MECHANICAL, ELECTRICAL OR HYDRAULIC TRANSMISSION?

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It is not very long ago that engineers had no alternative but to use mechanical drives in every situation, and there is thus a strong tendency to continue thinking only in terms of power transmission by mechanical connection; but at the present day, four possible methods of transmission are available to a machinery designer. These are the mechanical system, the hydraulic system, the pneumatic system and the electrical system. In considering the relative merits of these alternatives, the major and overriding point is that any one of the last three gives complete freedom for the functional design of a machine; this is because the transmission consists essentially of a flexible arrangement of pipe or cable between the driving and the driven members In the case of a mechanical system, however, the configuration of the machine must be such as to permit positive connection between driving and driven components. In other words, the flexibility of the hydraulic, pneumatic and electrical system allows the functional requirements of the machine to be the foremost consideration, whereas the rigidity of a mechanical system imposes severe limitations and forces a designer to think predominantly in terms of a suitable mechanical route. The second major point is that each of these three flexible systems can provide step-less speed variation over a wide range and can be stalled without damage; the latter feature is an advantage over variable-speed V-belt drives and so is the wider range of step-less variation which can be affected. On the other hand, a positive mechanical connection between components is most suitable where a precise fixed speed is required under variable load.

There are other advantages and disadvantages which will be discussed later, but it is first desirable to introduce the question of relative efficiencies. The efficiency of a mechanical system decreases directly with the number of components, since the losses are cumulative in a sequence of shafts, bearings, joints and gears, chains or belts. Thus, when power has to be transmitted through a complex mechanical arrangement in order to reach a certain component, the efficiency can be quite low (and the cost high). But the efficiency of an hydraulic, pneumatic or electrical drive is not affected by the relative positions of the driven member and the power source. Consider, for example, the transmission from a tractor engine to the auger of a baler: in one current design selected at random, the drive is through six pairs of gears and one V-belt, with considerable lengths of shafting, four universal joints and appropriate bearings; the efficiency will be about 75%. A comparable or better efficiency can be obtained with an hydraulic transmission to do the same work. There is little justification for any transmission system in which speed is first reduced (to the p.t.o. shaft) and then increased on the driven machine. Yet many examples exist. Another, selected at random, is the transmission to components of a forage-harvester through the usual P.T.O. gears and shafting plus a heavy chain drive, a 4-belt drive and two single-belt drives; the alternative consists simply of two hydraulic motors and a pump on the tractor engine.

It is therefore pointed out that comparisons between mechanical drives and the alternative types of drive need to be made on a specific basis, because the complexity of the mechanical system is a very pertinent factor. It is false to make a general assumption that a mechanical drive is always more efficient and less costly: this is only true in the case of the more simple mechanical arrangements. The point also applies when the extent or complexity of the mechanical system is due to a large speed ratio requirement, rather than to the position of the driven member on the machine; even when a mechanical system has a higher efficiency than the equivalent non-mechanical system, the latter may actually be justified on the grounds of a number of secondary advantages —such as complete safety, low maintenance under adverse conditions, no limitations on angles of movement, and compactness etc.—or because of the freedom of design which is afforded, or the ease and range of step-less speed variation which can be effected.

Pneumatic methods of transmission are most suitable for low power and high speeds, and are of particular value where a reciprocating action is required. In designing the drive to a mower sickle bar, for instance, it may be said that the alternatives are (a) the conventional pitman arrangement, (b) a rotary hydraulic motor with eccentric, or (c) a reciprocating pneumatic motor. The last two possibilities give less vibration and noise, and eliminate problems due to angular movement of the cutterbar. The pneumatic system has the least weight and probably the higher efficiency. However, it is suggested that there are very few applications for the transmission of power by pneumatic means on field equipment; but there is likely to be considerable scope for pneumatic actuation in the future automation of barn operations.

HYDRAULIC VERSUS ELECTRICAL SYSTEMS

Essentially, both hydraulic and electrical transmission systems are very similar. The hydraulic system consists of a pump driven by an engine, or other source of power, and supplying fluid at a known velocity and pressure through piping to an hydraulic motor; the electrical system consists of a generator driven by an engine and feeding through wiring to an electric motor elsewhere. In both cases, it is possible to effect step-less speed control, the motors have excellent torque-speed characteristics for variable-load installations, and the system can be stalled without damage to the transmission or overload on the engine.

In the case of power transmission between a tractor and a machine or between the engine and components of a self-propelled machine, there is little doubt that an hydraulic system is preferable to an electrical system. The latter is difficult to completely seal, is not so immune from damage, is not safe and generally does not have as high an efficiency. There is also the obvious advantage in that an hydraulic system can also be utilized to operate linear jacks for position control of individual parts of a machine.

Hydraulic systems are not only trouble-free as long as the oil is kept clean, but they are also foolproof; this is not always true with an electrical system. Another advantage of of the hydraulic over the electrical method is in the ease of effecting speed variation. In both cases, the speed of a motor can be varied by changing the speed of the engine and therefore of the pump or generator; this method is commonly used in the case of electrical transmission but has the disadvantage that the engine cannot be run at its optimum speed. With an hydraulic system, a variable-delivery pump can be used and the engine operated at constant speed; the equivalent electrical arrangements are less simple.

To permit variation of the speed of any one of a number of motors in the same system, it is necessary to insert a flow control valve in the line to each hydraulic motor, or a rheostat in the comparable electrical circuits. Although the latter may be less costly, the hydraulic arrangements for speed control are in general more suitable agricultural usage; furthermore, electrical systems usually require special arrangements for starting under load and must be specifically designed to withstand stall conditions.

There is not, however, sufficient evidence available at the present time to conclusively prove that either the hydraulic method or the electrical method is superior: the isue is still a matter of opinion and debate. Most of the work on oil hydraulics has been done in the U.S.A. and in Europe; most of the work on electrical transmissions has been in the U.S.S.R., with some in the U.S.A. and in Europe. An electrical transmission for a combine-harvester has been built in Denmark and the developments in the U.S.S.R. have also been mainly concerned with harvesting equipment. Should electrical energy ever replace mechanical energy from engines as the source of power for field machinery, then no doubt electrical transmissions will have a distinct advantage. It is interesting to note that an electrically-powered tractor recently developed in Scotland does not have an electrical transmission but uses hydraulic motors on the drive wheels.

HYDRAULIC SYSTEMS

Although hydraulic transmission methods are by no means new, the application of oil hydraulics for rotary power transmission in, for instance, the agricultural engineering industry has been retarded by the lack of small and reliable high efficiency motors. Although a pump can be run as a motor, the resulting efficiency is quite low and it is only recently that markedly improved units have been developed, particularly of the plunger type with which internal leakage is least. These improvements in efficiency and reliability have been paralleled in pump design and, in association with higher pressures, the result has been a remarkable increase in power rating for the same size or cost. For example, in the last fifteen years the power per unit weight has roughly doubled, the cost per horsepower has reduced to approximately one quarter and the estimated life of pumps and motors has been increased from 500 to more than 2000 hours. These and future developments suggest a new era of hydraulic drives with efficiencies and costs which are comparable to the mechanical systems which will be replaced.

To emphasize one advantage, the fact that designers will no longer be limited in scope by the restrictions of mechanical connection may in fact be the seed from which major developments in farm machinery design can grow. In adition, an hydraulic system eliminates all safety problems and reduces maintenance (for example, clutches wear but control valves do not); it may also be arranged by quite simple circuitry that if a motor on one component mechanism is stalled, the whole machine is stopped.

A variable-delivery hydraulic pump feeding to a fixed-displacement motor gives instantaneous reversal and a speed range from zero to the designed maximum in either direction; a fixed-delivery pump feeding through a reversing valve and flow control valves to fixed-displacement motors gives the same result, but at a somewhat lower efficiency. It is also possible to use variable-displacement motors, but these are not commonly employed.

There are thus two alternative systems if a number of components of a machine are to be driven from a single prime mover. On the one hand, separate variable-delivery pumps can be used to supply each of the motors on the components to be driven; this gives fingertip adjustment of the relative speeds of the individual parts of the machine, and with a high efficiency. On the other hand, the same result can be achieved with a single fixed-delivery pump supplying all the motors, each one of which has a flow control valve: but the efficiency will be slightly lower.

The choice of method obviously depends upon the requirements and the power which is being transmitted. In the case of drives to components of agricultural field machinery, the flow control valve arrangement is most frequently used. In the case of drives to the ground wheels of a tractor, where it is not required to vary individual motor speeds deliberately, a single variable-delivery pump system is most suitable, particularly in view of the higher power to be transmitted.

TRANSMISSIONS FOR TRACTORS

Since a tractor is a machine in which a considerable speed ratio between the power unit and the driven wheels must be provided, further discussion of transmission systems in this particular connection is apropriate. At the present time there are four arrangements to be considered: two of these are mechanical and two are hydraulic.

The first is the conventional mechanical transmission with stepped change-speed layshaft gearbox which has been used for so very many years. The second has the same rear axle design but a manual or semi-automatic change-speed mechanism using planetary gearing, which permits changes under load. This has been only recently applied in tractors and will be the mechanical competitor to the two hydraulic methods, the aim of the design being to provide as nearly as possible an infinitely-variable speed ratio and yet retain a geared system.

The third type is an hydraulic torque-converter in association with change-speed gearing and the conventional rear axle: this is probably best described as a hydro-mechanical transmission. The fourth is the completely hydraulic system with a variable-delivery pump feeding to motors on each of two or four wheels. These motors, as shown in Fig. 1, are in parallel with the opportunity for series connection when no differential action is desired. This system may be modified to suit a conventional wheeled tractor layout by having one motor driving the usual rear axle as shown in Fig. 2. It may also be utilized for tracklayer propulsion and steering by having two pumps and two motors, i.e. one pair per track. The relative merits of these four types of transmission are of considerable interest at the present time and will undoubtedly be thrashed out commercially in the immediate future.

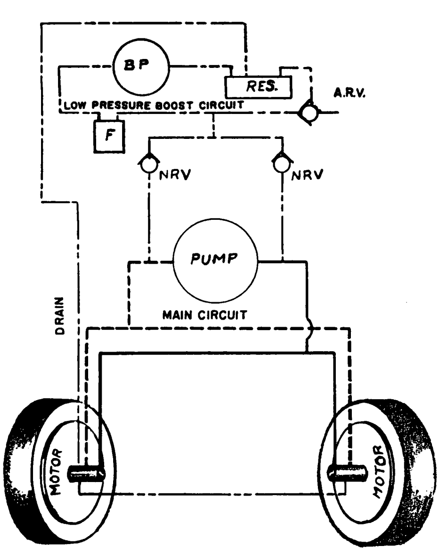

Figure 1. Hydrostatic tractor system with slow-speed motors at wheels.

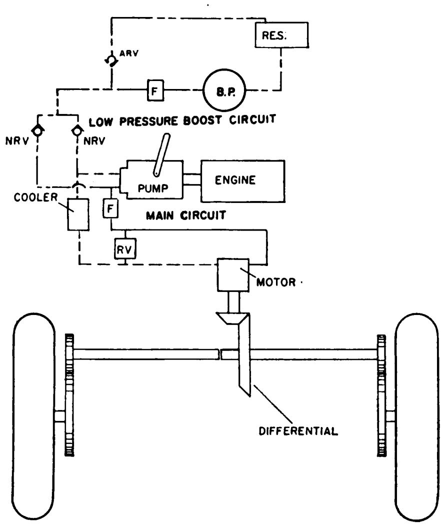

Figure 2. Hydrostatic system with conventional axle and gear reduction.

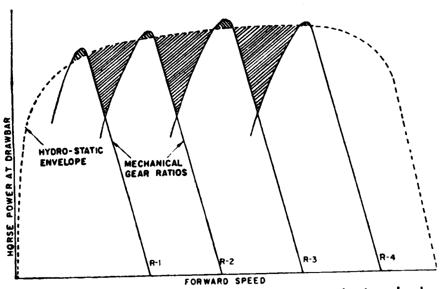

Figure 3. Gear transmission compared to hydro-static system

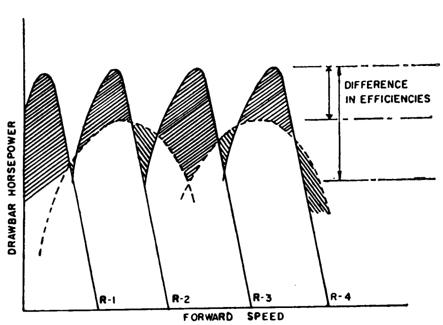

Figure 4. 4-gear mechanical compared to 2-gear torque converter system.

There are two main types of hydraulic system known as the hydro-kinetic and the hydro-static. In the former case, energy is transmitted by virtue of the velocity of oil, but the latter can be used for both high and low speed systems, since energy is transmitted by virtue of the pressure of oil. When a large speed reduction is required, an hydro-kinetic system—such as a torque converter must therefore be used in conjunction with a gear reduction; this also applies with hydro-static designs in which small and relatively high-speed motors are employed, as indicated in Fig. 2. But with hydro-static systems it is also possible to use large slow-speed motors specifically designed for the particular installation: a higher efficiency then results. The commercial point here is that the small, higher speed motors have a wider range of other applications.

An hydro-static, positive-displacement arrangement for an agricultural tractor using a variable-delivery plunger pump feeding to piston type slow-speed motors, developed at the N.I.A.E. in England is indicated in Fig. 1. The pump is driven at engine governed speed, e.g. 1500 r.p.m., and the motors operate at the required wheel speeds, e.g. 15 to 50 r.p.m. in either direction. The only connections between the two are lengths of piping, no brakes are necessary, and speed control is by means of a single lever moving the swash plate of the pump. The efficiency of slow-speed motors can be appreciably over 90%, thus giving overall transmission efficiencies comparable to conventional gear systems.

Tractor performance with an hydro-static transmission using slow-speed motors is compared with a mechanical 4-speed transmission in Fig. 3. The important point is that the whole area beneath the maximum performance envelope is available with the hydro-static system and minute changes of speed can be made under load with very sensitive control; this is not so with the mechanical transmission. When the hydraulic system uses a higher speed motor or motors plus a gear reduction at the axle, as in Fig. 2, or at each wheel (that is, the motor itself produces far less torque than in the previous case), then the maximum performance line will be further below the peaks of the gear transmission curves because of increased losses. It must be mentioned that the efficiency of an hydraulic system is, however, affected by speed and load to a greater degree than is a gear transmission; and that a decline in efficiency of gearing is apparent as a loss of torque and not of speed, whereas in any hydraulic system a loss of speed ocurs. However, since gear changing is eliminated and the engine can be operated at an optimum speed and loading, it is very possible that a higher working efficiency in terms of acres per hour and acres per gallon can result, although a slightly lower transmission efficiency may obtain.

The same advantage of a substantially constant engine speed and loading is derived with a torque-converter installation, since the impeller (pump) is again directly coupled to the engine. The torque-converter provides an automatic step-less speed variation in accordance with drawbar load, but can only do so with reasonable efficiency over a limited range and therefore has to be used in conjunction with a stepped change-speed mechanism as well as mechanical gearing for speed reduction. The transmission efficiency is between 10% and 30% lower than that of a completely mechanical transmission and it is worth noting that the wheeled tractor with torque-converter installation which is most widely available at the present time provides for an aditional mechanical by-pass between engine and wheels.

The comparative performance of a torque-converter and an entirely mechanical transmission is indicated in Fig. 4. However, any comparison is dependent upon the number of speed ratios in the mechanical transmission and in the hydro-mechanical transmission; the more gears in the former and the fewer gears in the latter, then the less the performance advantage of the torque converter. But the same two major points referred to in connection with hydro-static systems again apply, namely, a lower efficiency but availability of the whole area beneath the performance envelope. In figure 4, with a 2-speed torque converter and a 4-speed mechanical transmission, it will be seen that a fairly large area of the maximum possible performance is not available with the hydro-mechanical system. A 4-speed torque converter would show up to much advantage when compared with a 4-gear transmission, but in comparison with a 8-speed mechanical transmission the only advantages are reduction of gear-changing, optimum engine loading, and the ability to exert high drawbar pull under stall conditions—at the expense of lower maximum power.

Thus a torque-converter does not have as high an efficiency nor as wide a working speed range as an hydro-static system and still needs a manual change-speed mechanism (the clutch for which must transmit some multiple of engine torque), a reverse gear, brakes, and separate steering arrangements for tracklayers. Torque-converters have been used in agricultural wheeled tractors only since 1956 and only in the U.S.A. In Europe, on the other hand, the major development work has been on hydro-static transmissions, particularly in England and in West Germany. In Canada at the present time the torque-converter system and the semi-automatic epicyclic arrangement are available. Both systems require rigid mechanical connection between power unit and driven members.

A wide variety of types of hydro-mechanical, hydraulic and mechanical drives are feasible, but it may be suggested that hydro-mechanical and semi-automatic mechanical designs are transitory steps in the progress towards a completely suitable tractor transmission system, which seems likely to be an hydro-static one because of the high efficiency which can be obtained and the flexibility in design which can be achieved. For instance, it is not difficult to visualize an interchangeable basic farm power unit consisting of an engine with hydro-static propulsion and actuation system. Such an arrangement could result in more effective mechanization together with a reduction in capital investment per farm—which is in direct contrast to the history of farm mechanization up to the present time.

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The approach used in this analysis led to the synthesis of grainfeed handling systems. The assumptions that established the general framework for the analysis were as follows:

1. The handling systems must be designed in such a way that they can be built component by component over a period of years.

2. Each system must provide space for on-the-farm processing.

3. The maximum practical degree of mechanized grain handling must be possible in all systems.

4. Only grain destined for livestock feed need be considered in the system design. This includes purchased livestock feed supplies.

In addition to these assumptions, some general principles of grainfeed handling system design were formulated to establish a more specific design criteria. These were as follows:

1. Minimize distance
2. Minimize set-up and knock-down time
3. Design for multiple use of equipment
4. Use man time first to think and last for power
5. Plan in an open end manner for future growth and alternative action.

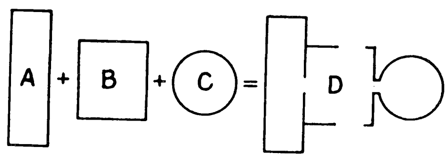

Figure 3. A schematic drawing of the basic grain-feed handling system layout. A—Corn Storage Unit, B—Feed Storage and Processing Unit, C—Small Grain Storage Unit, D—Grain-Feed Handling System.

Using the principles of grain-feed handling system design a number of system layouts were developed for various combinations of ear corn and shelled grain. The basic pattern of the layouts (Figure3) is to combine a corn storage unit and a small grain storage unit around a central processing area. The processing area is the focal point of all out-of-storage handling and processing, as well as storage area for supplement and processed feed.

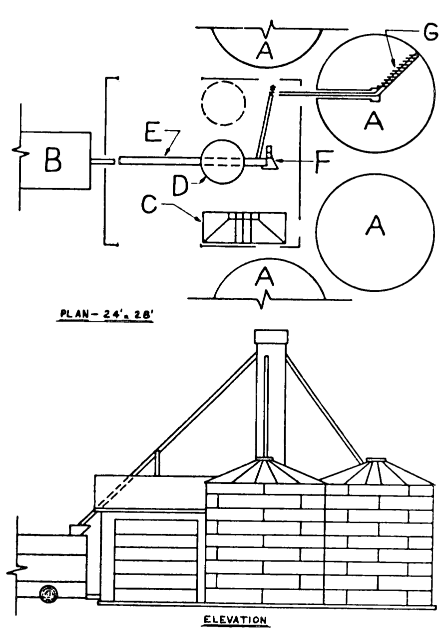

Figure 4. A grain-feed handling system for shelled grain. A——18' Dia. 3000 bu. bins, B—Dryer, C—Automatic grinder mixer with hopper bin, D—Wet Corn or Bulk Supplement, E—Belt, F—Bucket elevator, C—Unloader.

Figure 4 serves as a fitting conclusion to this discussion. The layout features a complete closed cycle mechanization system that is flexible. Into-storage handling could be by portable inclined conveyor. The dryer location can be replaced by an ear corn crib, or a flat storage for shelled or ear corn. Structures may be of any combination of sizes, equipped with or without drying. Finally the entire system can be built unit by unit, over a period of years, to permit an economical transition from the present to the future.

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