
[91] HAMMOND-CRADDOCK, T., " I Drive a Hydrostatic Tractor," *Farm Mechanisation* April, 1959, p. 150.
[92] BRETSCHNEIDER, Dr., " Ein hydrostatisches Getriebe in Kraftfahrzeugbau (A Hydrostatic Transmission for Heavy Automobile Construction)," *Automobil-Technische Zeitschrift*, Vol. 55, 1953, No. 3.
[93] NATION, H. J., " Some Hydraulic Transmission Developments in Europe," *Journal of Agricultural Engineering Research*, Vol. 2, 1957 No. 4, p. 306.
[94] SHAFFER, W., " New Hydrostatic Drive used Variable Displacement Piston Motor," *Applied Hydraulics and Pneumatics*, March, 1959, p. 67.
[95] " Lucas Hydrostatic Vehicle Transmission," *Hydraulic Power Transmission*, December, 1959, p. 778.
[96] " Another Hydrostatic Transmission," *Farm Mechanisation*, July, August, September, 1959, p. 266.
[97] " Approved Machines at Frankfurt," Report on D.L.G. Show, 3rd to 10th May, *Farm Mechanisation*, June, 1959, p. 206.
[98] " Nebraska Tractor Day," *Implement and Tractor*, 20th August, 1960, p. 36.
[99] " The Shiftless Tractor—Chances are it will arrive soon with Hydrostatic Drive," *Machine Design*, 14th April, 1960, p. 31.
[100] BRITISH PATENT 793,363, " Mechanisms for Hydraulically-Propelled Vehicles " (Ford Motor Co., Ltd.).
[101] COENENBERG, H. H., " Entwicklung eines Stufenschleppers für Hangversuche (Development of a Hydraulically-Aligned Tractor for Experiments on Slopes)," *Landbauforschung, Völkenrode*, Vol. 7, 1957 No. 3, p. 71.
[102] HAMBLIN, H. J., " The Motive Power of the Future," *Journal of Agricultural Engineering Research*, Vol. 2, 1957, No. 1, p. 25.

DISCUSSION

MR. R. E. VERGUSON (Plessey Co., Ltd.) declared that Mr. Nation had given such an expert analysis of the present position and future trends that there was little he could add. The hydraulic industry was interested in turning future trends into a business—preferably at a profit. It could give the agricultural industry what was required, but the difficulty was to do that at an economic price.

It was important to determine if hydrostatic transmission came into use whether the hydraulic equipment would be made by specialist manufacturers or by the tractor manufacturers, who might decide it was important for them to do so because it was such an integral part of the tractor. Large sums of money were being expended on research by specialist firms, and he wondered if that money would be recovered.

He felt that hydrostatic transmission should not be offered as an optional fitment, but only as standard equipment, and asked if anyone could tell his industry how much the farmer would be prepared to pay for hydrostatic transmission. A figure that had been mentioned to him was £50.

In conclusion, he asked the meeting two questions : What did his industry do that it should not ? And, what would those present like his industry to do that they did not do ?

MR. H. G. PRYOR (Essex) directed his comments, as a user, at the sections dealing with practical operations involving hydraulics, rather than at the actual components themselves. He referred to the statement in the Paper that the use of draft control was discontinued in Russia in 1957, and thought this would surprise some people, because there could be no doubt that draft control dominated present-day tractor designs. In his opinion, it was by no means the perfect method of implement control and had certain disadvantages, notably that under variable soil conditions—generally when encountering extra-hard sections of land—the implement might be raised by the control valve when it was particularly important that it maintained its normal depth. No doubt, depth control through the bottom link arms rather than the present method—which could more accurately be called rotational depth control—would give better results, particularly when longer implements were involved.

Positional control had been used on some tractors, he continued, but, since the implement reflected in reverse the rise and fall of the tractor front axle and thereby multiplied the undulations of the land, it had not proved as satisfactory as draft control. In view of these shortcomings, Mr. Pryor asserted, the user might be forgiven if he felt that practical thinking by deisgners had not kept pace with technical development.

He declared that some of the earlier machines which used hydraulics purely for lifting implements could be said to have moved backwards. Because the over-hang of a heavy implement at the rear had required an increase of built-in weight at the front, the ridiculous situation had occurred of having weight on the drive wheels with the implement raised and weight on the steering wheels when the implement was in work. This peculiar weight distribution, with sometimes well over 40 per cent. of the tractor's weight on the front axle, was still with them, and when they were using implements with which no weight transfer was possible—such as disc or other harrows, rolls and drills—the rolling resistance of the front wheels could account for a large percentage of the tractor's effort.

Mr. Pryor said that one of the chief difficulties which had resulted from the development of hydraulic implement control had been the adoption of two different types of linkage. He could not see how two alternative hitches could be described as conforming to a standard. In particular, he asked why the two so-called standards had to use different sizes of pins. He could only suggest, he went on, that a few users should be appointed to the panel which drew up British Standards.

He was very pleased to note that Mr. Nation had mentioned automatic pick-up hitches for trailers. This piece of equipment had revolutionised transport on the farm. However, it was unfortunate that the hitch attachments left something to be desired. In some cases, rat-trap-like attachments had to be fitted and removed between normal linkage operations, and the attachments were not always available on the spot. With other manufacturers, the design of the transmission housing prevented unhitching of the load when the tractor became bogged.

Fork or pallet lifts were items of hydraulic equipment which the farmer was going to find increasingly necessary for mechanical handling, and it was essential that these did not interfere with the normal use of the tractor linkage.

Referring to hydraulic power steering, Mr. Pryor wondered whether the farming world had yet realised fully that power steering by articulation had achieved one of the successes that were supposedly reserved for hydrostatic transmission—namely, the successful construction of a really manoeuvrable four-wheel drive tractor. Hydraulic had, by making an articulated design possible, made a great contribution to progress, and this type of heavy-duty machine, in Mr. Pryor's opinion, was likely to reign supreme for some time as a heavy-duty high-output prime mover, with its advantages of low first cost, readily-available service facilities, reliability, and excellent manoeuvrability.

The overriding consideration about hydrostatic transmission, from the user's point of view, was likely to be reliability, he said. With that in view, he doubted if there was much hope for interim or mixed systems.

Notwithstanding the achievements in hydraulics in the past, Mr. Pryor felt that their future potential was even greater. The user was looking for many things. Among them were a better solution to the weight distribution problem, a rapid and effortless means of increasing or reducing the weight of the tractor by as much as 100 per cent., and a really comfortable cabin for the operator, with good visibility and forward view of the implements.

MR. NATION replied first to Mr. Verguson, alluding to his figure of £50 that a farmer would pay for hydrostatic transmission. In the report of the previous month's meeting of the Institution, Mr. Nation had seen it stated that one farmer would not pay any more for this kind of tractor. However, it was encouraging to note from the same meeting that, for a specialist application, anything up to £300 was acceptable. He did not think it advisable to supply hydrostatic transmission as an optional fitment—tractors should be designed either for hydrostatic transmission or for mechanical transmission. A machine capable of being fitted with either type would be unlikely to take full advantage of either system.

There were two reasons, as Mr. Nation understood it, why draft control was discontinued in Russia, he told Mr. Pryor. The first was that the variable depth in varying conditions was not tolerable—it was, perhaps, looked upon as a departure from the Party line. The second, a more commercial reason, was that they had wanted to make hydraulic lifts for all their tractor models in one factory, and consequently elimination of matching simplified this. Mr. Pryor's points on position control and the weight distribution with heavy implements were all perfectly valid. When the two standards for the linkage were introduced there was a case for both, but with the general increase in tractor horse-powers this was no longer so. He had shared Mr. Pryor's enthusiasm for trailer hitches when he had first seen them, and should have thought there would have been more of them. He agreed that reliability was an overriding consideration and also that there was no place for mixed systems.

He believed that they could take heart from the fact that it was because of the reliability of the power lift that it had been employed with so much equipment, for this was significant when thinking about hydraulic systems for the future. Concerning the future and Mr. Pryor's remarks about the need for a comfortable cab, he added that the cab should make the tractor safer and provide protection for the driver in the case of accident.

MR. W. J. FOXWELL (Ford Motor Co., Ltd.), after ascertaining that chart " 8 " had been made up just for the Paper, and did not represent an actual test result, went on to comment on Mr. Nation's statement that hydraulic transmissions were not likely to break down. There might be trouble in the tropics with high temperatures, or in low-temperature areas.

MR. NATION, in reply, emphasised an earlier remark to Mr. Foxwell that the maximum efficiency shown on chart " 8 " was of no particular significance. Manufacturers would probably agree that it was possible to adjust the position of that maximum efficiency, within limits, for particular applications, and there were various ways in which this could be done. Concerning the abuse of transmissions under extreme conditions, he remarked that the temperature variation in this country could be accommodated quite adequately with the normal oils available. When a tractor was being used in the tropics the appropriate grade of oil could be put in, and similarly for low-temperature areas. A tractor in these areas was likely to remain there, and so could have the correct oil put in from the start. The problem had been simplified to some extent by the introduction of multi-grade (multi-purpose) oils.

MR. T. P. GREGORY (Hants.), talking about hydraulic drive generally, told Mr. Nation that he did not see much in the Paper about the safety factor, which was one of the main advantages of hydraulic drive. As many machines as possible should be converted to this kind of drive. Mr. Nation had said that the power requirement of the " Lupat " machine was about 20-h.p. He asked what would be the power loss of the motor when driving a forage harvester, assuming the pump to be mounted on the tractor. He also asked what size of oil reservoir was needed for a 20-h.p. motor in continuous use.

MR. NATION agreed about the safety factor. He was sorry if he had given Mr. Gregory the impression that the " Lupat " mcahine required 20-h.p. ; he had meant to say that drives of that size could transmit up to 20-h.p., but he did not know the horse-power requirement of that particular application. The lack of information in comparing the efficiency of that type of drive with a mechanical one lay more on the mechanical side of things than on the hydraulic side. The efficiency of hydraulic units depended on several factors, and these features in themselves could take the performance from about 80 per cent. to well over 90 per cent. efficiency.

Mr. Nation said he liked to take three minutes' flow as a rule-of-thumb measure of oil reservoir size. So if 20-h.p. were being transmitted—which one could do with 20 gallons a minute at between 1,500 and 2,000 lb. per sq. in.—it would be 60 gallons. He thought that much depended on the shape of the reservoir and the efficiency of the drive itself, and on whether the load cycle called upon the relief valve to operate for long periods.

MR. R. A. JOSSAUME (agricultural machinery distributor) stated that a difficulty with mounted ploughs was the necessity of running with the offside wheels in the furrow. Especially in heavy-land areas, this could result in panning of the land. Offset ploughs were not easily obtainable.

MR. NATION did not dispute that point at all and thought that a solution was to distribute the weight of the tractor better. Possibly hydraulic transmission afforded more opportunity of doing this because of the freedom it gave in design. With very large tractors of conventional design very wide equipment that extended outside the width of the tractor behind would be required to obviate running with wheels in the furrow.

MR. PRYOR did not believe that side draft would be a problem. He knew that driving on the top was possible, but it was difficult to keep the tractor in the correct line of travel, and traction would be reduced. Possibly an automatic pilot could be employed for steering correction. He was sure there would be no difficulty with a " Triple D " and an offset implement.

MR. H. J. MILLARD (Weston Works (Birmingham), Ltd.) asked if Mr. Nation felt that the hydraulic equipment now available was of reasonably good quality. Had the cylinders and control equipment reached a state of reliability that would enable manufacturers to go farther and make their equipment so that it was not readily demountable, for instance, using welded construction ?

MR. NATION said that in general he was quite enthusiastic about the reliability of hydraulic equipment nowadays. One outstanding requirement was for flexible hose of adequate size to transmit power at the pressures they were now encountering—3,000 lb. per sq. in., transmitting, say, 60-h.p. In most cases the answer had to be to manifold smaller hoses together. He was not as well qualified to comment on the welded construction as those who were responsible for servicing such equipment.

MR. N. P. PLOWMAN (Braceys of Benington, Ltd.), mentioning reliability, said that hydraulic ram seals quite frequently had to be renewed.

MR. R. M. CHAMBERS (Massey-Ferguson, Ltd.) asked if the efficiencies described with hydrostatic tractors would be obtained by the average farm worker, or whether any means could be devised to tell him when he was getting the maximum efficiency.

MR. NATION reported that, in their experience, tractor drivers using hydrostatic transmission models seemed quickly to get used to the knack of throttling down the engine and opening up the pump when possible. It was, however, quite reasonable, he thought, to include some provision on production tractors for doing this automatically.

THE PRESIDENT said that he could not possibly sum up such an important Paper. It was now up to manufacturers to carry out market research on, and above all demonstration of, hydraulic equipment and transmissions so that the farmer could appreciate their potentialities. He referred to the tremendous debt this country owed to the National Institute of Agricultural Engineering, where hydrostatic transmission in tractors had really started.

MECHANISING THE PUDDLING OF RICE LANDS

by Dr. R. H. Richharia and Sri M. Subbiah Pillai
(Central Rice Research Institute, Cuttack, India)

An abridged Paper presented at an Agricultural Engineering Symposium, Indian Institute of Technology, October, 1960.

Introduction

It is well recognised that a transplanted rice crop gives invariably a bigger and bettei yield than a direct sown crop for various reasons. But unless a variety is planted in its right planting period, it does not give its maximum yield. If the planting is delayed beyond its critical planting period (the critical period being defined as the time-lag between the beginning and ending of the planting in the season, the time-lag being about three to five weeks, depending on the variety), the yield is very much affected ; the amount of decrease in yield increases progressively with the delay in planting, and the very late planted crop gives less than half of its normal yield.*

Further, it is also well established that for the rice crop green manuring *in situ*, supplemented with 20 lb. of nitrogen in split doses, is the most economical and judicious method of increasing its yield, instead of adopting the customary practice of manuring the crop with farm yard manure, compost, etc.

With this background, the puddling of rice soils (which is obviously a pre-requisite condition for tians-planting) is discussed below in all its aspects.

Puddling by Bullock Power

The customary practice is to plough the land with 2 in. to 3 in. of water till a soft puddle is created. Usually five to six ploughings, done in three courses, with an interval of about four days between each course, create a good stirring of the soil and produce an ideal puddle for planting. A rice cultivatoı in a double-cropped land area would have to own one good pair of bullocks for a holding of about four acres, so that it may be possible for him to prepare the land and plant his crop within the critical planting period for good yield. A pair (the charge being Rs. 3.00 per day) can cover, on an average, 0·4 – 0·5 of an acre in a day, depending on the nature of the soil. But, in fact, this is not the case with amjority of the cultivators, and as a result the planting is delayed, with consqeuent reduction in yield. Further, it may also be mentioned here that the growing of green manure crop *in situ* is increasing in the rice areas ; but unfortunately, due to the poor build of the animals in wet land tracts, the incorporation of the green manure crop is not effective. This system therefore causes further delaying of the puddling operation.

It is evident that puddling with bullock power is drudgery and a tedious process. Therefore, the problem of puddling as expeditiously and efficiently as possible by mechanising the work with tractors has been experimented upon at the Central Rice Research Institute, Cuttack, in India since 1956. As a result of testing different types of tractors with puddling accessories, the Ferguson tractor with its puddling arrangements was selected, and this tractor was and is being used for puddling rice soils at this Institute (the pattern of soil ranging from sandy loam to loam and slightly heavy, silty loam) over a large area of about 100 acres. The results of trials for the past three years are given below.

* *cf.* " Optimum Time of Planting " of the ICAR monograph " Cultural Trials and Practices of Rice in India," by Subbiah Pillai.

Puddling with Tractors

The Ferguson tractor FE-35 (Diesel) with steel extension wheels fitted to standard pneumatic wheels, complete with Ferguson paddy disc harrow, is used for puddling. The field to be puddled (whether a green manure crop exists in the field or not) is irrigated the previous day to a depth of 9 to 12 ins., and the tractor is then worked lengthwise and breadthwise once. This operation buries the weed-stubbles and the green manure crop effectively, and makes the soil loose and partially puddled. Usually after a lapse of a week the tractor is again worked once or twice, as the case may be, depending on the state of puddle obtained, to round off the puddling operation for planting. This *modus operandi* seems to be ideal in getting the desired puddle.

The trial with this tractor has shown that it can cover an area of about 0·95 acre in one hour in terms of single disc harrowing. The cost of working (inclusive of depreciation on capital outlay, operative wages, fuel cost, etc.) per hour is Rs. 8/-. It would therefore be possible to puddle about 1·9 or 2·5 acres, in terms of 3 or 4 disc harrowings respectively, in a day of eight hours' working. The cost of puddling an acre would range from Rs. 25/- to 34/-. It may be pointed out here that the cost mentioned above would become much lower, by about 35 per cent., if the tractor is put to use for other agricultural and non-agricultural operations during the off-paddy season. The efficacy of the tractor is about twentyfold compared with bullock-drawn equipment. The cost of puddling an acre with bullock power or tractor would work out to Rs. 36/- to 45/- or Rs. 25/- to 34/- respectively.

Merits and demerits

1. By virtue of the greater inherent efficacy of tractor power over bullock power, rice crop can be planted in time, with attendant increased yield of about 25 per cent. (over delayed planting).

2. Tractor power can be requisitioned for a greater number of hours, if need be ; unlike bullock power, which has a limitation in that the bullocks cannot be made to work for more than seven to eight hours a day.

3. The tractor power can be made available throughout the season, whereas in the case of bullock power this

cannot be assured. Bullocks may fall sick now and then, especially, during the season, when accidents caused by the sharp stubbles of green manure crop or the running of plough shares into the animals' hooves occur.

4. In land infested with foul grass and weeds, where bullock power is useless to bring it to good condition, the tractor is found eminently suitable.

5. In fields of inadequate moisture, where bullock power is unable to open the soil, tractors can be used with ease for exposing the soil to a greater degree of weathering action and to facilitate the early sowing of the crop for better production.

6. In the off-season, the tractor can be put to various purposes (*i.e.*, hauling heavy loads, pumping water from great depths, etc.) for which bullock power is unsuitable.

7. Wherever feasible, it would be possible to bring an additional area, to the tune of 2 per cent. out of the existing area under rice, under cultivation if the bunds of the small fields separating each other are removed, uniformly levelled and converted into convenient blocks of about two acres. (The larger the size of the field, the greater is the efficiency of the tractor.)

8. Mechanisation would release labour, which can thus be diverted to other professions to build up the national economy.

As against the merits listed above for the tractor, the demerits are as follows :

1. If a major breakdown were to happen, it would take time to set it right, and this would paralyse the work of the cultivator and protract his planting. In the case of bullock power, it is most unlikely that all the pairs would be suffering from sickness at the same time, and therefore it would be possible to keep going with the puddling operation for planting, though with certain limitations.

2. It is essential to have carefully-planned and well laid out pathways and approaches to the fields for the easy access of the tractor for its efficient working (in most of rice tracts such favourable conditions do not exist).

3. It is technically possible to puddle the corner portions of a small field also with this tractor, but in practice it has been found that the work of puddling corners consumes more time than is required for puddling a similar area of the main portion of the field.

4. If a rice cultivator is to own one tractor, he should have a compact block of about 75 acres. The fields should be fairly large-sized ones, as otherwise it would not be economical. Except in flat alluvial tracts, the size of the field, owing to undulating nature of the soil formation, is rather small, ranging from 0·1 to 0·2 of an acre. The majority of farmers have very small holdings, and these too fragmentary and scattered over many places. These limit the scope for mechanisation.

5. Puddling with tractors is feasible only in land which has a fairly firm bottom at the subsoil. If the soil is very loose to a great depth, and the soil particles are of a sinking nature, the tractor is often bogged. For such soils, the tractor is not suitable.

6. Mechanisation may cause unemployment in rice tracts with dense population. But the labour so released can be profitably diverted to other professions, as referred to elsewhere.

7. In the rural areas, the facilities for prompt servicing and repairing of the minor defects that normally occur in a tractor are still rudimentary. Adequate spare parts are also not readily available from the dealers of the tractor manufacturers as a result of Foreign Exchange shortages.

8. The technical " know how " and the mechanical mindedness of the tractor drivers are not yet well developed, and there is great scarcity of skilled drivers in the country. The last mentioned two factors impede the progress of mechanisation where genuine attempts are made by progressive cultivators for better and more economic production of their crops.

Conclusions

1. Partial mechanisation—*i.e.*, puddling of rice soils—is very desirable, especially in tracts where the population of human and bullock power is thin and the planting or direct sowing of rice cannot be carried out within the critical planting or sowing period.

2. This is one of the best means by which rice production can be stepped up in the existing rice areas.

3. This will not greatly jeopardise the labour economy of rice tracts.

4. Mechanising the puddling of rice soils is more economical and more efficacious as compared with bullock power.

Appendix

Under actual operating field conditions, as encountered in Nellore, Krishna and Godavari districts in Andhra Pradesh, and Chingleput, Trichy and Tanjore districts of Madras State, the chief paddy growing areas in South India, users have recorded their findings in the following terms :

	MF Tractor	*One pair of Bullocks*
Average area covered in one hour (one run), taking all types of soils into account	1·25–1·50 ac.	0·06–0·86 ac.
Number of passes or runs required :		
(*a*) Light, loamy soils..	2 runs	5–6 runs
(*b*) Medium soils ..	3 runs	6–8 runs
(*c*) Heavy soils ..	4 runs	8–10 runs

When standing crops of green manure are to be trampled-in, an extra run will be required with the tractor in all cases. But with bullocks, manual labour will have to be engaged separately for cutting and trampling-in the green manure.

Levelling also can be done with MF tractor, along with the final run, thus getting the field ready for transplanting. With bullocks levelling is a separate operation.

Operating cost per acre :

With MF tractor and paddy disc harrow : 3 runs, Rs. 18·00 – 19·50 ; 4 runs, Rs. 24·00 – 26·00.

With one pair of bullocks : 6 runs, Rs. 45/- ; 8 runs, Rs. 60/- ; 10 runs, Rs. 75/- ; trampling-in green manure and levelling extra.

AGRICULTURAL ENGINEERING PROBLEMS IN AUSTRALIA

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SUMMARY

THE Australian farm must necessarily be highly mechanized. An extensive farm machinery industry serves the country with tractors and implements designed overseas and with some equipment developed for local conditions. But there is need for greatly increased research and development work on local mechanization problems. Water conservation and usage, tillage, fodder conservation and the sheep industry are briefly discussed in order to illustrate some tasks for the agricultural engineer. Research work would be more effective if a national institute led the efforts of the present research groups, industry and individual farmers.

Advisory services in agricultural engineering are limited, and it is argued that diploma-level training is urgently needed if this position is to improve. Soil and water topics would be as important as mechanical ones in the training courses for extension officers.

1 Background

The agriculture of a country and the consequent engineering problems are governed by climatic, geographical, pedological, social and economic factors. Australia, almost the size of the United States mainland, has more than its share of problems under each of these headings. First among them is the rainfall picture. The arid centre of a million square miles has an average of less than 10 inches annual rainfall. Even this meagre rainfall is unreliable and unevenly distributed, and much is lost because of the high evaporation rate.

Around this core lies a semi-arid area of more than a million square miles in which there falls sufficient rain to support grazing for sheep and cattle. Only in the remainder—about a quarter of the total area—are agriculture and animal husbandry of an intensive kind possible. When the inevitable deductions are made for mountainous areas, unmanageable weed growth, unsuitable soils and rotational practices, only some 25 million acres of this vast land are presently available for cropping. To increase this figure is a joint task for the agriculturist and the engineer.

Much of Australia's pastoral industry is made possible by the existence of artesian and sub-artesian water supplies. Twenty per cent of the sheep depend on such water, but it is usually too saline for irrigation.

One of the great hazards of our farming is drought, a very dry year which is likely to occur once in every seven or eight years; during a drought year stock losses (by starvation rather than drought) are very high, and crop surpluses are rapidly turned into deficits. Ironically enough floods are equally to be feared in low-lying areas near the major rivers.

Social and economic factors influence our farming practice. All workers receive fairly high wages at rates which are enforceable by law; working conditions are also legally prescribed. There is no pool of lowly-paid labour available at harvest time, a fact which must be borne in mind when reviewing the costs of our tropical crops like sugar cane, cotton, tobacco and pineapples.

Contracting services are limited in the main to work such as earth-moving, well-sinking and sheep shearing; the size of the properties and the great distances between country towns tend to make versatile contracting services uneconomic.

By European standards, production per acre is low and farming properties have to be large in order to give a reasonable income. Our export income derives largely from wool—a fibre which, for all its superb qualities, is feeling the competition of synthetic fibres—and wheat, a commodity which must be produced cheaply if the crop is to be sold on world markets. While there are protective practices for some farm products consumed within the nation, wool and wheat must meet external competition.

Thus, a faint picture emerges of the Australian farmer and his problems. He will need rugged machinery that can deal with large areas under tough conditions. Repairs of all kinds must be made on the farm if at all possible; hence the need for a good spares service and well-written, comprehensive instruction manuals. He will seldom employ more than one man and often will work hundreds of acres single-handedly; so he is always seeking efficient one-man methods of operation. He wants versatile machinery, and in particular is interested in tractor attachments which make him independent of contracting services. He is especially interested in materials handling methods and in efficient farm transport.

2 The Farm Machinery Industry

Australian agriculture is served by an extensive and varied farm machinery industry. All the large international companies of Britain and the United States market their products, and these dominate the market. But we also have Canadian, German and Italian machinery. With the growth of secondary industries, more and more companies find it profitable to manu-

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facture within the country and the state of Victoria in particular has felt the benefit of this development.

There has always been a local farm machinery industry producing machines that suit local conditions and these firms tend to align themselves with, or be absorbed by, the big international companies. Nevertheless, it would not be difficult to name a dozen small firms whose inventive genius has succeeded where the resources of a mammoth organization have failed. Often this arises because of an intimate knowledge of a local problem; it is a fact that the founders of many Australian farm machinery firms have been farmers who have exploited their own inventions. Some of this vitality of invention tends to be lost in large companies, where departmentalization, complex procedures and commercial caution slow down initiative.

Undoubtedly we suffer from the lack of a national body, something on the lines of the National Research and Development Corporation, which would examine inventions and carry out the necessary work on the most promising ones to make them acceptable to industry. In fact, this is part of a broader need for an institute having a research programme of its own and a testing division. Very little testing of an objective kind is carried on apart from the testing of tractors and ancillary equipment at a testing station at Werribee, Victoria. It is unlikely that any of the states can or will finance an agricultural engineering institute, and any such body would need federal finance. In any event, its testing activities would require facilities in several areas representative of different climatic and soils conditions.

Farmers' organizations repeatedly pass resolutions urging the establishment of a national institute of agricultural engineering of some kind. Some want only testing facilities, some research and development; and others a super-advisory body. Prominent members of the farm machinery industry have spoken in favour of the proposal, but so far nobody has produced a workable scheme with clear objectives.

3 Water Conservation and Usage

Water is the key to Australian farming and indeed to the whole future of the country. There are limited areas in which irrigation schemes can be developed, and at the present time the Snowy Mountains scheme is greatly enlarging the supply of irrigation water. But, outside publicly-financed developments of this kind, much can be done in making a closer study of the water resources we have and in devising economic means of using the available water. Mention should be made here of the Water Research Foundation of Australia, a non-government organization which is financing many projects in the fields of hydrology, farm water supplies and irrigation.*

Spray irrigation is a greatly expanding practice. There must necessarily be strict control of the water taken from rivers, since even the largest have been known to cease flowing in dry years. Consequently there is considerable interest in the question of on-farm water storage for spray irrigation.

A highly promising method of water conservation and usage, known as Water Harvesting, has been developed by Mr. H. J. Geddes, Director of the Animal Husbandry Farms of the University of Sydney. The system is particularly useful in areas of rolling country where the rainfall is reasonably good when viewed as a long-term average, but is so erratic in distribution that much water is lost in the myriads of small creeks which flow violently after heavy falls and then dry up.

The economics of spray irrigation, in the absence of permanent streams or huge public reservoirs, needed to be examined. The first step at the university farm was to site and build the first dam. This was done after an accurate survey, and the reservoir gave a storage of 36,000 cubic yards (6 million gallons) in return for moving 6,000 cubic yards of soil—a storage : excavation ratio of 6 : 1. The soil of the area is a poor, heavily-leached grey soil overlying a sticky clay sub-soil. While unfavourable for cultivation, it is excellent for building water-tight embankments. A series of contour drains helped in the efficient usage of the catchment area. Other dams have been built and all are adequately filled in the occasional deluge.

Mr. Geddes has also turned his attention to the problem of water storage in flat country. The outcome was the use of ring tanks, or turkey nest tanks, and filling them by high-volume, low-lift pumps from the creeks at times of heavy falls. In a ring tank, an embankment is built entirely above ground by removing soil radially outwards. The first turkey nest built at the University farm had a capacity of 8·5 million gallons and was 150 yards in diameter. The walls were built by excavating the soil from just inside the bank. The reservoir had a storage : excavation ratio of 6·5 : 1. Others have successfully built large turkey nest tanks and the biggest in New South Wales covers 30 acres and has a capacity of 67 million gallons.

The complete scheme now comprises 14 dams built across valleys and filled by gravity, and two turkey nests on the flat area filled by pumping from the creeks. The two forms of water harvesting have been carefully planned to be complementary to each other. While the gravity dams fill during the short periods of local run-off, the turkey nests can be filled by the more expensive method of pumping after the storm has passed. In pumping out, the lower reservoirs are used first, so that they receive the overflow from the higher dams as well as the run-off from their own catchment areas. Then, to reduce evaporation losses, shallow water is used first whenever possible.

None of the engineering features of the water harvesting scheme are claimed to be new, but it has shown that on-farm water storage for irrigation is practicable and profitable in areas thought to be denied irrigation. It has shown, too, that losses from exaporation are less serious than is generally supposed. One factor often

* A series of technical bulletins has been published by this body and can be obtained from the Secretary, Water Research Foundation, University of New South Wales, Sydney, Australia.

overlooked in this connection is that when evaporation is at its highest the need for irrigation will probably be greatest, and as soon as the irrigation pumps start the surface area of the reservoir begins to decrease. (The Mansfield cetyl-alcohol process may make a great reduction in evaporative loss from open tanks.)

Water harvesting has been widely adopted outside the coastal area for which it was developed, and it has made possible a much greater area of spray irrigation.

4 Spray Irrigation Equipment

With large areas to cover and high labour costs, irrigation equipment must use the minimum of labour, and so self-moving lines are of particular interest. A system of this type is the Rainline in which a long line rotates about a central position to which the main water supply is brought. In this system, the cost of the line is roughly proportional to its length, while the area covered is proportional to the square of the length; so for economy the lines have to be long.

A long line is built up of numbers of sections, each of which is moved by a trolley mounted on tracks and operated by a hydraulic jack and a ratchet mechanism. The jets along the line are graded in size, being larger the further away from the centre, thus giving a fairly uniform rate of application. A cantilevered arm at the end with a powerful jet further increases the irrigated area.

The speed of rotation of the line is set by the speed of the outermost trolley. As it moves around the circle, the outer section will form an angle less than 180 degrees with its neighbour. This angularity is used to open a valve which operates the corresponding hydraulic jack, and so this section will start to move. When it has straightened the line, the water supply to the jack is switched off. This action is taking place all along the line. Suitable safety devices are incorporated in order that the whole system can be left unattended for the complete period of irrigation. As one revolution of the line takes several hours, it is possible to continue grazing while irrigating.

The supporting trolleys can be turned through 90° in order to lie along the direction of the main line. Tension cables are then used to keep them at a fixed distance apart and the whole line can then be quickly disconnected from one supply point and towed to another.

5 Tillage Practice

In the early days of wheat farming it was found by bitter experience that the European practice of ploughing fairly deeply with a mouldboard plough, thus exposing the bare soil to the erosive effects of wind and rain, was unsatisfactory. In its place a method was developed using implements that leave a surface residue of crop residues and soil. The wide vertical disc or wheatland plough and the heavy-duty cultivator, known locally as a scarifier, are commonly used for both primary and secondary tillage.

For newly-cleared ground, robust disc ploughs are used in which each disc is carried on its individual arm, the arm itself being spring-mounted.

The scarifier is a popular implement because of its low draught per unit width and its axial line of pull. A model commonly used in the wheat belts has 25 tines at 6-inch spacing. Each tine is individually sprung to give a stump-jump action and the machine has a high ground clearance in order to avoid build-up of trash and consequent clogging. In recent years there have been spectacular sales of chisel ploughs. These ploughs have heavy-duty curved tines usually spaced at one foot intervals in a balanced array, and for the first working they are fitted with narrow chisel points. These may be replaced by sweeps for later workings in order to give better clearance of shallow-rooted weeds.

In the marginal wheat areas there is a great deal of interest in wide sweep ploughs of the type used in the drier areas of the United States wheat belt. An Australian-made blade plough excited interest a few years ago but it failed commercially, chiefly due to its excessive draught. A few wide V-sweep ploughs have been imported and tested but have failed to suit our conditions. Undoubtedly stubble-mulch farming is a proven practice for conserving moisture and avoiding erosion and there is little doubt that research and development work could develop acceptable implements for tilling the soil and sowing into the trashy surface.

Research into the problems of tillage is being carried on in several places. The Commonwealth Scientific and Industrial Research Organization at Melbourne is investigating the forces acting on a disc plough.[1] Dr. J. R. Phillips[2] of the University of Western Australia has made fundamental and experimental studies of the obliquely rolling wheel, analogous to the disc of a trailed disc plough, and of plough-frame design. The agricultural engineering group of the University of New South Wales has designed a six-component hydraulic dynamometer for the study, initially, of the forces on tined tools. A report will shortly appear on this work.

The draught of tillage tools is naturally of interest from the standpoint of power consumption, but of equal interest is the study of penetration difficulties. With widely-spaced tined tools, the shape of the undisturbed soil surface and the break-up of disturbed soil are clearly of interest. A further problem, on which the author has done preliminary work, is a study of the wear of tillage tools and the consequent change in draught and penetrating ability. Some Australian soils are highly abrasive and tillage costs are high owing to the cost of new tools and to the field time lost in their replacement.

6 Fodder Conservation

Until the nineteen thirties, the practice of fodder conservation was not widely spread in Australia. By various means it is possible to get through the winter without regular storage of pasture surplus, and provision for the occasional drought year was thought to be uneconomic.

This position has changed dramatically since the war. The advent of the pick-up baler has revolutionized haymaking; by comparison with other methods, baled hay requires little labour, is economic for large acreages, and is easily stored for long periods in open-sided barns. But the capital investment in the complete process from mowing the pasture to storing the bales is high, and hay-making by this method is largely restricted to properties having fertile areas such as as river flats where several cuts of lucerne are made in one season.

Fodder conservation took on an entirely different aspect when the forage harvester was shown to be a cheap means of making silage. The buck rake before it had prepared the way. The flail-type harvester with attached self-unloading wagon has become very popular and is the basis of present methods of silage making. Unloading at the pit is done in various ways; often the green material is dumped in piles near the pit edge, and later pushed into the centre in a separate operation by a front end rake. Wherever possible the wagon is driven right through the pit so that the load can be dumped as required. But the stability of the tractor and wagon combination is sometimes a problem and there are some accidents both in filling and in the compacting operation.

Recently the powered wagon in which the fodder is propelled sideways by a fast-moving belt has come on to the market, but the farmer has to be able to use this in other ways beside silo-filling before he can justify the high first cost.

Our silage-making methods are open to some objections. The flail-type harvester is criticized for its tendency to pick up dirt and stones along with the crop. The cut material is long and does not compact so well as chopped material. There is no wilting of the crop so that great quantities of water are transported from field to silo. The loss of nutrients in the pit silo is high and there is a good deal of spoilage at the sides, floor and roof through contact with the earth. And of prime importance is the problem of feeding out from a pit silo.

With all these faults, the hard fact remains that the process is cheap enough to work. Both labour and capital requirements are low, and the flail harvester itself is mechanically simple.

New ideas are constantly being tried. There have been experiments with polyethylene covers for silo stacks and also a vacuum silage technique. In the latter, the stack of silage is first built on a plastic sheet laid on the ground and the pile is made cylindrical by a surrounding steel strap. A man on the stack spreads the cut material evenly and treads it down at the edges. This treading has the action of raising the strap vertically so making a neat cylinder. Then when a suitable height is reached, a cylindrical plastic cover is placed over the pile and this is sealed to the base by means of wide adhesive tape. A suction pipe is then inserted through the wall and the enclosed air is withdrawn by a vacuum pump driven from the p.t.-o. shaft of the tractor. In two hours or so, the mass is compacted to a pile of about four feet high. Silage made in this way is highly palatable to livestock, but there are difficulties in avoiding accidental and rodent damage to the plastic sheet.

The Engineering Section of the C.S.I.R.O. has made a contribution to the feeding-out problem in their development of a silage loader. This takes the form of a small swivelling jib mounted on a turntable. The crane rope is actuated through a pulley system by a hydraulic ram, and carries a tined grab at its free end. The hydraulic system of the tractor is the source of power. This silage loader has a capacity of about six tons per hour and it is now being produced commercially in Victoria.

Our methods have to be still further improved before the practice of fodder conservation becomes as universal as it ought to be.

7 The Sheep Industry

Australia possesses about one-sixth of the world's sheep and produces one-quarter of the world's wool. Great numbers of merino sheep graze in the arid areas where the natural fodder supports one sheep on 10-15 acres. Under such conditions there is little call for mechanization except in fencing methods and in the shearing shed. Shearing machinery is highly perfected and, within the limitations of the standard bale, which is heavy (300 lb.) and cumbersome, handling methods are efficient.

Closer to the coast, however, the wheat-and-sheep farmers take a more critical view of production costs and engineering methods are replacing the hand-labour methods that have held for a century. Sheep dipping has been revolutionized by spray races in which an array of high-pressure jets cover every part of the fleece with a protective solution in the time it takes a sheep to be driven through a distance of about eight feet. A circular chamber, with the jets placed above and below, is also effective. Yet a third method, recently invented, takes a small number of sheep into a cage which is then bodily lowered into the solution by hydraulic means.

The classical methods of hand shearing are being tackled by the use of shearing tables of various kinds. These restrain the sheep while they are being shorn and the problem is to do this while still allowing the main fleece to be taken off in a single parcel. These tables are not yet acceptable to shearers for the main operation, but are useful for stud sheep shearing and odd beasts that miss the main shearing season.

The standard wooden press in which the wool is compressed into the bale by levers and brute force can now be modified to be operated by an ingenious ratchet mechanism requiring only a 1 h.p. motor.

So far nobody has solved the problem of continuous baling, which would appear to be a desirable method. Here the principal difficulty is the enormous capital tied up in handling and marketing the bales in their present form, shape and density. Wool is sold by auctioning individual lots of uniform quality and the system requires that the bales can be easily cut open for display to the buyers. After purchase, the lots are compressed in a hydraulic " dumping " press into smaller and denser bales for shipping.

It seems that any advance in wool handling techniques must suit this marketing system.

8 Extension Methods in Agricultural Engineering

Not all our problems in agricultural engineering are those for engineers alone, and extension work is an example. In all the states there are excellent advisory services on agronomic matters and animal husbandry; this is true also of soil and water conservation, although these services are the responsibility of different government bodies. The important omission in advisory work is in farm mechanization. The state departments of agriculture employ very few, if any, engineers although there are a number of farm mechanization specialists who do what they can to advise by lecture and pamphlet. Their efforts are necessarily limited by lack of engineering training and the absence of experimental facilities.

Much progress is due to farm machinery companies with their advertising literature and field demonstrations, and to farming journals. But if these are enough in farm mechanization, they should logically be enough for the many other forms of farm activity which everybody recognizes to need a network of advisory services.

Part of the trouble is the absence of training schemes for agricultural engineers. Until the introduction a few years ago of the degree course in agricultural engineering at the University of Melbourne, there was no integrated course of instruction at any level. The agricultural colleges in their diploma courses do give descriptive courses in farm machinery and practical workshop instruction and a few people have built on these by self-study a sufficient body of knowledge to claim to be agricultural engineers. Others have come up the hard way through the workshops of machinery companies and improved their theoretical knowledge in any way that offered.

But at this time in Australia agricultural engineering is hardly a profession as it is in the United States and Canada where it is identifiable by well-tried courses of instruction, professional recognition and a wide range of job opportunities. The degree course at Melbourne and the research activities in C.S.I.R.O. and the universities are jointly the means by which this situation will rapidly change. Many of our civil engineers in soil and water conservation become, in time, agricultural engineers although one could wish for a firmer base to their agricultural knowledge.

We need now to develop courses at semi-professional level to provide the men who will back up these professional engineers. In mechanical engineering generally, some five or six more technicians are required for every qualified engineer and the ratio will be no less for agricultural engineering. Indeed, because of the nature of extension work, the ratio may be a good deal higher. There are indications that some state agricultural colleges are considering diploma-type courses in farm mechanization, and for these to have an adequate foundation in engineering science there should be active collaboration with the engineering departments of the universities or major technical colleges.

In considering the type of training needed by extension officers, both at the degree and diploma levels, equal weight must be given to soil and water matters as well as farm machinery; for that matter, rural electrification should also be a strand of study. There are no ready-made models for the training courses we need and, apart from any problems in the recognition of Australian diplomas by overseas bodies, this is no barrier to an early start with them.

SUMMARY

There is endless scope for research and development in the engineering aspects of Australian agriculture. The farming community is receptive to new ideas and many advances have originated on the farm. An organization that developed and tested new ideas and products would return a worthwhile dividend.

Advisory services in farm mechanization are sadly lacking, but with training facilities at the technician level to supplement those already existing at professional level, this defect could be remedied within a few years. For greater effectiveness, advisory work should embrace soil conservation and water conservation and usage in conjunction with farm mechanization.

The paper has given as examples some problems in water usage, irrigation, tillage, fodder conservation and the sheep industry. But there are many others in land clearance, weed control, pasture improvement, materials handling,[3] and in the production of special crops such as sugar cane, peanuts, tobacco and fruits. While advances made overseas are readily available to Australian farmers, there remain many problems which only local effort can solve.

REFERENCES

[1] C.S.I.R.O. Engineering Section. Annual Reports 1959-60, 1960-61.

[2] PHILLIPS, J. R.: "Some Problems of Mechanics Met in Designing the Disc Plough." Vth International Congress of Agricultural Engineering, Volume II, 1958.

[3] ROBERTS, A. W., and WILLIS, A. H. "Performance of Grain Augers." Proc. Inst. Mech. Eng., 1961. In Press.

Further Publications on Australian Work in Agricultural Engineering

DOYLE, A. B., "Engineering in Primary Production," *Journal of The Institution of Engineers*, Australia, 1953, 25, pp. 163–174.

JOHNSTON, R. C. R., "Crop Behaviour during Mowing," *Journal of Agricultural Engineering Research*, 1959, 4, pp. 193–203.

KELSALL, D. F., and others, "Development of a Machine for the Dissolution of Gypsum," *Journal of Agricultural Engineering Research*, 1960, 5, pp. 355–362.

MCCLELLAND, J. H., "Static Grass Tester," *Australian Journal of Instrument Technology*, Nov., 1956, 12 (4), pp. 156–160.

MCCLELLAND, J. H., "Instrument for Measuring Soil Condition," *Agricultural Engineering*, July, 1956, 37, pp. 480–481.

MCCLELLAND, J. H., and SPIELREIN, R. E., "An Investigation of the Ultimate Bending Strength of some Common Pasture Plants," *Journal of Agricultural Engineering Research*, 1957, 2 (4), p. 288.

MCCLELLAND, J. H., and SPIELREIN, R. E., "A Study of some Design Factors affecting the Performance of Mower Knives," *Journal of Agricultural Engineering Research*, 1958, 3, pp. 137–146.

PHILLIPS, J. R., Brief description of the six-component oblique-rolling-wheel machine recently constructed and tested at the University of Western Australia. 1st Inter. Conf. on Mechanics of Soil-Vehicle Systems, 1961.

PHILLIPS, J. R., A discussion of slip and rolling resistance. 1st Inter. Conf. on Mechanics of Soil-Vehicle Systems, 1961.

PHILLIPS, J. R., "Experimental Determination of the Forces on some Towed Drifting Wheels," *Journal of Agricultural Engineering Research*, 1959, 4, pp. 294–306.

VASEY, G. H., "Rotary Cultivation in Australia," *Journal of the Australian Institute of Agricultural Science*," Mar., 1941, 7 (1), pp. 11–19.

VASEY, G. H., "Hydraulic Torque Convertors in Tractors, *Proceedings of the Automobile Division of the Institution of Mechanical Engineers*, 1957–58 (4), p. 103.

VASEY, G. H., and BAILLIE, W. F., "Tractor Testing in Australia," *Journal of the Department of Agriculture for Western Australia*, 1960, 1 (11), pp. 1,029–1,034; (12), pp. 1,085–1,086, 1,089, 1,090–1,092.

VASEY, G. H., and BAILLIE, W. F., "Some Experiences with the Testing of Spark Arresters for Tractor Engines," *Journal of Agricultural Engineering Research*, 1961, 6 (1), pp. 72-78.

DISCUSSION

MR. H. FAIL (University of Durham) began the discussion on the Paper by saying that it was pleasing to him that Professor Willis was the Dean of the Faculty of Engineering and not of Agriculture. He had known Professor Willis for many years and had sympathised with his struggles to get the powers that be in Australia interested in his subject. Mr. Fail had had the honour to be asked over to Australia for two months in 1960 to discuss Australian farm mechanisation.

He had found the people virile and vigorous and confident of the future. But his impression was that agricultural engineering and farm mechanisation were neglected in official circles in Australia, just as in this country immediately after the war. There was no programme of education for agricultural engineering, except the Melbourne degree in that subject, though the people Mr. Fail had met in the State departments and elsewhere seemed to be more anxious about farm mechanisation than agricultural engineering. Similarly, there was no national organisation for research in agricultural engineering, nor a specialist farm mechanisation advisory service. Advisory work in all other branches of agronomy was provided for, however, and was extremely well done.

Mr. Fail asked Professor Willis if some of the facilities in this country could be applied in Australia. He referred particularly to the Durham M.Sc. degrees in agricultural engineering and agricultural mechanisation, to the new National College of Agricultural Engineering, and to the various courses run by machinery manufacturers. He also referred to the achievements of the agricultural engineering industry in this country, which, he said, produced the best tractors and machinery in the world and exported over £100 million worth last year, this year's figure being over £130 million so far. Besides that, in this country there was one tractor to every 60 to 70 acres, and that had enabled production in Britain to be increased by 50 per cent. per acre and output per man by about 28 per cent.

Mr. Fail had read a lot in Australia about share farming, whereby a farmer provided most of the things wanted and the partner supplied, perhaps, the labour and various other items, and he wondered how this practice worked out. He thought that wool baling could be mechanised, for the physical labour involved was very hard and taxing. The other " cruel " thing he had seen was sugar cane harvesting by hand. It should be possible to develop a sugar cane harvester rather than using hand methods.

MR. J. C. HAWKINS (National Institute of Agricultural Engineering) mentioned the signs of erosion in so many of the slides that Professor Willis had shown. Was this erosion natural or man-made, resulting from mishandling ? Could it be avoided by better attention to the conservation of water at the point where it fell ?

Mr. Hawkins said he had been concerned in Africa with systems of water conservation other than the mulch system of ploughing. He showed three slides to illustrate the line of attack he and his colleagues were adopting. The first one showed the pattern that they were after, with crops growing on ridges ; they could be arable or grass. The furrows between the ridges were dammed at intervals, so as to form small multiple ponds over the surface, resulting in the rain being held until it could filter into the soil. The equipment used was a normal toolbar and fittings, with separate tools mounted behind to create the dams. Then Mr. Hawkins showed a composite slide to give some idea of the results. At the top of the picture was a crop grown on the flat, and at the bottom one grown on these tied ridges. The superiority of the latter was obvious. He thought this new method of cultivation might have a future in Australia.

Mr. Hawkins agreed that attention must be turned to areas of marginal rainfall if the land were to be found to produce the food that was going to be needed in the world. The development of new methods of tillage was going to be very important, and, if there was time, he would welcome some more words on this subject from Professor Willis.

COL. W. N. BATES (Chelsea College of Engineering) referred to two articles, published in 1959 in *World Crops*, dealing with the Mansfield process, which used cetyl alcohol to reduce evaporation from dams and reservoirs, and asked if it was a popular method. He also inquired if any Australian company was going ahead with the full mechanisation of sugar cane planting —*i.e.*, a machine with no labour requirements other than the tractor driver, or drives if self-propelled. He mentioned that a " Don " planter had been introduced into South Africa in 1951, but without any real success as far as he was aware.

Col. Bates also referred to teaching and extension work. It was difficult to keep up to date after one came home from overseas, and liaison and agricultural agronomists based in London were needed, so that information could be obtained reasonably quickly. While information was available from the F.A.O. and U.N.E.S.C.O., often it took so long that the student who wanted it had gone home by the time it arrived.

MR. L. C. PEARCH (Kent) declared that Australia could teach us something about irrigation. He was interested in the turkey nest dam system, and wanted to know if any work had been published giving the relevant information, such as on the thickness of dam walls required.

MR. D. J. VAN REST (University of Cambridge) took up a remark by Professor Willis about present-day technical training and inventiveness. Was there something wrong with technical training if it did not encourage inventiveness ?

MR. H. C. G. HENNIKER-WRIGHT (Ford Motor Co., Ltd.) saw a similarity between the conditions in Australia and those in Africa and some countries of Europe, such as Portugal and Spain. He suggested that greater use could be made of the results of the East African test unit of the National Institute of Agricultural Engineering, which tested implements and tractors under similar conditions to those in Australia.

MR. R. J. SIMS (Surrey Farm Institute) referred to Professor Willis's comment on the need for more educational staff in Australia. He had written to all the State departments inquiring about the prospects for employment, but had not received much help.

MR. I. J. FLEMING (Scottish Agricultural Industries, Ltd.) referred to an earlier remark that in Britain we had about one tractor per 60 acres. He felt that in this country we were wasteful of our tractive effort and that there was too much hand labour here, since the tractor could be used to lift unit loads. He asked if equipment to handle unit loads had been developed in Australia.

PROFESSOR WILLIS, in reply, first thanked Mr. Fail for his remarks and for his reminder that farm mechanisation and agricultural engineering were not the same. The share farming system was over 100 years old and worked very well. Like Australia's system of land purchase—and they had well-tried land purchase agreements—very little litigation resulted. Substantial progress in sugar cane harvesting was, in fact, being made, in particular by one big international concern. The barbarous conditions associated with wool baling had not been exaggerated, but a machine with a 1-h.p. engine, which had won a recent Orange Field Day Award of Merit, had been devised to mechanise the process.

Answering Mr. Hawkins, Professor Willis said that all the examples of erosion that he had shown were natural. In some cases man had interfered with Nature and had made the matter worse, but the Australian farmer was now very soil-conservation conscious and there was a good soil conservation service.

He thought Mr. Hawkins' device for pitting the soil excellent and did not doubt that it had an application in Australia ; if they could adopt it, then it should enable them to grow more maize. He said that he knew a little about Mr. Hawkins' work and would like to see experiments carried out in Australia on those lines ; he was sure that the same sort of results would be obtained.

The Mansfield process had come out with a blaze of publicity, although some engineers were still sceptical. The C.S.I.R.O. had allowed the process to be marketed, and the apparatus was known as the Mansfield raft. Speaking from memory, he gave the figure of 35 per cent. as the saving in evaporation by the use of this raft. He remarked that he did not know of a sugar cane planter on which a man to feed the cane into the machine was not required.

As for the point about liaison, he was a little surprised if the system was not working well. There was an agricultural attaché at Australia House and he thought that probably—with respect to him—he was overworked. Perhaps he had difficulty in getting engineering information. Professor Willis believed that the attaché would welcome some assistance in dealing with the many agricultural engineering questions that were raised with him. Speaking for Professor G. H. Vasey, of the University of Melbourne, as well as for himself, Professor Willis put out an invitation for anyone requiring information or assistance to write directly to them in Austrlaia.

He was not really in a position to answer the question on dam walls. So far as he knew, all the arguments had been as to the purpose of these walls. Some said that it was better to design a dam that was realistic and had less reliability than to put the whole question out of court by following public works practice and making the dams so expensive that they were not going to be built. Research was still being conducted on the strength of earth dam walls.

He could spend a lot of time to Mr. Van Rest's question on inventiveness. Teaching institutions all over the world were steadily knocking the creativity out of students, in his opinion—it was one of the biggest problems to-day. He thanked Mr. Henniker-Wright for his suggestion on the East Africa test unit. It was one more lesson he had learned while he had been travelling this year. Dpulication of effort could be avoided by personal contacts.

They were trying to develop the unit load system. There was a unit of the Ministry of National Development which had done a lot of work on unit loads for industry and had now turned its attention to farming, and the results looked fairly prmosiing.

THE PRESIDENT drew attention to the presence at the meeting of a representative of the agricultural attaché at Australia House. He would be pleased to see anyone with inquiries regarding Australia, and the President thought that was service indeed. The other most important thing that had emerged from the Paper was the difficulties they had in Australia with education and research. He hoped that in due course New South Wales would be able to have a similar institute to the National Institute of Agricultural Engineering. People in this country could be very proud of their facilities, and he referred to the parts played by the Institution and the A.E.A. in the formation of the National College of Agricultural Engineering.

ELECTIONS AND TRANSFERS

Approved by Council at their Meeting on 9th January, 1962.

ELECTIONS

ASSOCIATE MEMBERS

Basil, J. .. .. .. Lincs.
Dunn, J. S. .. .. Beds.
Ferguson, W. .. Warwicks.
Higginson, J. .. Yorks.
Mason, H. C. .. Herts.
Nation, H. J. .. Beds.
Percy, J. J. Northumberland
Rogers, H. B. Warwicks.
Wood, G. M. .. Beds.
Wortley, W. .. Worcs.

Overseas

Pinder, J. P. .. .. Angola
Sehgal, R. L. .. India
Thomson, J. I. Tanganyika

ASSOCIATE

Duckworth, J. .. Lancs.

GRADUATES

Evans, L. P. .. Warwicks.
Gedye, I. D. .. .. Essex
Griffiths, J. R. .. Worcs.
Hanavan, M. T. Northants.
Osborne, L. E. .. Herts.
Staples, R. O. Warwicks.

STUDENTS

Barber, A. D. .. .. Essex
Beeny, J. M. .. .. Lincs.
Halford, D. G. .. Suffolk
Shaw, G. J. Cheshire
Young, P. J. .. Yorks.

TRANSFERS

FROM GRADUATE TO ASSOCIATE MEMBER

Bottoms, D. J. .. Essex

Overseas

Gupta, R. West Germany

FROM STUDENT TO ASSOCIATE MEMBER

Overseas

Prempeh, H. R. B. A. Ghana

FROM ASSOCIATE TO GRADUATE

Holland, A. G. .. Staffs.

FROM STUDENT TO GRADUATE

Evans, D. J. .. .. Yorks.
Lewis, J. P. Shropshire
MacInnes, A. .. Scotland
Mundy, M. J. .. Surrey

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