The 'Drover' Transmission

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SUMMARY. The development history of a prototype hydrostatic transmission for motor cars is reviewed. The 'Drover' transmission, developed in Australia, was generally successful from performance aspects, giving substantial improvements in fuel economy, but was abandoned because of high production costs. Renewed interest is now being shown due to current concern over dwindling liquid fuel reserves.

1. INTRODUCTION

The 'Drover' transmission was a hydrostatic automatic transmission for motor cars that was developed in Australia during the period of 1955 to 1962.

The development was generally successful from performance aspects and the transmission, installed in a Rover 90 motor car, was extensively tested in Britain by the Motor Industries Research Association. The general driving of the car was found to be satisfactory and improvements of up to 40% in fuel economy were recorded when compared with the standard four speed manual gearbox.

However, manufacturing cost and the lack of market demand for automatic transmissions in Britain led to the abandonment of the project. In 1962, the improvements in fuel economy were considered only to be of academic interest, while performance parameters such as maximum vehicle speed were considered to be of much greater importance in the market place.

The Drover was primarily the brain child of R.J.Ifield, who was at that time employed by Joseph Lucas Ltd of England. The development work was done at Dural, on the outskirts of Sydney, where a small development team was set up under the name of Lucas Laboratories. The laboratory, under Ifield's leadership, carried out selected forward research and development for the Lucas organisation. The Drover transmission was one such project.

Today, as the world becomes more concerned about dwindling fossil fuel reserves, fuel economy is becoming a major force in the marketing of motor vehicles. This situation has led to a renewed interest in the Ifield hydrostatic designs and there are indications that the modern version of the Drover transmission could play a vital role in the motor vehicle of tomorrow. In view of this renewed interest, this paper describes the development of the Drover transmission as the historical background of the current and future development of the Ifield designs.

Sadly, the originator and inventor of the Drover concept has not lived to see its commercial realisation. R.J.Ifield, F.I.E.Aust., F.I.Mech.E., F.R.Ae.S., died after a short illness in August, 1982.

2. GENERAL CONSIDERATIONS

The hydrokinetic automatic transmission of today has simplified the driving of road vehicles at some expense of fuel economy. They meet some important needs, but fall far short of the ideal transmission performance.

In a hydrostatic transmission, variable positive displacement pumps and motors are used to give continuously variable positive speed ratios, depending on the relative displacements of the pumps and motors.

Early devices using hydrostatic principles were confined to critical applications where size, weight and first cost were not of major importance, such as ships steering.

The requirements of the aircraft industry led to the development of small high speed, high pressure pumps and motors which were the forerunners of the commercial variable displacement piston units of today. This equipment is used in many industrial applications such as presses and is used extensively on off-road vehicles such as grain harvesters. The current market for hydrostatic pumps and motors places greater importance on low first cost and component durability than on operating efficiency, with the result that commercially available equipment is not suitable for road vehicle applications.

However, the greatest potential market for hydrostatic transmissions is for motor cars and other road vehicles, but these demand the highest efficiencies, the greatest power to weight ratios and the quietest operation. The equipment must also be suitable for mass production techniques.

The numerous advantages of applying hydrostatic transmission to road vehicles has led to many attempts to meet the technical requirements. The Drover transmission, the culmination of Ifield's studies commencing in the 1930's, was technically the most successful.

3. THE 'IDEAL' TRANSMISSION

The 'ideal' transmission efficiently matches road speed to the engine speed most suitable for the prevailing power demand so that the overall system efficiency is optimised.

All engines have unique curves of optimum engine speed against power for best fuel economy, consistent with the requirements for long engine life, smooth operation and freedom from fuss. Essentially, the engine should be used at near maximum throttle over as wide a speed range as possible.

Figure 1 shows typical engine power and throttle opening against engine speed as specified for optimum performance by the engine makers. It was specified that the engine torque should increase linearly from zero at 600 RPM to a maximum value at and above 1500 RPM. The engine is then operating at near minimum specific fuel consumption at speeds above 1500 RPM. It is of interest to note that modern fuel injected engines can operate smoothly at maximum torque to lower speeds with a significant potential improvement in low power efficiency, providing that durability is not compromised.

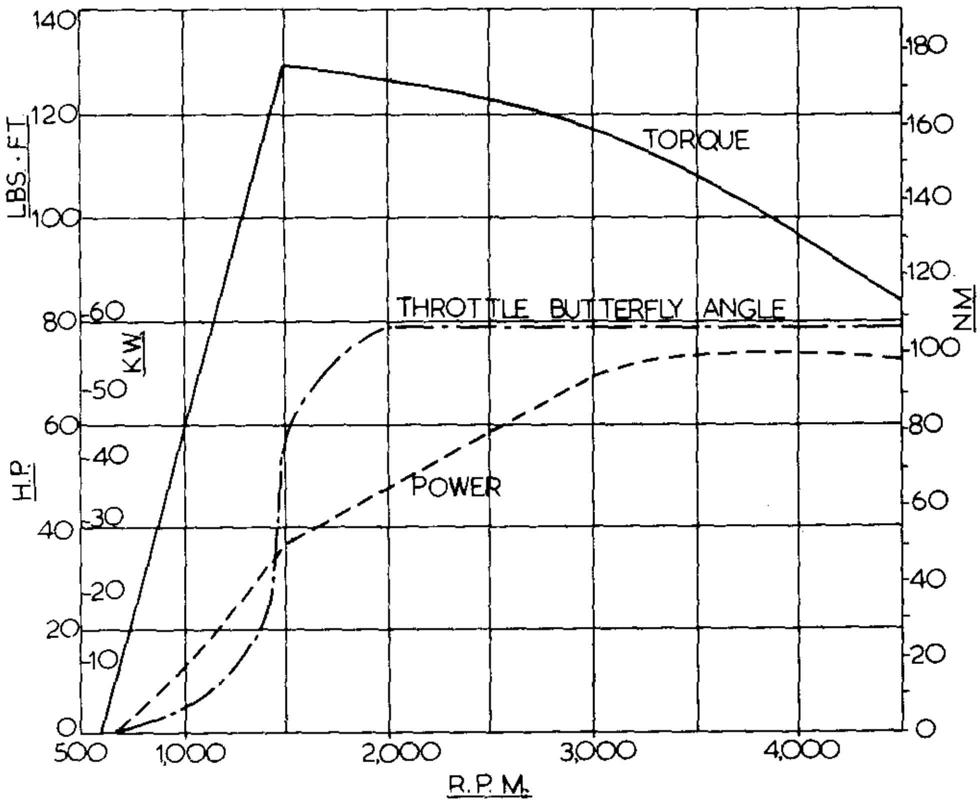

Figure 1. Engine performance for optimum fuel efficiency.

Figure 2 shows typical level road resistance horsepower against road speed and superimposed is the optimum gear ratios required to match the resistance load to the optimum engine power. It can be seen that overdrive ratios up to 0.42:1 are required for level road use. In normal driving, overdrive ratios to about 0.3:1 can be usefully employed. The Drover transmission had a variable displacement motor as well as a variable displacement pump and overdrive ratios were achieved by controlling the motor to a smaller displacement than the pump thus providing an output speed higher than input speed.

As the engine is being used at substantially full throttle at all times, acceleration of the vehicle cannot take place without a change of transmission ratio. This is the main reason why high overdrive ratios cannot be used successfully with step-gear transmissions as some loss of power usually occurs during gear change. However, continuously variable transmissions can smoothly and quickly change ratio to the new requirement without loss of drive. Similarly, because the road conditions continuously vary, the transmission ratio also needs to change continuously.

In hard accelerations, the engine should be governed to that speed corresponding to the prevailing power demand. This means that starts from rest are done at an engine speed of 600 RPM even at maximum throttle because the initial power demand is substantially zero. This is somewhat disconcerting to a driver accustomed to a hydrokinetic transmission, but is obviously logical. Under full throttle acceleration the engine speed increases with vehicle speed until the maximum power engine speed is reached. The engine then holds at this speed as the vehicle continues to accelerate.

The control of acceleration, particularly at low speeds, was found to be unexpectedly difficult. Early Drover controls caused the accelerator pedal to control the engine power along the desired optimum power curve. In order to avoid fuss the engine speed was also trimmed at low road speeds. However the very low power requirements at low road speeds made it difficult to avoid violent initial accelerations from rest and 'kangaroo' starts were the order of the day.

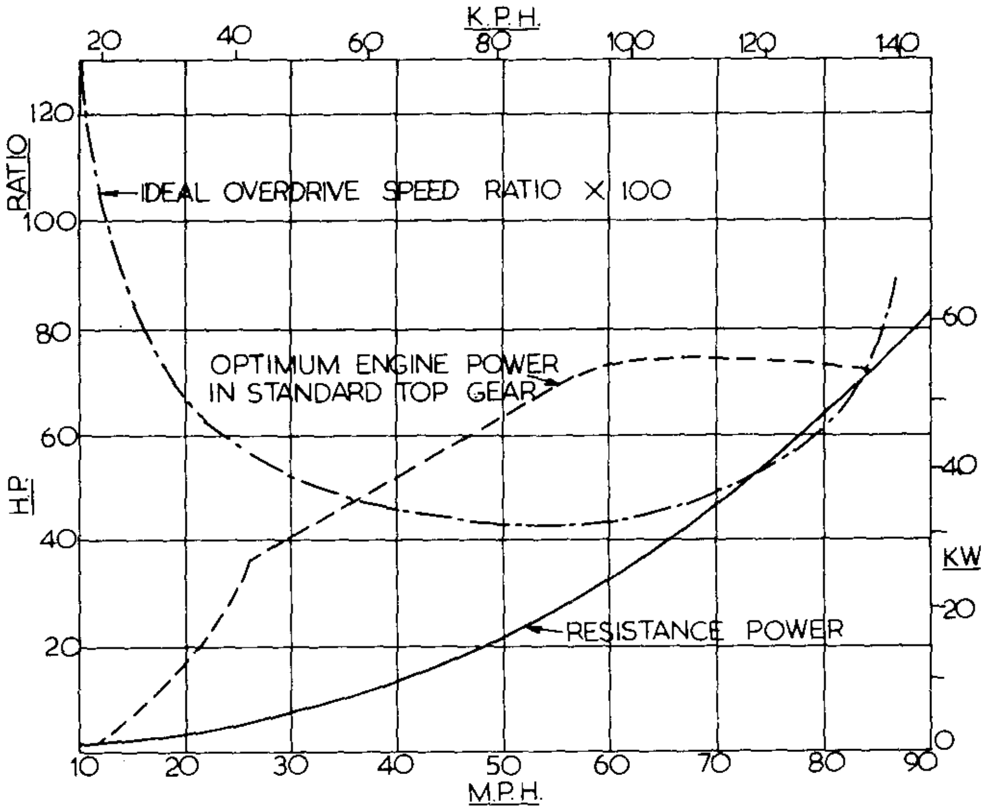

Figure 2. Transmission ratios for optimum engine utilisation.

Later transmission developments included a tractive effort control in combination with a power control, so that the accelerator pedal position set a limiting output torque and a limiting output power from the engine and transmission, and the control system them selected whichever of these represented the least power demand. Thus, at low road speeds, pedal movement progressively increased tractive effort while at high road speeds pedal movement progressively increased engine power. This straight-forward algorithm is considered 'ideal' because it provides very similar feel to a carburettor throttle at higher road speeds in conjunction with a precise and positive control of take-off acceleration. The take-off performance is noticeably superior to either a slipping clutch or hydrokinetic coupling.

A transmission must also allow the engine to be used for over-run braking for long steep descents. Various schemes were tried, some coupled to the normal braking systems, but the most satisfactory scheme was the provision of a manually operable over-riding control to determine the upper limit of speed ratios. Three limited ratios are normally satisfactory and their use is identical to the hold-gears of present day automatic transmissions.

Reverse, neutral and a mechanical parking lock must also be provided, although in 1962 the need for the parking lock was not firmly established.

This overall concept of the 'ideal' transmission was evolved over a number of years and the importance of many aspects, particularly from the control point of view, was only discovered the hard way through prototype experience.

4. EARLY HYDROSTATIC WORK

Ifield's motor car transmission studies started in the 1930's and many designs, investigating the use of differential 'split' drives were drawn up and discarded.

An ingenious and complex multiple differential system was close contender for the transmission and steering of British Army tanks, but the Meritt-Brown system was adopted, logically in the wartime emergency, because it contained fewer unknowns and could be produced on existing production machinery.

These early transmission designs included an advanced design of hydraulic pump, which was later developed as the high pressure fuel pump used for the first production Whittle jet engines. Subject to continued development, this pump is still used for many modern aero turbine engines, such as those used on the Concorde. This design is now some forty years old.

The problems of pumping kerosene and petrol at pressures up to 2000 PSI, with high efficiency and long life, led to the development of special bearing treatments, and the experience gained was of great value in the later transmission developments. There is little doubt that this successful fuel pump development has had an important influence on the design of the modern axial piston pumps and motors.

The basic design is shown on figure 3 and the development is well described by Watson (1). The port face and piston slippers are hydrostatically balanced so that heavy mechanical loadings are minimised. This basic configuration is now standard in modern axial piston equipment. The special bearing materials and treatments for pumping kerosene and petrol are not required for pumps and motors operating in lubricating oils, although some of the treatments have proved valuable for pumping cheap non-flammable fluids having poor lubricating properties as described by Ifield (2).

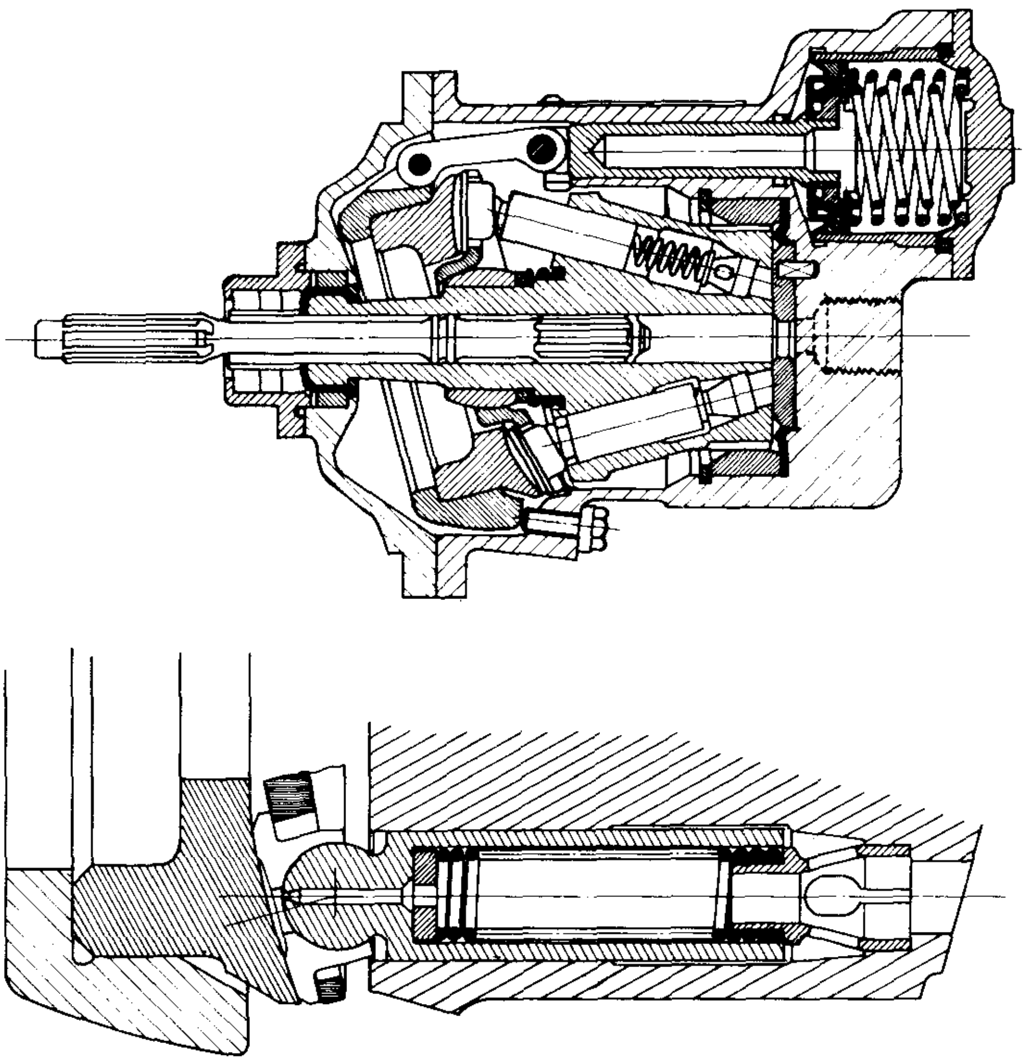

Figure 3. Jet engine fuel pump.

The pumping cylinders of the aircraft fuel pumps have a conical disposition, for three reasons; firstly, the port face velocity, and thus the inlet pressure loss, is reduced; secondly, the pistons tend to centrifuge outwards and thus assist in maintaining slipper contact with the swash plate; and thirdly, this arrangement provides the maximum pump displacement for a given size and weight of pump.

The conical cylinder disposition necessitates the use of a part spherical surface at the swash plate, with accurately mating part spherical faces at the slippers. These spherical surfaces are costly to produce, and the absence of selfalignment at the port face calls for high precision manufacture. For this reason the industrial versions of these pumps have parallel cylinder bores and consequently are not capable of the high speeds of the fuel pumps even with high boost pressures.

Later, a differential (split drive) hydrostatic transmission was successfully developed to provide a constant speed alternator drive for the Bristol Brabazon Aircraft. The transmission was based on standard fuel pumps applied as pumps and motors, but never went into production because the Brabazon was abandoned.

In the mid 1950's, after twenty years mostly concentrated on gas turbine fuel systems, Ifield finally returned to motor car transmissions.

5. CONSIDERATION OF TRANSMISSION TYPE

The split-drive transmissions originally proposed had advantages in reducing the size of hydraulic units for a given horsepower rating, and in reducing the percentage of power loss in conversion to and from hydraulic power. The fundamental disadvantage of these scheme was that they could only be used as gear box replacement transmissions.

One on the important advantages of hydrostatic transmissions applied to road vehicles is that they can be applied to give greater flexibility in vehicle design. If all the power is converted to hydraulic power at an engine driven pump, it may be transmitted through pipes to a remote hydraulic motor, or to several wheel mounted motors in parallel. This eliminates the propellor shaft and the engine can be mounted where convenient, and the vehicle designer would have greater freedom in meeting the needs of the driver and passengers.

The power weight ratios achieved in the development of the fuel pump gave promise that motors, operating on oil, could be developed to give satisfactory power weight ratios for wheel mounting, and a flow divider was developed to minimise wheel spin with two separate wheel motors operating in parallel.

Schemes were prepared showing wheel mounted motors in independent suspension systems, and these greatly reduced the transmission complexity compared with mechanical drives, especially for four wheel drive vehicles.

These considerations led to a decision to base the development on conversion of engine power to hydraulic power at a pump, with reconversion at a hydraulic motor, although the initial designs and development were confined to gear box replacement units for convenience in application to existing vehicles. This decision placed greater emphasis on the need for maximum pump and motor efficiencies and on the highest power to weight ratio.

It is possible that the development would have been more rapid and less costly if it had been based on the original schemes for a split-drive gear box replacement unit. However, it is unlikely that this type of transmission would have been cheaper to produce and high estimated production cost was a major factor in bringing the Dover project to an end in 1962. It is interesting to note that the Ifield transmission designs are now so efficient that the extra complexity of the split drives is no longer warranted.

6. THE FIRST TRANSMISSION

It was decided to base the first transmission design on the use of standard jet engine fuel pumps. These theoretically met the requirements of small motor cars, and the transmission was designed to replace the gear box in a small rear engine car which was popular at the time.

The scheme was very compact and consisted of two fuel pumps mounted back to back with very short interconnecting passages through a shared port block. Both the pump and motor were of variable displacement so that overdrive speed ratios were available. A theoretical maximum pressure of 35 MPa (5000 PSI) provided the required maximum torque.

The transmission was acceptably small and light, but rig tests exposed several serious faults which could not be remedied in that design. Because of this, there was little control system development and the transmission was never subjected to road tests. The major faults were as follows:

- Volumetric losses at high pressures were excessive.
- Mechanical losses were excessive at high speeds.
- The torque conversion efficiency under static motor conditions was poor.
- The transmission was intolerably noisy at all duties.

A comprehensive series of tests were carried out to establish the sources of noise and losses. Unfortunately, space only permits a brief discussion of the major findings.

The use of heavier oils reduced the leakage losses and slightly improved the static torque conversion efficiency but only at the expense of increased mechanical losses at high speeds.

The major leakage losses occurred at the port face, mainly as a result of elastic deformation of the components. These losses could be greatly reduced by providing a more rigid construction and for self-alignment of the port faces, but it was also found necessary to ensure uniform temperatures across the sealing faces, otherwise the leakage became excessive due to thermal deformation.

Careful testing revealed that there was another serious loss in volumetric efficiency apart from leakage losses. This was found to be due to the compressibility of the liquid, resulting in a discharge from the cylinders to the low pressure port. This loss depended to a large extent on the ratio of swept to unswept volume in the cylinders.

The swash plates were pivotted on centre as shown in figure 4, so that the unswept volume increased as the swept volume decreased. As the highest pressures are produced at small pump displacements, the conpressibility losses become significant at high pressures. These losses can be greatly reduced by pivotting the swash plate at a point in line with the TDC piston position as shown on figure 5. This maintains a constant minimum unswept volume and greatly reduces compressibility losses at small displacement settings.

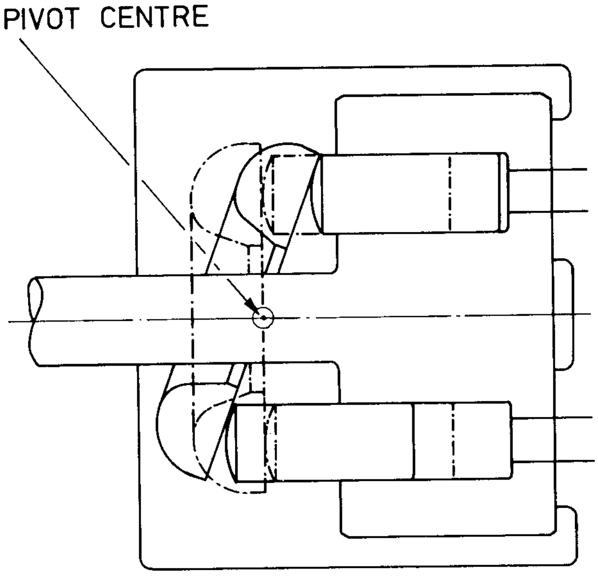

Figure 4. On-centre pivot causes unswept volume to increase with reducing swash plate angle

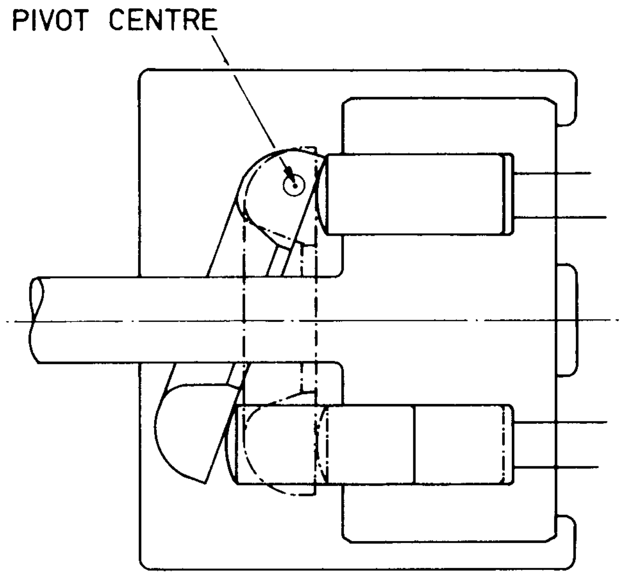

Figure 5. Off-centre pivot maintains minimum unswept volume.

At high speeds, the major losses in mechanical efficiencies were found to be due to porting pressure drops, to viscous shear losses and to turbulence within the housings. These losses were mainly a function of the oil density and viscosity, and they could be greatly reduced by the use of very thin fluids.

There are some hydrostatic transmission applications where static torque conversion efficiency is of no great importance, but this does not apply to vehicle transmission, where the greatest output torque requirements are under static or near static conditions, as when starting the vehicle on a steep hill, or climbing a kerb.

The static torque efficiency of small hydraulic motors was as low as 50%. In order to meet the static torque requirements, the motor size would have to be double the theoretical displacement. This would increase the transmission cost and the power to weight ratio would become unacceptable.

The mechanical conversion efficiency was also poor at low speeds and leakage increased. This found to be due to increased piston friction under the high unit loads produced by piston side loads. This increasing piston friction upset the hydrostatic balance at the port face and at the piston slippers, and caused the sealing faces to part, so that there were serious leakages as well as poor mechanical conversion efficiencies. Port faces are usually balanced for mean conditions, but it was found that, at low speeds, the port face design alternated between offloading with excessive leakage and over-loading with high friction loss; the conversion efficiency and leakage varied considerably with rotational position.

Noise proved to be the most recalcitrant problem because when one predominant source of noise was located and remedied, another only slightly less objectionable noise became apparent. Development work still continues in this area to this day and is expected to continue for some time before the noise factors are fully understood.

The first most distressing noise was found to be due to reversing couples at the swash plate, caused by the centre of thrust moving back and forth across the trunnion centre line. This noise ceased to be predominant when the swash plate was pivotted off-centre as previously described.

Much of the remaining noise was found to be due to compressibility shock waves caused by the sudden opening of the cylinders to the high pressure and by high pressure in a cylinder being suddenly decompressed into the low pressure port. The resulting pressure shock waves have been measured on oscilloscope/transducer equipment as being typically twice the transmission pressure. They are usually followed by a cavitation wave.

The energy of these shock waves is reduced at smaller displacements by pivotting the swash plate off-centre and high boost pressures were also found to have some beneficial effect.

At that time Ifield considered that the combination of correctly designed anti-shock notches, combined with a robust design avoiding high stresses in areas subject to stress reversals, would bring the noise to acceptable levels. The Drover transmission approached acceptability but it has not been until more recently that significant advances in this area have been made.

7. THE NEW DESIGN

The investigation into the sources of noise and efficiency losses led to the realisation that an entirely new design of pump and motor had to be evolved to meet the technical requirements for road vehicle transmissions. The units needed to be quieter and more efficient than any existing production units and to have a higher power-to-weight ratio.

The transmission must be capable of operating on very thin oils to minimise losses at high speeds, yet must maintain high volumetric efficiencies at high working pressures.

The greatest output torque requirement is under static conditions at the motor, so the conversion efficiency must be high to minimise the size, cost and weight of the transmission.

The operating pressures in a motor car transmission are very much lower under normal driving conditions than peak values which may be encountered occasionally. A study of the required duties led to the decision that the pumps and motors should be designed and developed for peak duties up to 10,000 PSI. This would greatly reduce the size of the transmission and significantly improve the high speed efficiency and high speed losses which are largely a function of dimension. Normal working pressures would be in the most efficient range from 2,000 PSI to 6,000 PSI.

The new design was based on the known bent axis principle because it is theoretically possible to eliminate piston side loads in this type of unit. It was necessary to introduce many important and novel design features as the standard variable displacement designs were too bulky, too heavy and too inefficient.

The high efficiency pump and motor design was developed over a number of years (from 1955 approximately) before the Drover transmission. Generally this development was of a detail nature and the first unit built to the general design principals is still to this day occasionally used as a slave unit in the Dural development laboratory.

Successful development to met a technical challenge generally requires meticulous attention to detail and only the most important of the novel design features will be described.

Instead of using skirted pistons with ball and socket joints to the connecting rods, the pistons were formed in one piece with part spherical heads to allow for the small angular movement. The heads are fitted with low friction self-sealing piston rings. Piston leakage and viscous friction is practically eliminated and the light piston design allows higher operational speeds without tilting the cylinder rotor.

The axial thrusts from the pistons were directly opposed by hydrostatically balanced slippers, also fitted with sealing rings, sliding on a robust thrust plate. This feature greatly reduced the size and weight of the units, increased the permissible duties and reduced the pumping noises, compared with conventional bent axis designs having massive ball or roller thrust bearings.

The port block was fully supported against mechanical deformation by the large radius curved surface of the robust end cover. In order to maintain the minim= unswept volume, the centre of this curved surface was on a point in line with the top dead centre position of the piston ball ends. Servo pistons slid the port block around the curved face to vary the displacement. The flow to and from the port face passed axially through the port block, and through specially sealed transfer ports to inlet and outlet connections in the end cover. This important design feature greatly reduced the size and weight of the units compared with conventional bent axis designs.

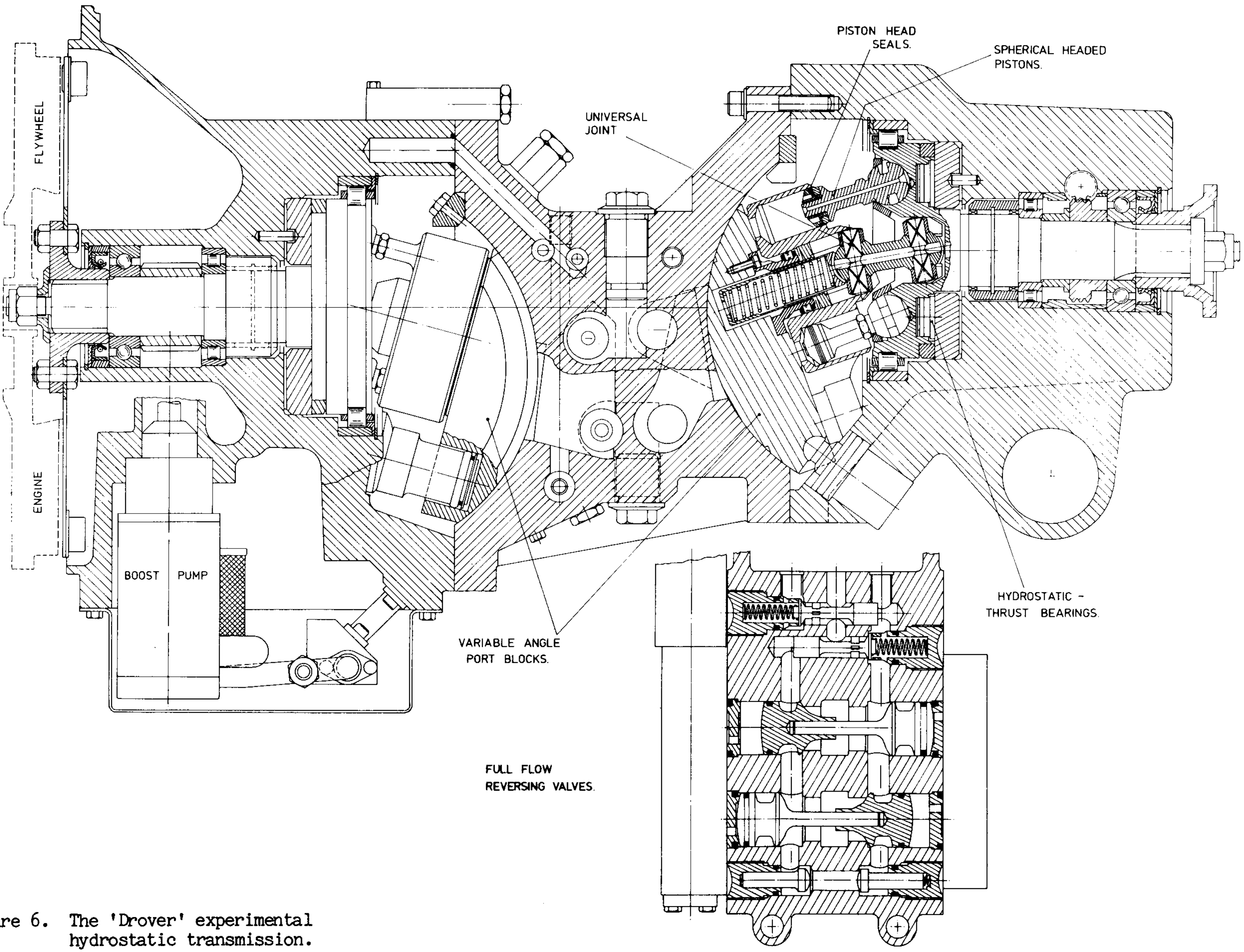

Figure 6. The 'Drover' experimental hydrostatic transmission.

The port face was developed to ensure even hydrostatic balance at all rotational positions of the rotor, and incorporated the optimum form of anti-shock notches for the range of operating duties.

A great deal of development work was required to refine these features and deal with the many detail problems. After development these units were capable of pumping very thin fluids up to 10,000 PSI and the motors gave outstanding static torque conversion efficiencies of about 98%, even under prolonged static loadings on very thin fluids. The power to weight ratio and the efficiencies were far greater than anything previously achieved, and the units were very much quieter in operation.

It was apparent early in the development that outstanding improvements could be achieved and this encouraged a belief that they would meet the requirements of a motor vehicle transmission, so experimental transmissions were built for road testing and development before the development of the pumps and motors was completed.

8. TRANSMISSION PERFORMANCE

The high efficiency pumps and motors were built up into three experimental transmissions as shown in figure 6. These were designed for a high quality car having a normal laden weight of 1.8 tons. The pumps and motors at that time had been cleared for peak pressures up to 6,000 PSI, so they were about 67% larger in displacement than would have been required for the later approved peak pressure of 10,000 PSI.

As a demonstration in a vehicle was the first priority, considerable development of the boost system and the control and servo systems was completed in haste.

In the interests of maintaining minimum unswept volume, the pump was not designed for overcentre control and full flow reversing poppet valves were used between the pump and motor. These valves could be fully opened to allow a hydraulic neutral.

A boost pump driven from the input shaft provided an engine speed responsive flow for governing purposes in addition to supercharging the low pressure transmission passages and providing a cooling circulation through the transmission.

The speed governor controlled the pump and motor displacements through servo pistons operated through a pilot valve and sequence valves to ensure that the pump reached maximum displacement before the mtor displacement was reduced and vice versa.

The control for the variable speed governor was coupled to the engine throttle valve and to the accelerator pedal to provide the desired engine performance characteristics. The pump displacement control modified the characteristics at small displacements to give the desired limitation to engine speeds at low road speeds. The response rate of the system was controlled to allow starts from rest -the tractive effort control concept was not developed until later.

The variable hold gear control determined the upper limit to the speed ratios. It could be brought into operation at any time and was on of the earliest of the successful control system developments.

The experimental transmissions showed considerable promise in preliminary road tests, which were mainly concerned with the development of the control system; it was realised however that they were still too noisy for motor cars, although much quieter than other piston pumps and motors.

The pumps and motors were seven cylinder units, it being traditional to use odd numbers of cylinders in hydraulic pumps and motors as torque and displacement ripples are theoretically much less than with even numbers of cylinders.

However, extensive studies and tests taking compressibility into account showed eight cylinders units, combined with optimised port face notches, were in fact quieter and smoother than the seven cylinder units.

Eight cylinder units were made to have the same displacement and fit into the same casings, which provided quiet and efficient operation at low speeds. The transmissions were still too noisy and inefficient at high speeds.

Two of the experimental transmissions were despatched to England, the third being retained at Dural for continued development.

One of the transmissions was evaluated at the Motor Industries Research Association (M.I.R.A.) and was found to achieve much of the theoretical fuel economies available to 'ideal' transmission, with a 40% improvement at 35 mph steady speed when compared with a manual transmission in top gear, as illustrated by figure 7.

Generally, the driveability and technical achievements were highly praised but some criticisms were made.

- The transmission, though quiet enough at low and moderate speeds, was considered unacceptably noisy at high engine speeds.
- The power losses were considered excessive, but only at high engine and speeds, the performance during normal driving being highly praised.

- It required some skill to avoid violent initial acceleration from rest.
- External oil leakage was excessive.

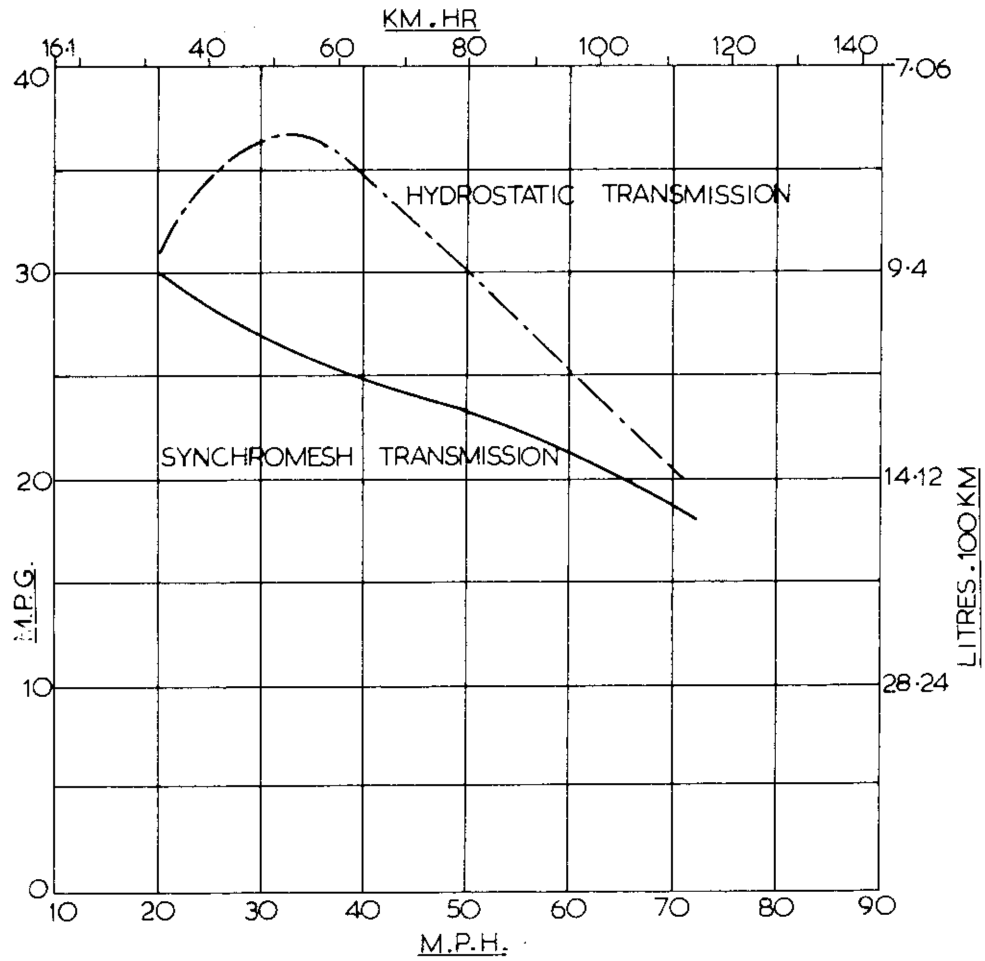

Figure 7. Fuel economy improvement shown by Drover transmission.

Interestingly, the external oil leakage was a very damaging point as it inhibited appraisal by people without a technical background. By this time, of course, the highly developed control system was a nest of temporary pipes so some drips were inevitable, but easily remedied by a proper redesign using the proven developments.

The acceleration problem was overcome by the tractive effort control previously mentioned. Movement of the accelerator pedal varied the upper limit of transmission pressure, which was used to reset the power control. The accelerator, pedal then gave proportional tractive effort control or proportional power control, whichever represented the least power demand. This gave ideal control characteristics for all driving conditions.

Tests revealed that a large part of the efficiency losses at high flow rates was due to the pressure losses at the full flow reversing valves. New designs were prepared allowing for a small overcentre displacement at the pump for reverse operation which did not greatly increase the unswept volume at small displacements. This would reduce the losses and also the transmission weight and cost.

Further tests showed that replacing the oil originally used (3.5 cs at 60 degrees C) with a lighter fluid such as diesel fuel would give significant high speed improvements.

The reduction of noise levels at high engine speeds could at that time only be achieved by gearing down to lower pump speeds and, as this would also improve high speed efficiency, this proposal was seen as inevitable. The existing size of pumps and motors would have been suitable for the lower speeds by increasing the peak pressures from 6,000 PSI to 10,000 PSI, which had been proved by a parallel test program.

The recommendations at the end of 1962, to meet the technical requirements for motor car hydrostatic transmissions, were to employ eight cylinder pumps and motors of the high efficiency type as developed at Dural, geared to a maximum speed of 3,000 RPM, the pump to be provided a small amount of overcentre for reverse speeds, and the control system to include the tractive effort control for low vehicle speeds.

9. THE PROJECT ABANDONED AND REVIVED

Following the M.I.R.A. tests, it was agreed that, despite the criticisms, the 'Drover' transmission was far advanced on other hydrostatic schemes and that it showed sufficient technical promise for further consideration. This led to a production cost and market investigation, which revealed that it would not be possible to produce transmissions of this type at a price suitable for mass produced motor cars on the British market.

The disappointing results of the cost investigation led to a decision to close the development and to shut down the Dural laboratory at the end of 1962.

In 1963, Ifield, with four of his sons, formed an independent company and took over the Dural premises and continued with development at a slower rate. The following years led to significant advances in cost reduction, particularly in the control system, and to successful means of reducing noise levels to acceptable levels.

But, more importantly, the market has changed. Due to rising fuel costs and increasing scarcity, the public concern for fuel economy has increased enormously and an automatic transmission that uses less fuel than a manual transmission and provides superior acceleration performance holds obvious attractions.

Also, there are many short term energy storage schemes being studied and tested for vehicles. Frank and Beachley (3) have shown that a 100 % gain in city fuel economy can be achieved using a small flywheel, providing that a continuously variable transmission is available. An Ifield transmission has been supplied under contract to the Lawrence Livermore Laboratory in the U.S.A. for this study and tests show that it meets the stringent performance target.

Similar studies, notably by Advanced Energy Systems again in the U.S.A. (5), have shown that a transit vehicle, such as a postal van, can improve mileage by 50% using an accumulator storage where start/stop cycles are frequent, providing that hydraulic equipment with high enough efficiencies is available. At this stage it appears that only the Ifield design can meet the efficiency requirements

Buchholz and Mathur of N.A.S.A. (6) report that studies of an electric hybrid vehicle using an hydraulic accumulator system for short term braking and acceleration storage failed to meet cost/value targets in the absence of hydraulic equipment with the necessary efficiency levels. They were not aware of the Ifield developments at the time of study.

All in all, the future for the Ifield transmission concepts appears brighter than it has for many years. The only sad note being that commercial success did not come in the lifespan of their inventor.

ACKNOWLEDGEMENT

The material for this paper was largely drawn from the unpublished transcript of an address entitled "Hydrostatic Variable Speed Transmission" given by R.J. Ifield to the Sydney Branch of the Institution on 21st June, 1967. In that original address, Ifield thanked the Directors of Joseph Lucas Limited for permission to give his paper and for their help and encouragement over the previous 26 years.

Thanks are due to the members of the Ifield team who took part in the development, many of whom assisted the author in bringing this history of the 'Drover' to publication.

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