Hydro-Kinetic Drives, Hydraulic Torque Converters and Hydraulic Couplings

By NICHOLAS A. D'ARCY, JR.

WIDESPREAD interest in hydraulic drives was created in this country when hydraulic couplings were incorporated in several popular automobiles. This was the outgrowth of the inventions of Dr. Ing. Hermann Foettinger in Hamburg, Germany, over 30 years ago. Dr. Foettinger developed both the hydraulic coupling and the hydraulic torque converter for use in Diesel-powered vessels having up to 20,000 horsepower available for driving the propeller.

The use and development of hydraulic drives spread to Sweden, where the Ljungstrom works further developed the hydraulic torque converter under Lysholm-Smith patents, and to England, where Vulcan-Sinclair developed the hydraulic coupling. The Swedish applications were made largely to rail cars and the English applications to trucks and buses.

It has been in the last four or five years that widespread industrial development has occurred in these two hydro-kinetic drives. The American Blower Corporation was sub-licensed by Vulcan-Sinclair to manufacture hydraulic couplings, the Twin Disc Clutch Company licensed under Lysholm-Smith patents to manufacture industrial hydraulic torque converters and hydraulic couplings, and Spicer Manufacturing Corporation to manufacture torque converters for automotive uses. These three American organizations are rapidly extending the uses of hydro-kinetic drives, and new industries are rapidly availing themselves of the advantages of this development.

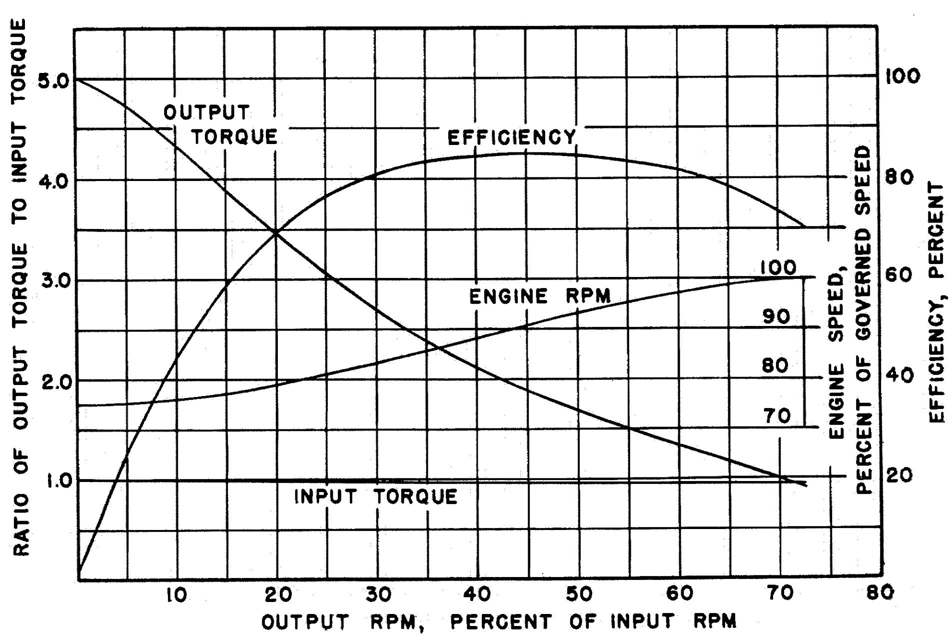
Positive-drive hydraulic units are also in widespread use in the United States, but this type of drive is a separate and important field which will only be touched upon at this time.

ADVANTAGES OF HYDRAULIC DRIVES

The original developments of Dr. Foettinger were connected with the development of the Diesel engine. Some simple device was needed to absorb the torsional vibrations and "un-equality" of operation of this engine, and the hydraulic torque converter and hydraulic coupling proved to be the devices needed. One of the most important advantages of all hydro-kinetic drives is the reduction of vibration and smoothing-out of the flow of power from internal combustion engines. In addition, they absorb shock loads, prevent stalling of the engines, and provide a smooth method of starting a load. These fundamental characteristics of the hydro-kinetic drives apply without regard to whether the unit is a hydraulic torque converter or any of the several types of hydraulic coupling.

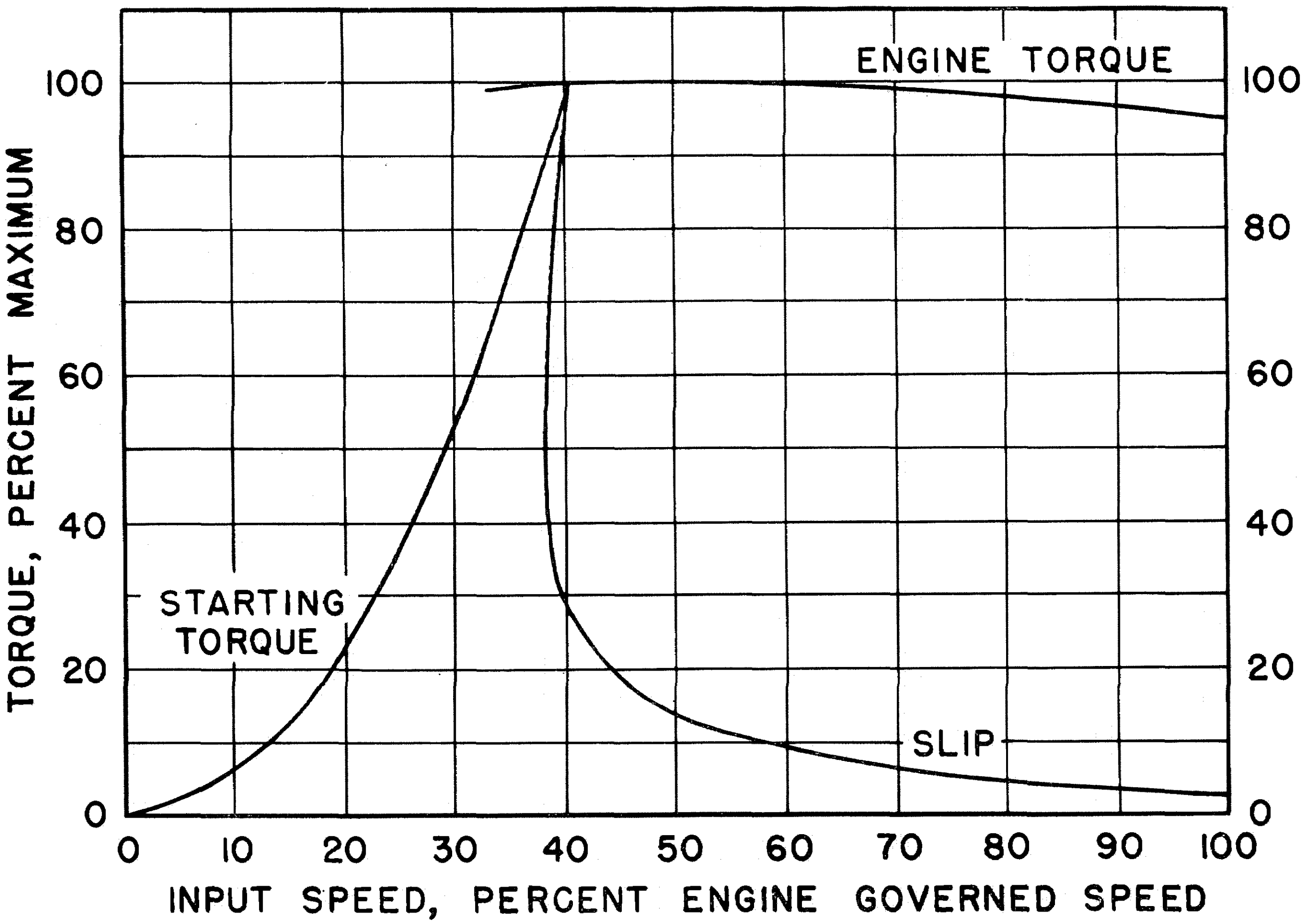
Hydraulic torque converters have the further advantage of developing high output torque at low output speeds while maintaining high operating speed in the prime mover. The over-all efficiency of the torque converter reaches a maximum of approximately 83 per cent, which is low compared to certain electrical units, but it allows the prime mover to develop full input horsepower by running at maximum speed. For this reason the output horsepower from a torque converter is often higher than with mechanical transmissions with the engines operating at reduced speeds.

The hydraulic coupling, on the other hand, has a maximum efficiency of over 95 per cent, but the output torque of a coupling can never exceed the input torque. From these radical differences one can see that each type of hydro-kinetic drive has its own particular advantage, and care must be used in selecting the correct unit for any particular installation.



AT LEFT:

Ratio of output torque to input torque.

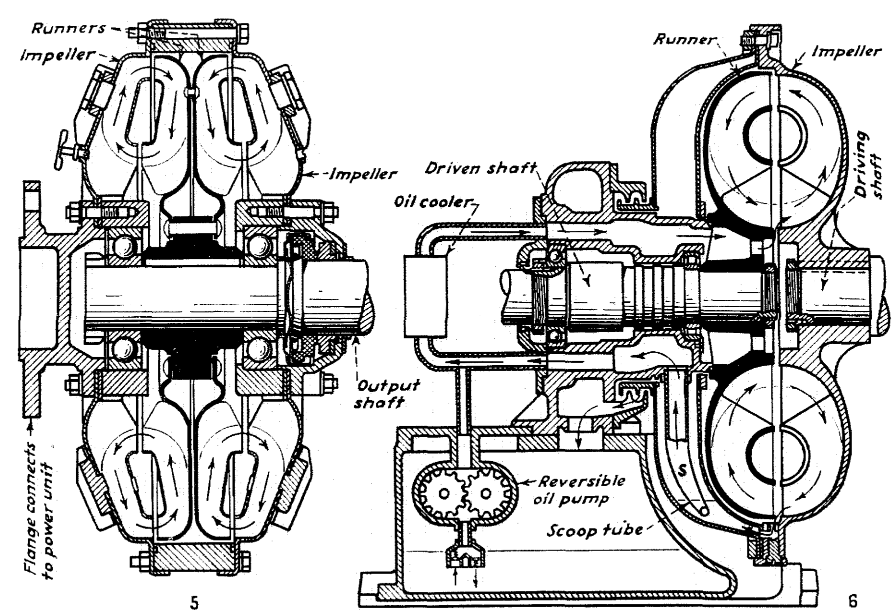


Performance characteristics of hydraulic coupling used with an internal combustion engine.

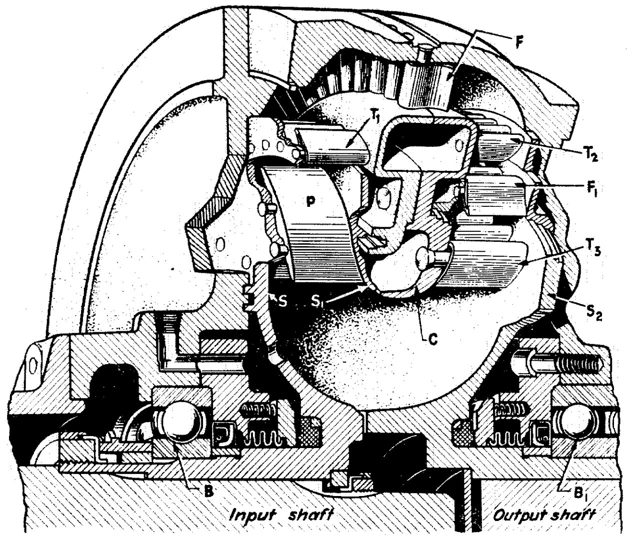
BASIC PRINCIPLES OF HYDRO-KINETIC DRIVES

Both the hydraulic torque converter and the hydraulic coupling are closed-circuit hydraulic units consisting of a pump or impeller on the driving end and a reaction member on the driven end. The rotation of the impeller imparts kinetic energy to the fluid in the closed circuit and drives the fluid to the outer periphery of the unit. The turbine member then absorbs the kinetic energy of the fluid in its blades and the fluid, having lost its velocity, is returned to the central portion of the unit. The impeller again picks up the fluid and the cycle is repeated. There is no mysterious characteristic imparted to the fluid at high velocities, as has sometimes been described. The entire action is based on well-known laws of hydraulics.

There is no positive connection between the impeller and the turbine member, and this feature allows the fluid to absorb shock, absorb vibration, and provide smooth starting. Both torque converter and coupling depend upon the kinetic energy imparted to the fluid for their drive. Both units transmit horsepower in proportion to the cube of the speed of the driving member and the fifth power of the diameter. Both units de-



AT LEFT: Axial hydraulic forces balance each other in this twin coupling. AT RIGHT: A variable-speed coupling in which working fluid is removed, cooled, and returned to circuit. (Illustration courtesy Power Magazine.)



Construction of a typical hydraulic torque converter: P is impeller, T_1, T_2, and T_3 are runner vanes, and F and F_1 are the fixed vanes. (Illustration courtesy Power Magazine.)

velop torque in proportion to the square of the speed of the driven member and the fifth power of the diameter.

HYDRAULIC COUPLINGS

The hydraulic coupling is the simpler of the two hydro-kinetic drives. It consists essentially of two identical opposed vaned members, so that either half can be used as the driving or driven member. In certain adaptations of the hydraulic coupling, added features are incorporated to alter this arrangement slightly, but the basic principle remains. The two opposed members being identical, one would expect to find the character of power transmitted identical with the power driving the coupling, and this is the case, except for friction losses. In the traction or sealed type of coupling, the simplest and most common hydraulic coupling, the output speed is only about three per cent less than the input speed, and the output torque is always equal to the input torque.

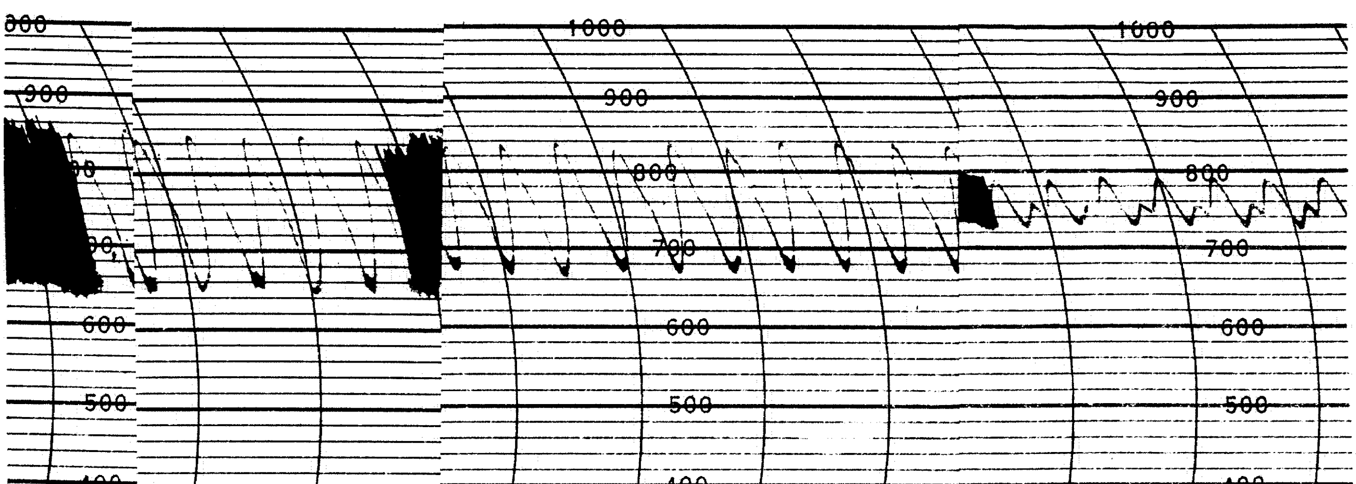
In addition to the simple traction or sealed coupling, one may obtain scoop tube or variable speed couplings, ring type couplings, dumping couplings, and clutch type couplings. These have all been developed to meet certain requirements, but they are basically the same as the traction coupling. Perhaps the most interesting of these special couplings is the scoop tube coupling, which allows the operator to control the volume of fluid in the coupling. This controls the amount of slip for any given output speed and torque requirement. In addition the scoop tube coupling allows the fluid to be constantly removed from the circuit, cooled, and reintroduced into the circuit.

APPLICATIONS OF HYDRAULIC COUPLINGS

The hydraulic coupling is essentially a constant-speed, constant-torque hydraulic unit, and as such it should be used on drives requiring this type of power. It is also an efficient drive, and one need not be concerned with loss in power through this type of unit. The passenger automobile is one of the outstanding successful applications of hydraulic units, since it has a relatively constant-speed, constant-torque drive after the unit gains speed and is one in which economy of operation is a prime factor.

One of the best industrial applications for hydraulic couplings is that between the internal combustion engine and the propeller shaft on moderate-sized power boats. The coupling absorbs engine vibrations and provides a very smooth drive. In new developments for fishing boats hydraulic couplings are being incorporated into multiple-engine drives to compound the power of two engines into a single propeller shaft. This drive has the added advantages of balancing the power of the two engines and protecting the compounding drive equipment. It is interesting to note that the original development of hydraulic drives was made in connection with ship propeller drives incorporating up to 20,000 horsepower, and now the drives are being developed for fishing boats having requirements of approximately 300 horsepower.

Couplings are also useful in connection with electric motors which must be started under load. The fact that



Engine speed variation, hydraulic coupling on engine: 22.4 strokes per minute; left, 105-115 pound pressure; center, 132 pound pressure; right, 200 pound pressure.

the coupling transmits torque in proportion to the square of the speed allows the electric motor to gain speed under light torque. With this type of drive, standard push-button controls and standard electric motors can be successfully used to start heavy loads. The load is also started much more smoothly than with special high-starting-torque electric motors. Electric motor drives of this nature are in operation on grease mixers, belt conveyors, ball mills, and many similar types of machinery where the unit must start under full load.

Consistent reports of reduced maintenance of equipment are received from operators using drives incorporating hydraulic couplings. One of the most interesting came from a major contractor operating heavy dirt-moving equipment. One set of earth movers was capable of transporting 13 yards of material per load and another set was capable of transporting only five yards. Both were of a similar nature and both working on the same job, and both employed the same mechanical transmission in the drive. The 13-yard unit included a hydraulic coupling and the five-yard unit had a conventional drive. In almost a year's operation, only two repair jobs were required for the transmissions in the large units equipped with hydraulic couplings, while there was an average of one a week on the smaller units which were not protected by hydraulic couplings, despite the fact that the smaller units were loaded much lighter.

Hydraulic couplings with built-in friction clutches are now being used in power shovels and on engines supplying power to oil-well pumping units. Both of these operations are carried on with the engines working at relative constant speeds, but the horsepower requirements vary rapidly. The coupling reduces the peak load on the engine by smoothing out the power requirements. The recording tachometer and vacuum gauge readings taken on an experimental oil-well pumping installation show how the coupling smooths out the load on the engine when pumping conditions remain as nearly constant as possible. Without the coupling the engine speed varied from approximately 600 *rpm* to 900 *rpm* on every stroke of the unit. This variation was reduced to less than half that obtained with the standard drive after the hydraulic coupling had been installed on the engine. A similar reduction of the intake manifold pressure variation was observed. The clutch type of coupling allows the operator to disconnect the engine from the driven members when necessary, but allows him to remain in hydraulic drive at all times while operating.

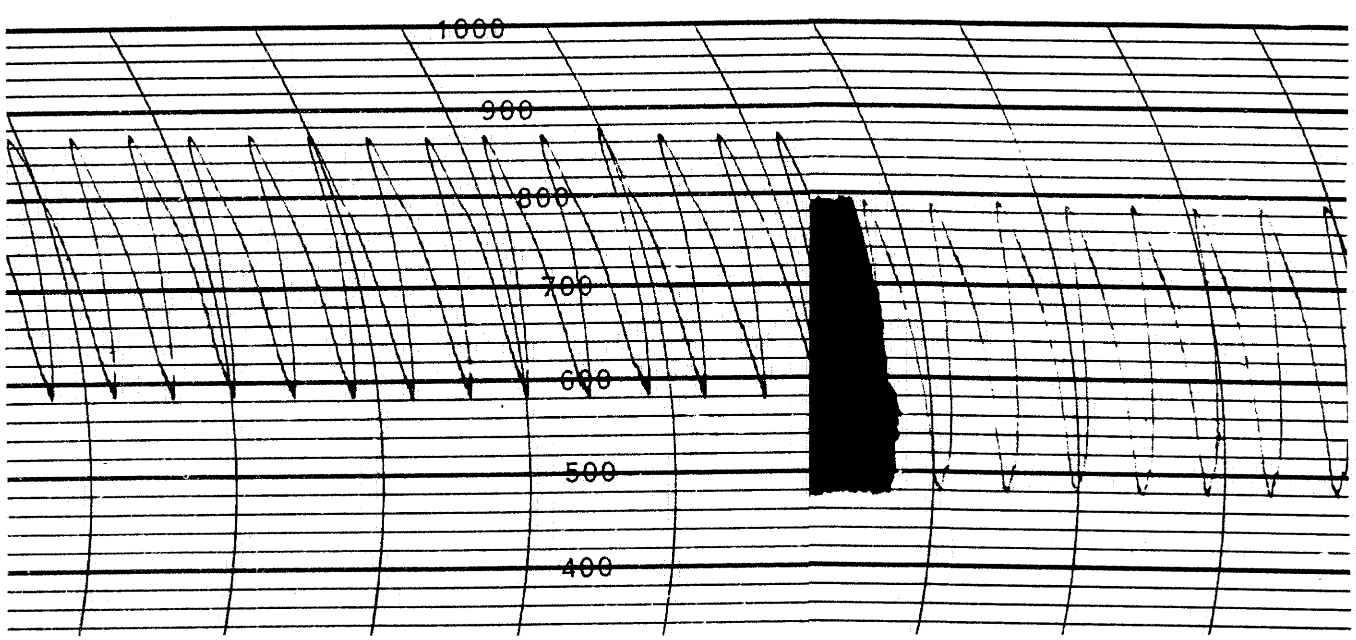
The scoop tube, or variable speed, hydraulic coupling has the added advantage of controlling the speed of the output shaft by regulating the amount of fluid in the coupling. In this type of coupling an adjustable tube extends into the hydraulic circuit and drains the fluid down to any desired level, thus allowing the coupling to slip. The amount of fluid and the degree of slip control the output speed of the coupling. It is apparent that the efficiency of the scoop tube coupling is inversely proportional to the slip.

Scoop tube couplings are used to advantage in driving slush pumps in drilling oil wells. It is sometimes advantageous to hold a constant pressure on the drilling fluid, even when there is no circulation of fluid. This is done with the scoop tube coupling by adjusting the tube to give the desired driving torque at the rated speed of the prime mover. As the scoop control coupling has provisions for cooling the coupling fluid, this condition of full slip in the coupling can be maintained for an extended period without overheating the coupling.

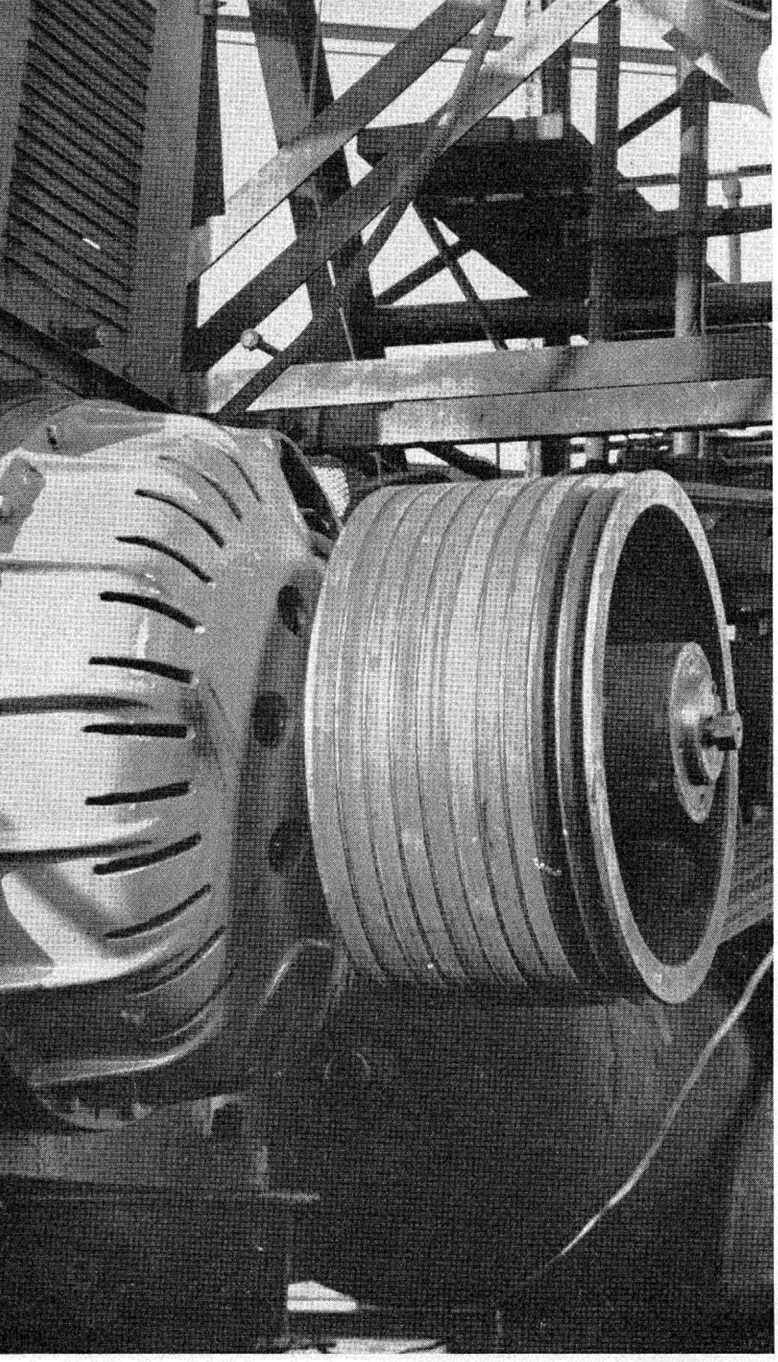
Variable speed couplings are also used in the automatic control of superchargers on airplanes. In this case the reduction in air pressure, as the plane gains altitude, operates a diaphragm which introduces fluid into the coupling. The higher the plane goes, the more fluid is introduced into the coupling and the more the coupling output speed increases. This increase in fluid and output speed is regulated so that the output speed of the coupling, and, in turn, the speed of the supercharger, will be correct for any given altitude.

LIMITATIONS OF HYDRAULIC COUPLINGS

Hydraulic couplings are best fitted for those drives in which the prime mover is operating at a uniform speed over long periods of time and where the output speed and torque are fairly constant. Couplings are not



Engine speed variation, friction clutch on engine: 120-143 pound pressure; left, 22.2 strokes per minute; right, 19.4 strokes per minute.



Hydraulic coupling installed on oil-well pumping engine reduces variations in engine speed and impact loads on sucker rods.

suitable for operating at various input speeds or on loads where the torque requirements change rapidly. An examination of the typical performance curve of a hydraulic coupling driven by an electric motor shows that the coupling output speed stalls under full torque at about three quarters normal prime mover speed. This prevents using the coupling at reduced prime mover speeds.

HYDRAULIC TORQUE CONVERTERS

Hydraulic torque converters consist of three basic members. The impeller, or pump, provides a means of imparting kinetic energy to the fluid as in the coupling, but in this case the pump is so designed that it will operate in one direction only. The turbine consists of several sets of blades which absorb the energy of the fluid. Between each set of turbine blades is a set of reaction blades which are stationary and which redirect the flow of fluid from one set of turbine blades to the next. The reaction blades and turbine blades are very similar in appearance to the blades in a conventional steam turbine and the impeller has the appearance of a simple centrifugal pump. The torque converter is not reversible, nor can the driven or turbine blade be used as driving members.

The output and input members of a torque converter are very different in appearance, and the output and input speeds and torques are also very different. The output speed of the torque converter varies from full engine speed at zero torque to zero speed at five times engine torque. Thus we can see that the converter runs at zero efficiency both at stalled output speed and when the output speed equals the speed of the prime mover. The hydraulic torque converter is a very successful hydraulic transmission between these two limits. One of the first reactions to the converter is the loss of from 15 to 30 per cent of developed horsepower when working in the recommended speed limits of the hydraulic unit. The converter efficiency does not tell the entire story in this case, as it is the work done in a day's time that counts, not the fuel consumption nor efficiency.

One of the outstanding cases of torque converters working at almost zero efficiency and getting a job done that could not be done in any other way came just after December 7, 1941. Pearl Harbor was lined with ships lying in the mud on their sides, and a means had to be found to right them. Six Wheels, Inc., in Los Angeles, built six heavy-duty winches including twin disc torque converters in the drive. These were shipped to Pearl Harbor and rigged up with the necessary blocks to pull the ships upright. For hours the converter shafts were almost stalled with the engines running at full speed and developing full horsepower. Each time a fraction of an inch was gained on the hoist drum the converter held it and a continuous pull was maintained on each hoist drum all of the time. The ships were righted and the torque converters, working much of the time at zero efficiency, get much of the credit for doing the job. No other known drive would keep the high torque on the drum drive hour after hour without rest.

APPLICATIONS OF TORQUE CONVERTERS

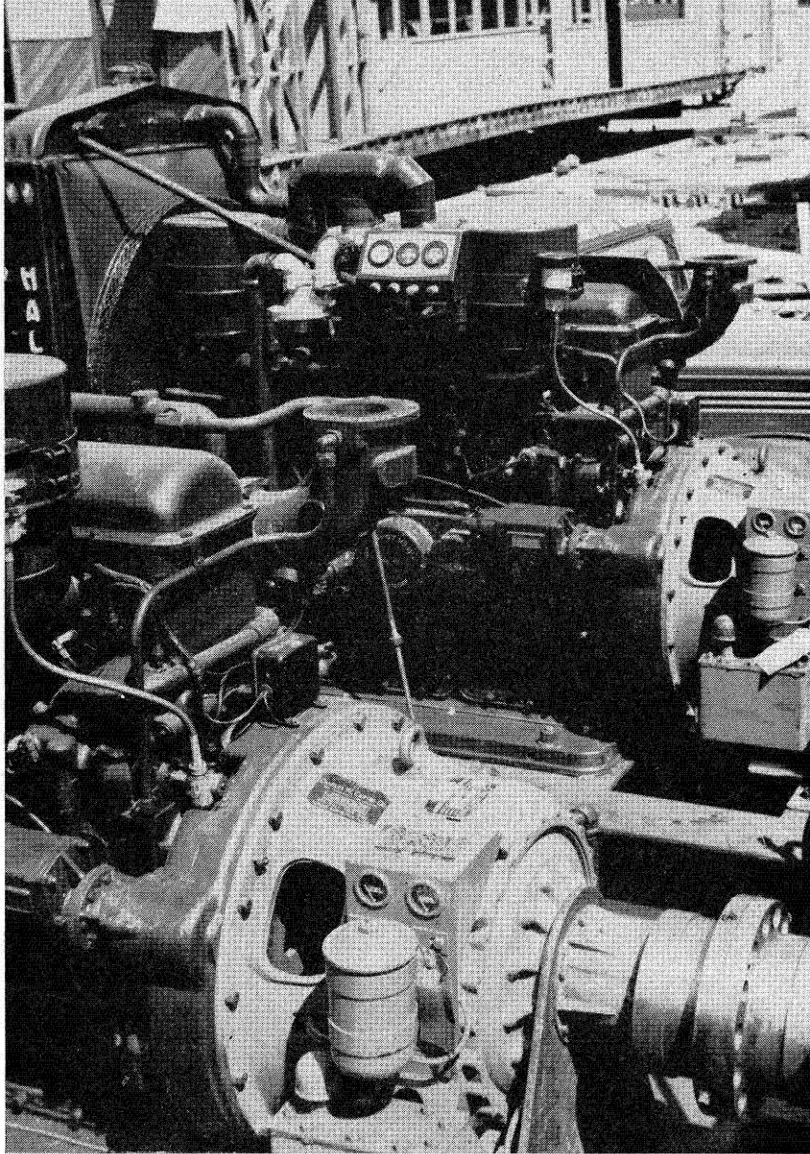
The torque converter is essentially a hydraulic transmission capable of developing torques varying from full prime-mover torque at about three-quarters speed to five times prime-mover torque at stalled output speed. A drive of this type is very useful in any operation requiring repeated changes in torque requirements, as it automatically selects the proper output torque and output speed for any load within its working limits. Hoists of all natures are the most logical application for torque converters, but study reveals many other suitable applications.

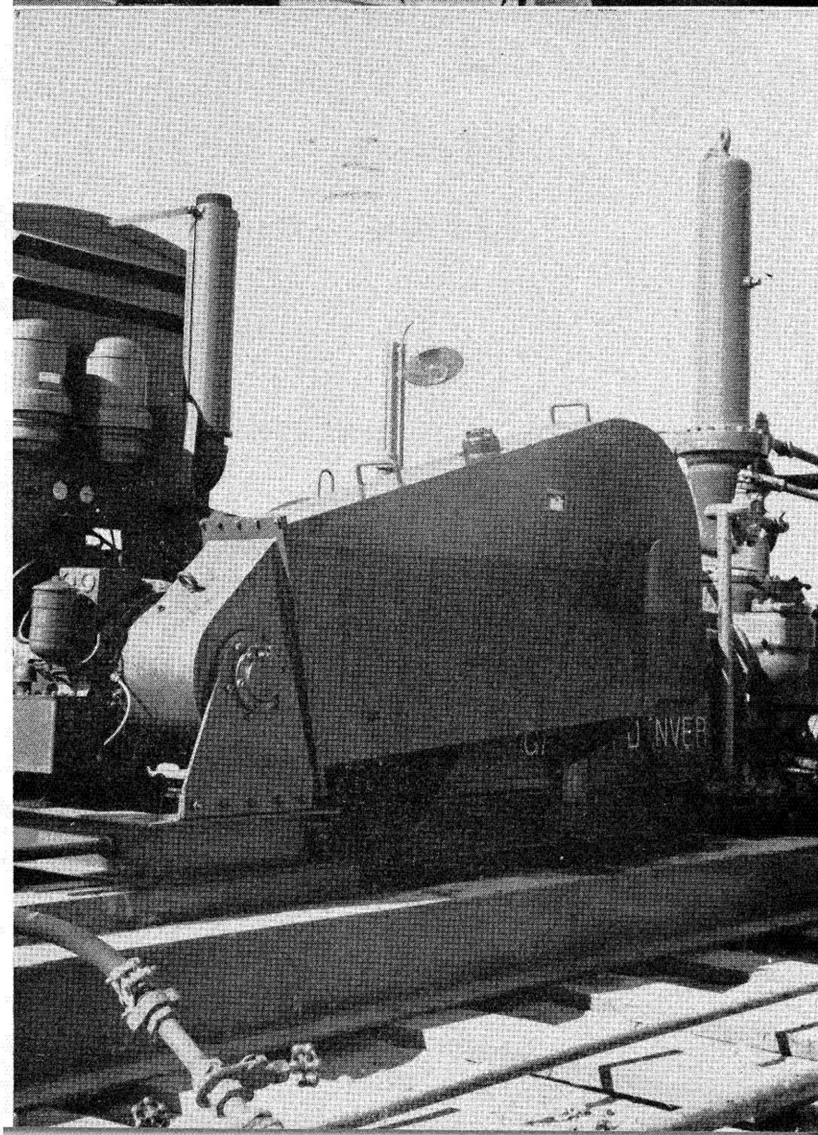
One of the early commercial applications of torque converters in large numbers was made in the logging industry of Washington, Oregon, and northern California. Internal combustion engines were replacing steam donkey engines on the hoists, but the gear transmissions fell far short of steam engine operation. Torque converters were installed on several hoists; they provided hoisting characteristics which did some things it was not possible to do with steam and they allowed loggers to use economical internal combustion engines in place of steam donkey engines. Each section of log to be moved would vary in weight and the hydraulic torque converter automatically selected the maximum speed at which any given log could be moved or hoisted. In yarder hoists the units driving through torque converters are able to hoist the logs at full throttle, hold them suspended at an even elevation while swinging them over the truck bed with the engines at partial throttle, and then lower them against the torque converter as the engine throttle is closed a little more. In this entire operation it is not necessary to touch a single clutch or brake lever from the time the log is hoisted until it is in position on the truck bed. All movements—hoisting, holding, and lowering—are done by control through the engine throttle only. In addition it has been found that many more logs can be loaded each day with converter-equipped units, and wire line and chockers give materially greater life.

Another early commercial application of torque converters was that made to oil-field hoisting equipment, or drawworks. The torque converter proved in the oil fields, as in the logging industry, that it would do more work in a day than similar units not provided with this hydraulic drive. It also proved that over-all maintenance on the rigs was greatly reduced through the protection of the hydraulic drive. The torque converter has its best opportunity to show its advantage in pulling the drill pipe from the hole, as each stand of pipe pulled reduces the weight of the remaining pipe to be hoisted. Time studies taken on rigs equipped with torque converters show that hoisting time is reduced as each stand of pipe is removed, and this is not true on rigs powered with internal combustion engines not equipped with torque converters.

The oil-field operators are also using torque converters to provide smooth power to small independent rotary table drives. These remove much of the impact loads and shock from the drill pipe and have proved their advantage in fields where they are suitable. Three interesting pump drives are now being developed in the oil field, including torque converters in the drive. This drive has often been questioned for torque converter application because of the continuous operation with maximum horsepower requirements and the possibility of damage to the pump when the stalled converter develops five times normal torque. Two of the pump drives are very special and are ideally suited for torque converter drives. One is an oil-well cementing pump used where the initial requirements on each job are to provide high-volume, low-pressure fluid. When all cement has been placed, it is necessary to build up and hold very high pressure against the cement until it has set. The other drive is used on an oil-well clean-out pump where the operator desires very high starting pressures to break circulation in the well and then wants to increase the volume rapidly as the pressure required to circulate reduces. Torque converters provide the required power and output torque to perform these jobs with the greatest assurance of successful operation.

The late war was responsible for two interesting applications of torque converters. Many of the landing craft were equipped with torque converter drives in their anchor winches. These landing craft drop their anchor several hundred feet before they run up onto the beach. When they have unloaded, the throttle on the anchor winch engine is opened and the drive through the converter puts a strain on the anchor line. This





AT TOP: Hydraulic torque converters on oil-well drilling unit improve hoisting performance and reduce maintenance cost. AT BOTTOM: Duplex reciprocating pump driven through torque converter insures maximum pressure and volume under all conditions. (See also cover illustration caption, page 1.)

strain is greatest at stalled speeds, but is substantial up to a speed equal to the reverse speed of the craft. The hydraulic torque converter insures maximum pull on the anchor line at all times and also sufficient speed on the spooling drum to make sure that all slack is taken up as the boat is floated by the combination of the anchor line pull and action of the waves.

Many of the army tractors used in transporting moderate field pieces included torque converters in their drive. The latest of these units are powered by two 215-horsepower engines, each equipped with its own torque converter. It has been proved that the smooth flow of power to the tractor treads has allowed the converter-equipped tractors to move equipment in areas where other units cannot travel. The army tractors are an outgrowth of early developments of Allis-Chalmers with converter-equipped industrial tractors, and Allis-Chalmers is again in production of these units in limited numbers.

City buses, heavy-duty short-haul trucks, and rail cars show other interesting applications of torque converters to mobile equipment. Many of the newer buses in Los Angeles are now equipped with torque converter drives. They can be identified by their rapid acceleration and even engine speed. No change in exhaust sound can be detected as the buses pick up speed, since they do not shift gears and the engines maintain maximum speed at all times. The loss of efficiency at high road speeds limits the use of torque converters, but this is not a problem on city buses in view of the number of stops and starts they make and the short distances they travel at high speeds. Rail cars present a different problem. They require high starting torque and smooth application of power to the wheels in starting the trains, but they also require full power and speed between stops. Special direct-drive converters are used for drives on buses and rail cars so the operator can shift from converter drive to direct drive when the high starting torque is not required.

Many other suitable applications will no doubt be developed for torque converters. At the present time plans are being made for off-the-highway trucks with a gross load of 300,000 pounds, powered by two 200-horsepower engines driving through torque converters. Fishing boats are also using converters to provide a constant strain on the lines used in recovering their heavy nets. The Navy uses torque converters on submarine net hoists guarding one southern California harbor.

LIMITATIONS OF TORQUE CONVERTERS

Care must be used in selecting the ratio of all drives in connection with torque converters in order that they may do most of the work in the efficient range of the converter. The high torque developed in the output shaft also places added loads on all conventional gear trains installed in many pieces of machinery. The loss of an average of 25 per cent of power through the converter makes this type of drive undesirable in those units operating at their maximum horsepower capacity and relative uniform loads for long periods of time.

SUMMARY OF HYDRO-KINETIC DRIVES

Both hydraulic couplings and hydraulic torque converters require relative high input speeds in order to operate to their best advantage. Industrial internal combustion engines operating at 1400 *rpm* and greater rates are very suitable for use with the present hydraulic drives. Both drives provide smooth starting of loads, prevent overloading and stalling the prime mover, and absorb much of the torsional vibration of the engines. Couplings are suitable on constant-speed, constant-torque drives where efficiency in excess of 95 per cent is desired. Torque converters are adaptable to those operations in which the prime mover will be operated at various speeds and loads, and where the output speed and torque varies with successive operations.

There are many applications in which couplings and converters are not suitable, and many more suitable applications will be developed as more experience is gained with these drives. Each new development will require careful study of the operations to be performed and careful engineering to select proper speed and torque requirements.

POSITIVE HYDRAULIC DRIVES

In addition to the hydro-kinetic units which have been described, there are several fine positive hydraulic drive units in widespread use in industry. These units are often built into various machine tools and generally develop but a low horsepower. In this type of drive a hydraulic pump provides a flow of fluid at the required pressure and volume for the drive. The fluid is carried through suitable lines to the positive-driven hydraulic motor. In most types of positive-drive units either the pump or the motor has a variable volume control to regulate the speed of the driven unit. One of the manufacturers of positive hydraulic drives very aptly compares his unit with an electric generator and an electric motor. The hydraulic pump generates hydraulic power which can be transported reasonable distances and around obstructions to the hydraulic motor, just as electricity can be carried over wires. The power developed depends upon the volume and pressure of the fluid, just as electric power depends upon the voltage and current.

Positive hydraulic drives have three outstanding characteristics. The hydraulic motors can be reversed very easily, a wide range of motor speeds can be obtained, and the hydraulic power can easily be transported reasonable distances through suitable pipes. The hydraulic fluid is in a closed circuit so that it is used repeatedly.

The positive hydraulic drive units do not have the ability to absorb shock loads which is so characteristic of the hydro-kinetic drives.

ESSENTIAL OILS

(Continued from Page 9)

for plant life and as if, because of the nature of the oils, the plant reacted by walling them off, as is also the case when intradermal oil injections are made in animals.

The question has repeatedly come up as to what function the oils could have in plants, and many guesses have been made, such as the attraction of insects for pollination, protection against snails or other enemies, sealing of wounds, varnish against excessive evaporation, etc. The experimental evidence for these opinions is not very strong: it rests on a few individual experiments which do not allow generalization.

The interesting field of the biochemistry of the oils, which also includes our perception of these as odors and flavors, is still practically a closed book. Our chief interest up to the present has been to enrich our statistical knowledge, mostly in view of commercial advantages. A diversion of this interest to the underlying biochemical principles will undoubtedly be of benefit to all concerned.