DEVELOPMENTS OF AUTOMOBILE TRANSMISSIONS

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DEVELOPMENTS OF AUTOMOBILE TRANSMISSIONS

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THESIS

PREFACE

Every invention is crude in its original form, and passes through an evolutionary process of variation and modification until it approaches perfection. The automobile industry has a similar history.

The modern automobile has been the result of enormous improvement in the engine and chassis of the original model, and it can be said without hesitation that the present day automobile is a piece of engineering art. This, however, is not true of its components, especially its transmission. This is one of the burning problems in the automotive industry, and is causing many headaches to engineers.

In the primitive automobile, the transmission was difficult to operate, and it was very noisy. After the first World War, public demand gradually arose for a quieter and more easily operated transmission. The change in transmissions became necessary because of the introduction of increasingly powerful engines, capable of attaining much higher power and acceleration. In the past two decades, every new model put out by different manufacturers has been more powerful than the preceding one. There has also been corresponding improvement in the transmissions, although to a lesser degree, and as a result, helical gears were introduced, which made the transmission quieter and easier to operate.

In this country, a three forward-speed transmission was introduced and commonly used in the earlier models, but in later years, a fourth speed was introduced with the increase in the power of the engine. This proved detrimental, as the transmission had to sacrifice acceleration, ease in gear-shifting, and gradient climbing. Automotic over-drive was then introduced to overcome these difficulties which, in combination with transmission, developed later into the automatic transmission.

During the second World War, the auto engine was improved considerably as regards high-compression ratio and efficiency, but the actual goal of perfecting automatic transmissions and their introduction on a commercial basis in automobiles still remained unaccomplished. Metallurgical research helped a good deal in producing metals of the desired physical properties, which were used in the construction of simple precision machines for polishing and gear cutting.

These developments in metallurgy and in machining of parts and gear cutting improved considerably the stepped transmission, making it more or less noiseless, and reduced the weight of the whole car including the transmission gears, because of the increase in the working stress of the gear teeth. On the other hand, modification in overdrive led to the introduction of a synchromesh transmission so that gear shifting became no more than child's play.

In modern cars, the new types of transmissions have been introduced by different manufacturers with slight modifications. All the manufacturers are trying to build fully automatic transmissions, which would completely relieve the driver from changing gears when the engine loses speed, so as to adjust the transmission ratio according to the road resistance. The steam turbine principle introduced the idea of hydraulic coupling for automobiles, which had worked satisfactorily for many years in marine engineering.

The ability of hydraulic couplings to adjust the speed according to the road resistance made it very adaptable for car transmissions.

Today, many cars have hydraulic couplings attached to conventional transmissions, while others have hydrodynamic couplings or planetary transmissions. The working principles are the same for respective categories of transmissions, but the commercial names are quite different. The demand for an automatic transmission and its performance is so great that even tractors have been fitted with torque converters.

Many articles and books have been published on the conventional type of gear transmission, but there is a great paucity of literature on automobile transmissions, and no consolidated work on auto transmissions has so far been published. The existing literature, in the form of articles and sketchy notes, is scattered throughout various journals and magazines.

The present thesis is an attempt to furnish all the available information on auto transmission for the use not only of the engineering students and auto technicians, but also for automobile owners, so that they may be able to understand all the intricacies and complexities of the new automatic transmission and its working principles.

This report, however, is not proposed to be the final word on auto transmissions, as the subject is still making great advances. The auto engineers and research workers are striving to attain a greater degree of perfection and are introducing changes almost daily. But the writer has the satisfaction of doing a preliminary survey in this field, and of furnishing an up-to-date review of the literature on automobile transmissions.

ACKNOWLEDGEMENT

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INTRODUCTION

The term "transmission" is a cosmopolitan word in that it includes an extensive field; in this discussion, however, the term is restricted only to torque and speed changing devices in automobiles. It is rather surprising that even in this restricted field, no universally satisfactory transmission has been designed. The elimination of clutches and transmissions has long been the goal of engineers, and is still the great, unsolved problem in auto design. The reasons for the engineers' headaches have been the varying service requirements.

Automobile transmissions or torque converters have three main purposes:

1. To impart motion to the vehicle from rest into high gear.
2. To increase the torque of the driving wheels of the vehicle so as to overcome the increased resistance due to gradient and bad road conditions.
3. To keep the engine speed from falling below its stalling speed when the car is operated at part-throttle and at reduced speeds.

Transmissions are necessary because the torque of an automobile engine is never constant. It must run at several hundred revolutions per minute to develop useful torque, and at several thousand revolutions per minute to develop maximum power. The torque is zero at zero speed, but it is not maximum at maximum speed. Therefore, to have economy over a wide range of operation and to improve operating conditions it is necessary to install a transmission that has a variable speed ratio.

As it has already been stated, the main function of a transmission is to increase the torque or give a point of variable mechanical advantage between the engine and the driving wheels. Cars are run mostly in direct drive, except where the country is hilly, or the road conditions are bad. Therefore, for economic reasons, a slight decrease in the fuel consumption, and a small increase in performance efficiency would be gained by having a large number of steps in the transmission. On the other hand, the economy or fuel consumption might depend 75% on the skill of the driver. A test carried out in this country showed that a "cowboy driver" would consume 75% more fuel than an experienced driver, with a decrease of five minutes in time for that particular test.

As the steps in the transmission are increased, the initial cost of the automobile is also increased. On the other hand, in decreasing the steps in transmissions, considerable ease in driving and high efficiency at high speed and low load is obtained at the sacrifice of efficient operation on full load and low speed.

A car fitted with a greater number of steps in its transmission would use a lower octane fuel, which may reduce the cost of driving, but a dual fuel carbuetor and a two fuel tank, which would increase the initial cost, has to be installed. In Europe, people who sacrifice smoothness of driving and acceleration for economy, buy a cheaper car having greater steps in transmission and a smaller power-by-weight ratio, but such a car necessitates greater skill in driving.

Driving in a city or town requires maximum acceleration in moving the car from rest, while the maximum speed has very little to do with its city performance, since that speed is never attained in driving. At the same time, the acceleration required should be as smooth as possible, so as to give maximum comfort to the passenger.

In cases where driving is done in the country, the requirements of the transmission are quite changed. A greater acceleration in driving from half speed to full speed is required, while the acceleration from zero to half speed is of little importance in country driving. In addition, acceleration, high speed, and fuel economy are desired at a greater load factor.

Heavy commercial vehicles which operate at smaller power-by-weight ratios and have to run in city streets as well as country roads require innumerable transmission ratios for driving from zero to maximum speed at greatest economy.

It is obvious that for good performance, an infinitely variable transmission would prove best in automobiles, but the reason for the inability of the manufacturers to install such equipment is its high manufacturing cost. The public, wishing to be relieved of the trouble of changing gears by hand, demands an automatic transmission which would select the best ratio according to the engine performance and speed. A good driver, however, would drive a carefully selected ratio-stepped transmission more economically than he could drive a car fitted with an automatically operated transmission. In practice, the installing of automatic transmissions is mostly controlled by the economic considerations of the manufacturer, which means that there is greater scope for a fully automatic transmission (dynaflow) in higher-priced cars than in the ordinary passenger car. A semi-automatic transmission (hydramatic) which is cheaper to build has greater possibilities of application to ordinary cars.

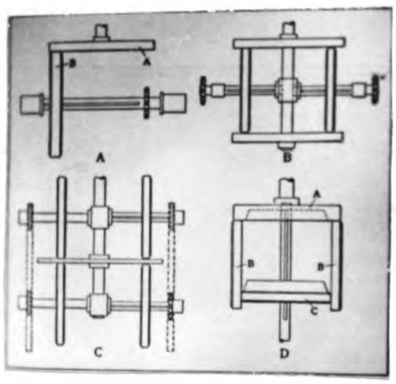


Figure 1

Constantly Variable Friction Drive

HISTORY OF EARLY TRANSMISSIONS

In the early days of automobile history, cone pulleys and belts were used to vary the engine torque. This mechanism was soon given up because it was not easy to operate, and friction-driven discs were used. The principle of friction-disc-drive was very simple. This system is still used in some of the workshop machinery for adjusting the cutting speed of a cutter.

In those early automobiles, the propeller shaft of the engine was connected to disc A as shown in Fig. 1. Another disc, B, connected to the driven shaft, slid over the surface of disc A and along the driven shaft. Whenever a change in speed was desired, disc B was slid on the surface of A by a lever along the driven shaft. When the pulley was moved on the other side of the center of disc A, a reversal in the direction of rotation of the driven shaft was obtained. Besides the change in direction, a change in speed ratio was also obtained. Both of the above factors were convenient and necessary for an automobile transmission.

This transmission was soon given up since there was considerable friction loss and slippage, and spur gears were introduced.

From the viewpoint of good performance of the automobile, an infinitely variable gear box should have been developed so as to enable the driver to adjust the gear ratio according to the circumstance for maximum economy in fuel consumption. Because engineers were unable to produce a suitable transmission having the above characteristics, they selected a few gear ratios in geometric series and produced a three-speed gear box. From experience, they found that a three-speed gear box worked quite satisfactorily in this country. In Europe, the tendency is more towards economy of fuel consumption than towards the power of the engine and quick acceleration of the car. European engineers developed a four-speed gear box which, no doubt, gives great economy in fuel consumption and increases the life of the engine. American drivers like better acceleration and do not like to take the trouble to shift gears. A fourth speed ratio was introduced which operated automatically and is called the automatic over-drive. This mechanism, which was added in the rear of a conventional type three-speed gear box, funtioning as a four-speed, is still used in automobiles.

In short, the power transmission system of automobiles has gone through a number of stages in the last fifty years. First came the combination of engine, friction clutch and transmission, differential and chain drive to the rear wheels. Then the chain dirve was dropped for the system used in most cars today: engine, clutch, transmission, differential and axle to rear wheels. Last, but not least, fluid couplings were added. In three-speed transmissions, the gear ratios are mostly determined by highest and lowest speed of driving, but it is advisable to have the consecutive ratios in geometric series as they have greater economy. In practice, ratio in geometric series is very hard to develop, due to the manufacturing difficulties, and a ratio close to it is selected.

From the above discussion, it is clear that a transmission which has an infinitely variable ratio and in which the change in speed is automatically operated, is by far the best transmission. To approach this situation, an electric transmission was developed. In this arrangement, the gasoline engine was directly connected to a generator. The electricity generated was used in driving a motor connected to the wheels. It provided a gradual acceleration, but since the machinery was costly, occupied much space and proved very efficient. This system was given up by the automobile industry. However, it is still used by the railroad transport industry.

Another type of transmission used in automobiles is known as the planetary transmission. It can be automatically adjusted within a wide range of speed variation. However, its efficiency is low and requires greater space, therefore it is not commonly used at the present time, except in combination with hydraulic couplings.

Hydraulic couplings, which were originated in marine engineering, have been modified, and at the present time, are used in many makes of cars. Broadly speaking, there are two types of hydraulic transmissions: the hydrostatic and the hydrokinetic. In the first type, the torque from one wheel is transmitted to the other by the pressure of fluid contained between the driver and the driven members.

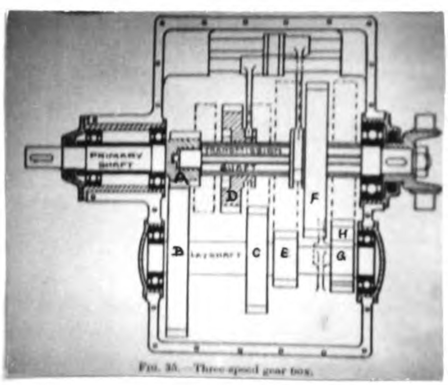
In hydrokinetic transmission, power is transmitted by utilizing the momentum of fluid which is set into motion by the prime mover. They have different trade names and will be discussed later in this report.

CONSTANT MESH TRANSMISSIONS

The conventional type countershaft gear box is widely used in present-day automobiles, from the small cars to the heavy hauling road vehicles. It is easy to understand, has few component parts, is cheap to manufacture, and requires very little maintenance. Any other transmission which might be introduced now would have to compete with the above unit not only in simplicity, but in cost as well. Synchromesh has made the countershaft transmission so easy to manipulate that it has become doubly difficult for any other type of transmission to compete successfully.

Generally, the countershaft type gear box has three forward speeds. First speed has the highest gear ratio and it transmits maximum torque. Third speed or high gear has a direct drive, which means that the engine-driven shaft meshes directly with the propeller shaft. Intermediate ratio is known as second gear, and is approximately the square root of the first gear ratio.

Renault gear boxes are the most common ones used in present-day cars. They have a primary shaft split into two parts. The front end of the shaft is connected to the engine, while the rear end is connected to the propeller shaft. The arrangement of this kind of gear box can be easily understood through Fig. 2. An examination of the figure will clearly show that there are four shifts. The front end shaft is directly connected to the engine through the clutch, and it revolves at the engine speed. The splined shaft along the same axis is the transmission shaft, which is directly connected to the propeller shaft. All the spur gears on this shaft can be shifted by means of forks. The third is a countershaft



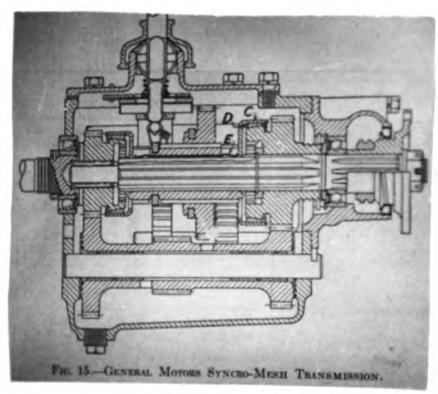


Figure 2

Three-Speed Gear Box.

which is fitted with gear positions, and which always remains meshed with the front end shaft through gears A and B. The fourth shaft or pin is very small and carries only gear H. Gear H is constantly in mesh with gear G on the bottom shaft. In this particular position, the gear box is in neutral position since both the front end and transmission shaft are free to rotate. Low Gear: When high speed is desired, the low speed ratio is employed and the gear D is meshed with A by sliding the gear D. Gear D has internal teeth which directly mesh with the external teeth on the gear A. This change is also known as third gear, and the transmission shaft rotates at the same speed as the front end shaft.

Intermediate or Second Gear: Gear D is slid over the transmission shaft and meshes with gear C. This time, the external teeth of gear D mesh with that of C, which gives the required ratio. The motion is transferred through gears A, B, C and D.

High or First Gear: When low speed and high torque is desired,, gear F is meshed with gear E. The motion is transferred through gears A, B, E, and F.

Reverse Gear: When it is necessary to move the car backwards, gear F is meshed with gear H which in turn, is directly meshed with gear B on the bottom shaft. Thus the torque is transferred through gears A, B, C, H, and F.

Gear Ratio: The gear ratio for a car is determined by the weight of the car and the power of the engine. The direct drive should be such as to give maximum speed at maximum power of the engine. The bottom ratio is selected to give maximum torque at low speed. In cars top gear ratio is generally 1:1 and the low ratio is nearly equal to 4:1. The intermediate ratios are selected according to geometric series.

Ideal Gear Ratio: It is found in gasoline engines that maximum torque occurs at certain speeds which is lower than that of maximum power. To have a nice selection of gear speeds, all the speed ratios should form a successive geometric series. For example, let top gear ratio be 1:1 and high gear ratio be X:1, and y be the common ratio between two successive speeds. Finally, let Z_1, Z_2, Z_3...Z (Zi)...Z_n be the gear ratio of speed 1, 2, 3,...n. The geometric progression will be in a form: x, xy, xy^2; xy^3...xy^{n-1}. The gear ratios are to be in geometric series. As such:

1st Gear Ratio	equals	Z_1,	equals	x
2nd Gear Ratio	"	Z_2,	"	xy
3rd Gear Ratio	"	Z_3,	"	xy^2
4th Gear Ratio	"	Z_4,	"	xy^3

In all cases, the top speed ratio is 1:1 and the common ratio between successive speeds should always be equal to, or more than, the ratio of the speed of maximum torque and maximum power of the engine.

According to the preceding assumption of geometric series, the car having two gear speeds should have its top speed ratio equal 1:1

xy equals 1
x equals 1/y

For three-speed gear box: Gear ratio equals xy^2 equals 1
x " $1/y^2$

For n-speed gear box: Gear ratio equals xy^{n-1} equals 1
x " $1/y^{(n-1)}$

The gear ratio thus obtained is known as an ideal ratio. It is very difficult in practice to build spur gears with this ratio, because of the limited number of teeth per gear and also because of the working stress per tooth.

Smallest gear: The smallest gear in a transmission generally has twelve to fifteen teeth or more. The limiting factor in gear design is the distance between the root of the tooth and the bottom of the sliding groove. This thickness of material should be strong enough to provide sufficient strength for transmitting power.

The unit load on teeth is determined by the type of teeth and the material used in the gear. The r.p.m. of the gear can be determined from the r.p.m. of the engine at maximum torque. The following equation may be used:

$$\text{RPM of the gear equals} \quad \frac{\text{RPM of engine}}{\text{Low gear ratio}}$$

In the design of the gear box, bending of the shaft should be kept as much at a minimum as possible, and the shape of the teeth should be carefully selected for that particular speed and ratio of the gears. All the parts should be very accurately machined and ground, and the shafts should be made rigid enough to have minimum bending. The best way of preventing the bending of shafts is to install an intermediate bearing, and to increase the diameter of the shaft.

The quietness of the gear box in passenger cars is of great importance to the passengers as well as to the manufacturers. Both quietness and bending of the shaft made manufacturers install a center bearing in their gear box, which not only made the gear box longer, but split it into two sections. This design helped greatly in assembling the parts, but it required more expensive machining operations, which made it costly. The tendency toward jumping out of gear was greatly reduced, and greater nominal loading of gears could be obtained without sacrificing reliability.

Transmission Design: From the principle of the toothed gear, it is found that maximum torque transmitted is directly proportional to the square of mean tooth thickness at base and face width and pitch diameter of the gear. According to Mr. P. M. Heldt, the distance between the main and counter shaft for a three-speed gear box is given by the following equation:

$$d \text{ equals } 0.5 \sqrt[3]{T} \text{ in}$$

Where T is the maximum torque of the engine in lbs. ft.

D is equal to the distance between main and center shaft in in.

The distance between the mainshaft supporting bearing lies between the two limits given by the following equation:

$$l \text{ equals } 1.20 \sqrt[3]{T} \text{ to } 1.50 \sqrt[3]{T} \text{ in.}$$

Another simplified equation for three-speed span gear transmission gives a very close result:

$$L \text{ equals } \frac{CW}{P} \text{ lbs.}$$

Where L equals maximum load tangent to the pitch circle.

P equals normal diametral pitch.

W equals width of face in inches.

C equals coefficient.

C equals 18,000 to 21,000 for first ratio

21,000 to 24,000 for intermediate ratio

28,000 to 32,000 for low speed gear

Face width of spur gear is calculated by the following formula:

$$W \text{ equals } \frac{LP}{C}$$

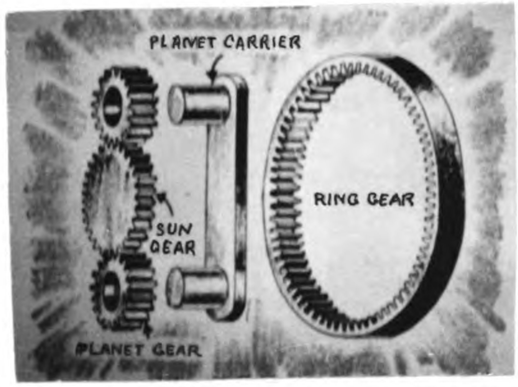
Shaft Design: The shafts are made as thick as possible to minimize deflection due to torque transmission, but it is limited by the fixed distance between the two shafts. The deflection in the shaft depends on the diameter of shaft and the distance between the bearings supporting it. The diameter of the shaft is generally 0.53 times the distance between main and countershaft.

Bearings: Roller bearings are used in most of the gear boxes and some bearings are made of double-tapered roller bearings to take the end thrust.

Synchronizers: In early types of gear boxes, great difficulty was experienced in changing speed ratios due to the fact that in changing speed ratios, gears running at different speeds are meshed together. Synchronizers were introduced, which practically eliminated this difficulty.

In this system, the gears on the transmitter shaft should be free to rotate, and if a change is desired, the particular gear is clutched to the shaft. Positive clutch, which had a collar and internal teeth, was used. The collar could be slid axially on the shaft and could rotate at a definite relation to the shaft. Besides this, the synchronizing mechanism consisted of two male and female members, which were part of the gear to be meshed.

Transmission Housing: This was made of cast aluminum alloy in early models but now it is made of cast iron.



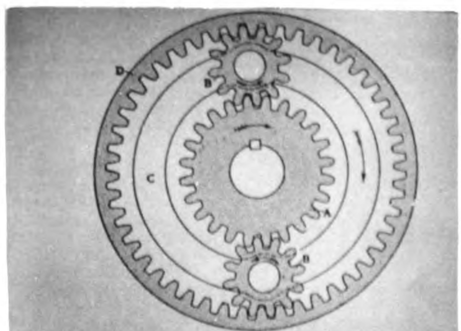


Fig. 1.—Internal-Gear Planetary Unit.

Figure 3

Internal-Gear Planetary Unit.

PLANETARY TRANSMISSIONS

In early automobiles, the planetary transmission was commonly used, but because of further developments in the sliding gear transmissions, it was abandoned. When the transmission wore out, it became very noisy. Most of the trouble was located in the brake bands which this kind of transmission had. No difficulty, however, was experienced in changing speed, since all the gears remain constantly meshed. It was first used in English cars in combination with hydraulic couplings. Even when the engine was running at idle speed due to the drag of coupling, changing gears was practically impossible in automobiles fitted with a sliding gear attached to the hydraulic coupling. At the present time, most cars which are equipped with automatic or semi-automatic transmissions have a planetary transmission in combination with the hydraulic coupling.

Working Principles: Planetary transmissions are classified into two groups:

1. Internal gear type.
2. All external or all-spur type.

Internal Gear-type of Planetary Transmissions: Its working principle is shown in Fig. 3. Pinion A is the driving member, which is connected to the engine shaft. Two or more identical pinions B which mesh with it are equally spaced around the circumference of A, which is also known as a sun gear. Pinions B are mounted on a planet carrier C, which may be a ring or spider supported by concentric bearings on the main shaft.

Pinions B are carried on studs welded or moulded to the planet carrier, which in turn is connected to the output or driven shaft. All these pinions mesh internally, as it is shown in the figure, with ring gear D, which is also supported by bearings concentric to the driving shaft.

If the rotation of ring gear D is checked, gears B start to rotate in the same direction as the driving shaft, but at a definite ratio and at lower speed, which gives the increased torque.

In order to shift into direct drive the brake holding the ring gear is released, and a clutch connecting the drive shaft and the driven shaft is directly engaged. It is done through a clutch which locks the planet carrier to either the sun gear or ring gear. In either case, none of the gears can turn on each other, so the whole mechanism is locked and rotates all together without affecting the drive.

Principle of All-Spur Type Transmission: The principle of this type of transmission is shown in Fig. 4. There are three independent gears, A, B and D, which are mounted on bearings concentric to driving and driven shaft. One of the shafts has one end fitted inside the other and is telescoped.

Gears A^1, B^1, and D^1, which are meshed with gears A, B, and D, respectively, are rigidly connected to each other and are mounted on a spider, which in turn is mounted on bearings concentric to the driving and driven shafts. Generally, there are three such sets, equally spaced around the axis of the shaft.

Gear A and shaft S are the drivers, while gear D and shaft S are the driven members. When low forward speed is desired, the planet carrying the set of gears A^1, B^1, D^1, is checked from rotation through a brake drum connected to it. Power is then transferred through pinions A, A^1, D^1 and D.

When direct drive is desired, pinion A is directly coupled to D through a clutch.

For reverse motion, gear B is checked from rotation by a clutch provided in it. Power is then transmitted through gears A, A^1 , D, and D^1 ,

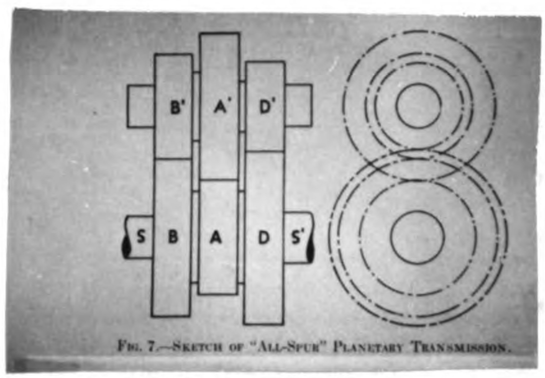


FIG. 7.—SKETCH OF "ALL-SPUR" PLANETARY TRANSMISSION.

Figure 4

All-Spur Type Transmission

but this time the motion of D is in the opposite direction and at a speed ratio of $\frac{D\ (b - a)}{a\ (d - b)}$ to the driver, a, b, and d, being the number of teeth on gears A, B and D.

Speed Ratio: Assuming a, b and d to be the number of teeth on gears A, B and D, respectively, in Fig. No. 3 the number of teeth on gear D should be equal to a plus 2 b equal to d as they are meshed in one circuit.

When the sun pinion is rotated and ring gear D is checked from rotation, there are two motions to the planetary gears, each one rotating about its own shaft, and, at the same time, they all move around in a circle on the teeth of ring gear D. The number of revolutions of pinions B with respect to ring gear D on their own axis would be equal to d/b. But by revolving a revolution around their own axis, they move b/a around the circumference of gear A. The combined rotation equals d/b x b/a which equals d/a. But as the sun pinion has to rotate once in the same direction as the planetary to impart first motion of the planetary pinions, the total motion of the sun pinion on reduction ratio is equal to (d/a plus 1) equals $\frac{(d \text{ plus } a)}{(\quad A \quad)}$.

Gear Trains: In order to have a higher speed ratio, the planetary pinions are made in sets of two unequal pitch diameters. They are made integral and are placed side by side. The smaller pinion is meshed with the sun pinion, while the bigger one is meshed with ring gear D. Because of practical difficulties the diameters are limited and remain within a ratio of 1.66 to 2.5.

There are various modifications of simple planetary gears. There are some with double planetary pinions of different sizes, which consist of

HYDRA-MATIC CROSS SECTION

FIG. 5

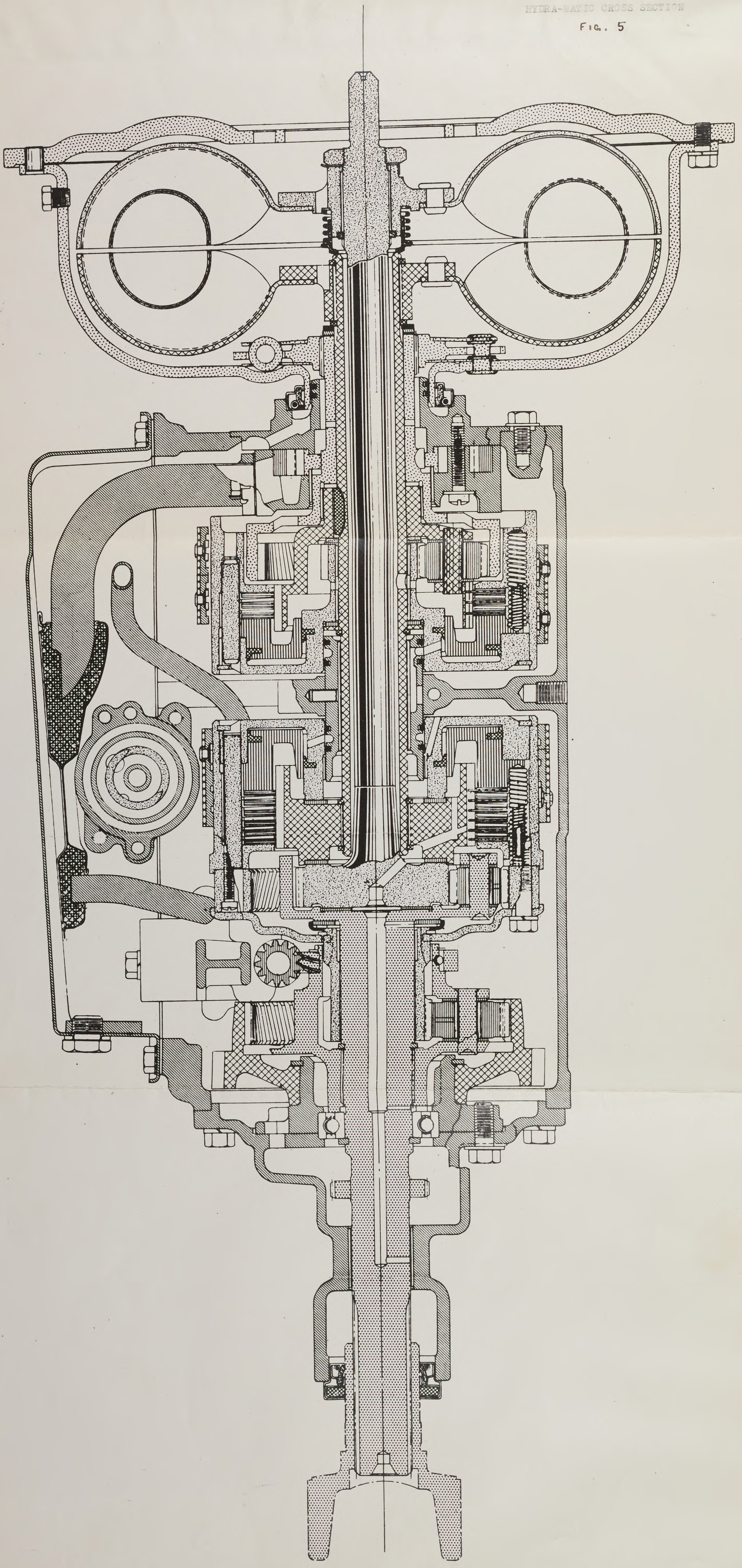


Figure 5

Combined Planetary Units.

two planetary gear sets with certain gears of one connected to a certain gear of the other. The principle of working is the same, and such set-ups are known as compound planetary assemblies.

Planetary gears are used in automobiles largely as automatic or semi-automatic transmissions, which are discussed in later chapters.

HYDRAULIC TRANSMISSIONS

Automobile engineers of this country as well as of others are doing extensive research work on the development of the automatic transmission. The main type of transmission, which has been developed now and is being further developed, is the hydraulic transmission. It is classified into two groups, generally known as the hydrokinetic and hydrostatic transmission. In both systems the fluid is employed to transmit power.

In the hydrokinetic system, fluid travels at high velocity in a steady stream, whereas in the hydrostatic system, the fluid does not flow in a uniform steady stream, but rather it is subjected to a number of cycles of pulsating pressure, as in the case of AC current. This kind of transmission obviously has some disadvantages as compared with the steady flow system. When fluid is subjected to high frequency of pulsating pressure, it is apt to warm up, thereby decreasing the mechanical efficiency. But from the manufacturer's point of view, the hydrostatic type of transmission is easy to build because it does not require so much precision work in machining. On the other hand, if a positive displacement pump of reciprocating or rotary abutment type pump, driven by pulsationless motor is employed, and a road wheel motor is used for converting torque, an ideal differential and braking system is obtained. When braking is desired, the flow of fluid can be restricted through the communicating lines. A transmission of this type would replace the clutch, gear box, propeller shaft joints, rear axle, differential, brake drum, shoes, and all of the accessories of today.

This new system would consist of a pump driven by an engine, two oil motors installed within brake drums, operating valve, reverse valve, and flexible pipe connection for the communication of fluid.

In the early design of the oil motor, straight vanes were employed which gave little encouragement in the development of this type of transmission. After great consideration, curved vanes were employed which had some qualities superior to those of straight ones. It is only natural that vanes bounce in some order at high speed, but the liability of curved vanes to bounce together has never been experienced in practice.

The second advantage is that the vanes are always in hydraulic balance at the moment they break contact with the starter, and therefore no pulsating effect is experienced. At the same time, this method minimizes the friction loss and requires a low pressure to set it in motion.

<u>Main Advantages of Hydraulic Transmissions</u>

Let us take the example of shifting gears in a multi-speed gear transmission in which each time the gears are shifted, extra fuel is pumped into the engine, increasing both the fuel consumption and the amount of time the engine does not operate at the maximum fuel efficiency.

One can say that a particular gear ratio can have maximum economy if the engine is driven at constant load, at constant speed, and at constant grade. But this condition in the case of the automobile is hardly obtained, as the vehicles are operated at variable speed, load, and also frequently stop and start, which makes a hydraulic converter quite adaptable to automobiles, even though its efficiency is lower than the conventional type gear box.

The infinitely variable torque ratio of the converter is the main advantage over the mechanical transmission, which must have fixed gear ratios. The best design of torque converter is one which can work under all operating conditions, with the engine running at the most economical speed to overcome the vehicle resistance to motion.

We can summarize the advantages of hydraulic coupling as follows:

1. It gives a steady torque and smooth acceleration and starting.
2. It eliminates shocks and jerks and thus reduces maximum stresses.
3. The engine cannot stall due to overload or to slow driving.
4. It is noiseless, has longer life, and does not require gear shifting in driving.

Nowadays, the hydraulic coupling used in automobiles is a centre baffle hydraulic coupling. The centre baffle circuit breaks the oil circulation at low speed, thus producing a sharper cut-off, lower stall and drag torque, and reduced slip at low running speed. A similar effect can be obtained by the use of symetrical couplings. This system, however, is unable to alter the cut-off speed readily by variation in baffle diameter as can be done with the centre baffle type.

Semi-automatic Transmission: This type of transmission can be semi-automatically operated at many different ratios. It consists of a hydraulic coupling (discussed later) in front, a conventional three-speed countershaft type transmission in the middle, and a semi-automatic planetary overdrive at the rear.

With the lever in the "low" position, the car is started in second gear on level road, and the accelerator is depressed and then released after a certain speed is attained. As the speed of the shaft crosses the certain speed, the overdrive will be second speed, which is a little higher ratio than the direct or third speed.

Again the accelerator is pressed so that the car attains the desired pickup. The shift lever is then placed in high position with the converter clutch. At this position a gear ratio of 0.772 to .1 is obtained.

If the operator wants to downshift, he can depress the accelerator to the full extent. This will create a momentary torque reversal and thereby permit the sun gear to be unlocked, giving a direct drive from the overdrive.

Hydraulic Coupling or Fluid Flywheel: This has taken the place of the friction clutch, and serves the purpose of a centrifugal clutch. In some arrangements it partly or fully serves the purpose of a friction clutch, and, as such, it is used either singly or in combination with a friction clutch. If the engine is run slowly it will not transmit torque, but when the engine is speeded up, it will gradually take hold until finally the torque will be transmitted to the rear wheels with practically no slip.

Principle of Working: Take the example of a water wheel in which water strikes the blades at a certain velocity. Now if instead of water, round pebbles are shot at the blades, each pebble will impart to the wheel a little push, and the wheel will turn around. If we can increase the number and velocity of the stones, the wheel will turn faster. In fluid flywheel, instead of stones, round masses of oil are shot at the blades.

The construction is very simple. The working parts of fluid flywheel look very much like a pipe ring or a doughnut. The pipe ring is sliced down the middle, so there is no connection between the two halves. One half, which is known as the driver, is connected to the engine, while the other half is connected to either the friction clutch or transmission.

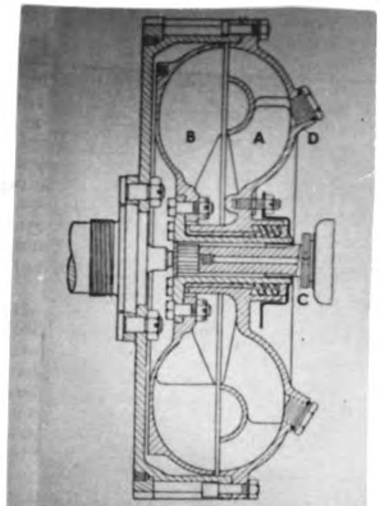
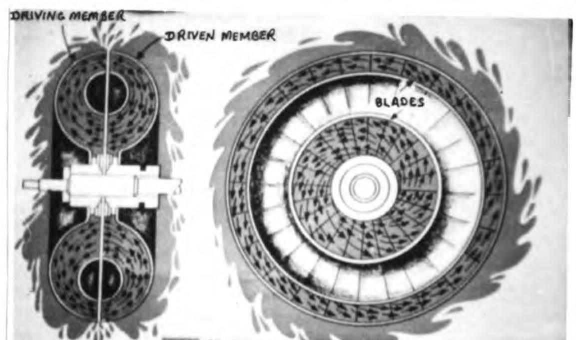


Fig. 1.—"Fluid-Flywheel" Type of Hydraulic Coupling.



Oil flows outward in driving member, inward in driven member, and is also forced in other direction by blades of driving member.

FIGURE 6

Fluid Flywheel

Each half has a number of straight radial blades leading from the hub to the outside edge as shown in Fig. 6. A section from the middle of each blade is cut away and in that space is placed a metal plate or guide ring, shaped like half of another pipe ring. There is no difference in the shape of the two halves of fluid flywheel. When it is assembled, it looks like a small pipe ring inside a large diameter pipe ring, connected to each other through thin blades. Both of these parts are enclosed in a casing, which is firmly connected to one of the two halves of the hydraulic coupling. The casing in turn is connected to the crankshaft, and is filled with oil.

When the engine is started, the front half of the fluid flywheel connected to the crankshaft starts to rotate. The oil inside the cup-shaped pockets of the first half rotates with it. By rotation of the coupling, a centrifugal force is exerted by the mass of oil, which depends upon the square of the speed of rotation. The higher the r.p.m. of the engine, the higher the force exerted by the oil in the pockets of the rotating part of the coupling. Due to the centrifugal force, the oil is thrown toward the outside of the pipe ring. When the oil gets to the outside, it keeps on going, and the only place where it can go is across into the other half of the pipe ring which is a driven member.

The oil, besides being forced outward, also rotates along with the driver. Consequently, when it crosses over into the driven member, it hits against the blades just as the pellets hit the blades of the water wheel, thereby rotating it. When the oil loses its kinetic energy, it slows down and travels toward the hub of the driven member, then across to the driving member, and so on. In this way, the oil circulates continuously outward in the driving member, and inward in the driven member.

At the same time, it travels in a direction at right angles to this, being pushed by the blades of the driving member, and pushes on the blades of the driven member.

There is always a certain amount of slip irrespective of the speed of the driver. As the speed of the engine is slowed down, the slip increases accordingly, and finally, at a certain speed, the torque transmitted becomes so small that it is not able to move the vehicle at all and the car stops. This allows one to stop at a traffic signal with the transmission in gear. When the engine is speeded up, the driven member begins to turn, gradually picks up speed, and finally runs at practically the same speed as the engine.

The use of fluid flywheel gives a smoother pickup and makes it impossible to stall the engine when starting or climbing a hill. It also smooths out jerks, especially at low speeds, and in some way acts as a centrifugal clutch. It should be remembered that fluid flywheel is not a transmission, but a clutch. It cannot replace the transmission because it does not increase torque. It only transmits the torque which is supplied by the engine.

Completely Automatic Transmission: This transmission consists of two planetary gear sets, one behind the other. Along with a fluid flywheel, each planetary has two speeds; a reduction ratio and a direct drive, but the reduction ratios are not the same. We can get four speeds by choosing the proper ratios. In low gear, both planetaries are in action, giving us a double reduction. In the second speed the front unit is in direct drive, and the rear unit alone gives a reduction of about two and one-half to one. In third speed we do just the opposite; the rear unit is in direct, and the front is working. This has a ratio of approximately one and one-half to one. In fourth speed, both units are in direct drive, as engine torque flows straight through to the rear axle. There is also a reverse gear, which is a third planetary unit behind the other two. It works in combination with the other two to furnish a low ratio in the reverse direction.

A fluid flywheel is a very important part of this combination. It is located between the engine and the transmission, and the flow of power first goes to the first planetary unit, then to the fluid couplings, and then to the secondary planetary units. The effect is just the same, however, except that the fluid coupling runs at a reduced speed when idling and prevents creeping. There is no friction clutch. The transmission will shift under load without being disconnected from the engine. This is possible because the fluid flywheel cushions the shocks; it is one of the big differences between this and most other transmissions, even some which use a fluid flywheel.

The planetary gears are controlled by brake bands. These brake bands operate automatically by oil pressure depending on how fast the car is going and how far the accelerator pedal is pushed down. All the driver has to do is to control the speed of the engine, and the gear shifting will take care of itself.

HYDROKINETIC TRANSMISSION OR TORQUE CONVERTER

This is not a torque transmitter like the fluid flywheel, but a torque multiplier.

The working principle is not much different from that of the fluid flywheel. All we have to do to a fluid flywheel to make a torque converter is to add another set of blades -- stationary blades. Newton's third law of motion states that to every action there is an equal and opposite reaction. In transmission it means that we have to take reaction on some stationary member to impart motion to the other.

In conventional transmission the whole casing is fastened solidly, and this holds the shaft in place. In planetary, we have to check one of the three members from rotation before we can multiply torque. We have to hold it stationary in relation to the frame. In a fluid flywheel the whole thing turns around together. But if we put in a new part, a set of blades tied solidly to the frame, we have something to take the reaction that is to furnish the reacting force, which then multiplies torque.

The driving element and driven element takes up half of the converter, and the stationary, or reaction element fills the other half. The whole thing is filled with oil, which circulates in the same manner as in fluid flywheel, outward from the centre through the stationary member. The blades are not straight and flat, however, for the spaces between the vanes of the impeller, runner, and reaction member form a closed circuit through which the liquid circulates.

In torque converters, it is often found convenient to make the flow path substantially rectangular in section instead of circular as in fluid flywheel, and also to make the sidewalls plane, at least the central portion, as that makes it easier to accommodate the vanes of the various members, which can then be made of uniform length and width.

If we could spread the members out flat and look down on them, we would get an idea of their shape and how the liquid flows through them.

The impeller, or driving member, pushes the oil in the direction it is turning, and this oil hits the turbine or driven member and forces it to turn in the same direction. In so doing, the oil bounces off from the blades in the opposite direction, and if the reaction member were free to turn, it would turn backwards. But since it is held tight, it straightens out the oil before returning it to the impeller, and starts it moving in the forward direction again.

In most of the converters, there are three rows of blades on the driven member, and two on the reaction member. Imagining all the blades set in a straight line and the fluid passing at right angles to them, we can see how the torque is transmitted and multiplied. The action is like a turbine. The pump, or impeller, forces it against the first set of blades, which move forward. The oil has been deflected in a backward direction, but the stationary guide blades are of the right shape to make it go forward again, so it can drive the next sets of driven blades in the right direction.

Then it strikes again the two rows of driven and stationary row of blades. The three rows of driven blades are mounted on one member so that the forces on all three are added together to make the output shaft rotate.

A hydraulic torque converter is wholly automatic in itself. It smoothly changes from one ratio to another in a uniform continuous fashion, without definite break or steps. It is a continuously variable transmission as the characteristic torque curve is a smooth curve, while in a conventional transmission, torque characteristic curve is not a uniform curve but a stepped curve. At idle speed the torque transmitted is zero but as the speed is raised, the torque gradually increases, until at full speed, torque transmitted is from 85-90 percent.

Because the efficiency is low, this apparently perfect device, completely automatic in itself, having nothing to shift, combining the advantages of a fluid flywheel with an automatic transmission, is seldom used in automobiles. The efficiency of fluid flywheel ranges from 98-99 percent. Some designers solve this problem by using a hydraulic torque converter along with a transmission, such as a planetary gear arrangement. A great many combinations of this sort can be developed.

To increase the efficiency at full speed and to obtain smoother performance, the reaction members of the converter were mounted as a free wheeling unit so as to let reaction members freewheel when torque reaction reverses and the torque ratio becomes unity. During their freewheeling, the members rotate at the same speed as the impeller and runner. Such a type of coupling was produced by Salerni in Britain and Trilok by Kruge in Germany and the hydro torque converter by Schneider in America. Freewheeling effectively gets the reaction members out of the way of the flow of fluid so that the converter, changes to a straight fluid coupling at driving speeds.

As the torque converter operates in one direction only, the torque converter in automobiles has an auxiliary planetary transmission for backing up.

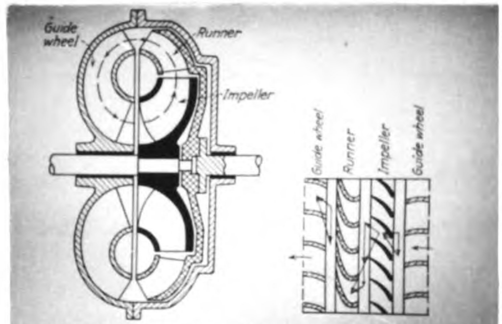


Fig. 1.—Diagram of Hydro-Kinetic Torque Converter and of Its Vanes.

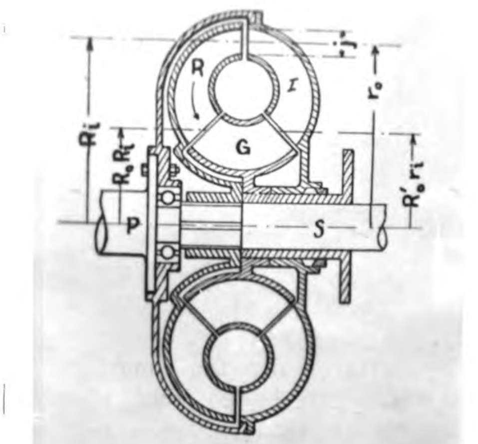


Fig. 1—Diagrammatic cross section of turbine torque converter

Figure 7

Torque Converter

The same unit also provides an "emergency low" that can be engaged to the converter for such purposes as pulling out of mudholes, and a clutch that disconnects the unit from rear for running the engine at high speeds while making adjustments.

Details of Design

In the simplest form, it is a combination of a pump impeller, a runner, and a stationary wheel which forms a converter.

Impeller I, mounted on driving shaft P, delivers fluid into the runner R mounted on driven shaft S. The fluid set in rotation by the impeller impinges on vanes on the runner; after leaving the runner it enters the stationary guide vanes G, where its course is changed and its angular momentum increased, and it then flows into the impeller, again circulating continuously through the system.

When the engine is idling, the impeller does not deliver the fluid to the turbine at sufficient rate, and the vehicle remains stationary. When the throttle is opened, the speed of the engine as well as the impeller is increased, and the latter delivers fluid to the turbine at a greater rate, thus moving the car. Road resistance slows down the turbine and thereby increases the difference between the speed of runner and impeller. This difference in speed tends to increase the flow of fluid which, in turn, automatically increases the turbine torque, and therefore a new torque ratio is obtained.

Because of the hydraulic medium between impeller and runner, the runner could be stopped by a heavy load, but the engine will continue running because there is no direct mechanical connection between the impeller and runner. When the car starts coasting, the runner overruns the impeller.

Since there is no provision for reversing the runner or guide vanes to provide a reverse motion to the car, a reverse gear is necessary. It is furnished by installing a planetary gear set behind the converter which provides extra low as well as the reverse.

Converter guide vanes are inefficient at light load because they absorb angular momentum from the fluid, thereby decreasing the runner torque, but in case the runner torque load increases, the guide canes impart an additional angular momentum to the fluid.

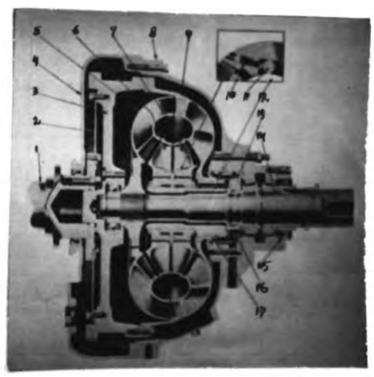


Figure 8

General Motors Converter

GENERAL MOTORS CONVERTER

According to the cut away cross section of the converter, Fig. 8, housing No. 8 is connected to the flywheel housing, and it also supports the outer bearing through which the output shaft passes.

Besides this, it provides the passage for the incoming and outgoing oil to and from the converter. The stators 5 and 7 are also supported by the housing through a sleeve, No. 12, and overrunning clutches No. 10 and No. 11 over which the converter pump No. 9 overruns. The overrunning clutches which support the stator, are composed of roller, springs, spring caps, and the races.

The stator is confined to its place by snap rings and thrust washers. When the torque is positive, the spring pushes the rollers of the overrunning clutch between the fixed sleeve and the cam surface, thus engaging the clutch; but when the torque is reversed, the centrifugal force compresses the spring, which removes the force on the rollers and reduces the friction.

Flywheel No. 3 is not mounted on the crank in the usual way, but it is bolted to the converter pump on the rear end, and is bolted to the crank through a laminated flex plate. Thus it provides an enclosure for rotating parts as well as eliminating side thrust of converter and vibrations reaching the crankshaft.

Operation: The pump, which is connected to the engine, gives the kinetic energy to the fluid, which is directed at the correct angle by the stator and strikes the blades which are connected to the output shaft. The passage of oil in converter is always in a circular direction.

The angle of blades is fixed for a particular speed to give the best

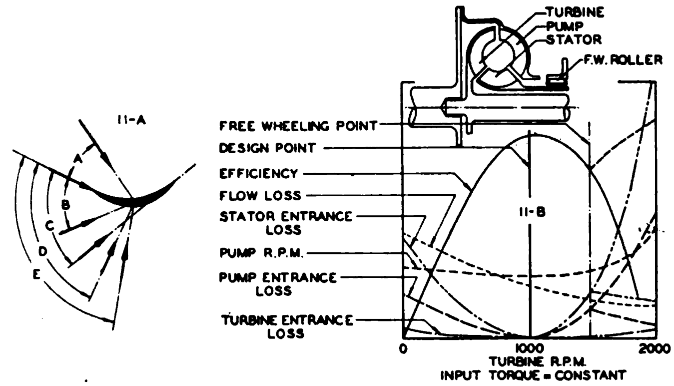


Fig. 2—Effect of a freewheeling stator in a three-element torque converter. It helps increase efficiency

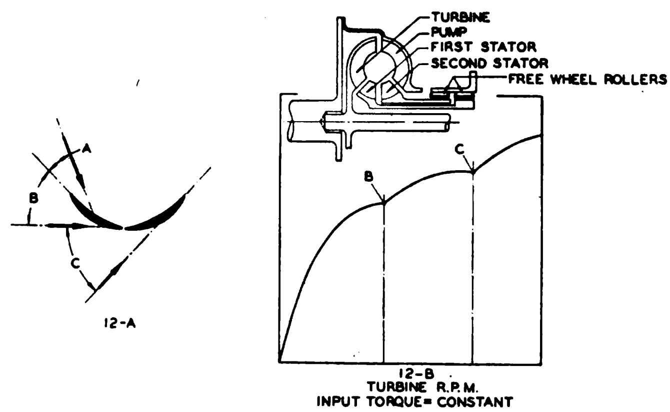


Fig. 3—Using two independently-freewheeling stator members cuts shock losses considerably

Figure 9

Performance Curves of G. M. Torque Converter

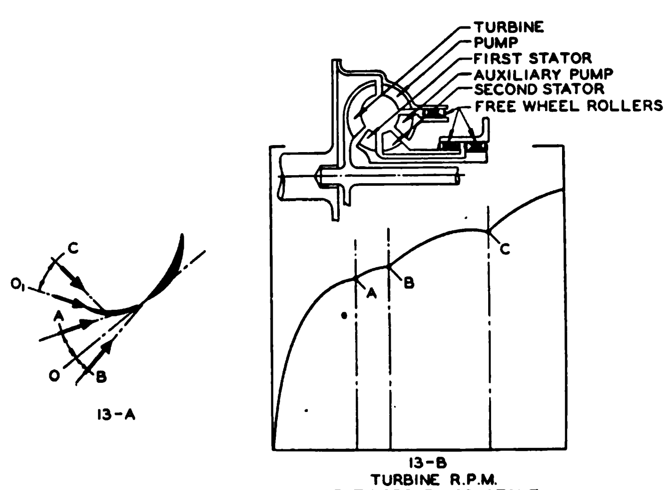


FIGURE 13

Fig. 4—Two-piece pump vane construction makes pump shock losses negligible

performance, and in the automobile, where the speed is never constant, a fixed stator will have a peak performance at a particular speed. But as the stator in this converter is mounted on an overrunning clutch, two more blade angle combinations are provided which improve the characteristics. The full throttle performance curves are drawn in Fig. 9. The dark line shows the three blades combination in which the effect of the overrunning clutches is clearly marked.

To determine engine r.p.m. and output torque with respect to different speeds and speed ratio, the torque absorption characteristic curve of the converter is superimposed on the engine torque curve. For ideal operation of converter, a nearly constant engine speed is obtained, as shown in Figures 2 and 3. The maximum torque is determined by stopping the output shaft from rotation and measuring the torque, which delivers maximum draw bar pull. From the above statement, it is clear that the engine should be run at optimum speed to have maximum torque output, and that is why this converter is efficient at high speeds and light loads, or when the relative speed of the pump and turbine is low.

In this converter, a certain amount of drag torque always occurs even at idling speed, and if a gearshift is used, a clutch should be installed between the converter and the gearshift. Any heavy duty oil of S A E No. 10 can be used in this converter. The cooling system of this converter comprises a pump which circulates the oil through a cooler and increases the pressure of oil to 60-90 p.s.i., which eliminates the chances of air being trapped in the oil circuit, and also provides sufficient circulation for cooling.

Every rotating part is made fluid tight by two successive oil seals.

Any oil which comes out of these seals is drained back to the oil tank through the annular space. The oil leak past the power take-off shaft is checked by the ordinary lip type seal.

Buick transmission, known as the Dynaflow, consists of a torque converter as described above. It has two impeller pumps, two overrunning stators and a turbine, and a planetary gear train which furnishes the low range, and the reverse. In the reverse and low range, the ratio is about 1.82 to 1, and at maximum torque transmission, the ratio is about 4.09 to 1.

Its over-all efficiency is nearly equal to that of the conventional gear drive. At the best driving range, it simply works as a straight coupling of fluid flywheel to the propeller shaft; there are no gears engaged, and hence there is nothing to wear.

The selector lever has five positions: park, neutral, drive, low and reverse. The engine is usually started at park or neutral position of the selector. The low is provided for descending steep hills and for heavy pulling. A special gear, consisting of a heavy gear with square teeth cut in it and a wedge which is inserted between two of the teeth is provided, and it checks the output shaft from rotation. This secures the selector lever when it is placed at park position.

OVERDRIVE

This mechanism is to utilize the excess power of the engine which is not required when driving a car 1:1 gear ratio at light loads. The engine is designed to drive the car with full load and at a rated speed. When the car is not fully loaded and is being driven over a level road, a considerable amount of available power is not utilised. Moreover, since the road speed is generally below the maximum, a gear designated as overdrive which would enable the car to run at high speed with low engine r.p.m., was introduced. This mechanism is operated automatically in most cars and as such it does not affect the driving facilities. It automatically or manually engages and disconnects the different gear ratios and enables the car to run at faster rate with lower engine r.p.m. The other mechanism used for this purpose is installed in the differential of the car, which is known as Two Speed Rear Axle. It is also operated automatically and is controlled either by vacuum or electrically.

Tip-tow-matic or Truckstele Overdrive: This consists of a planetary gear set and overrunning clutches arranged in such a way that it can be engaged to the transmission circuit by pulling a knob connected to the double end jaw clutch. This was manufactured by Truckstele Manufacturing Company for Chevrolet cars. It has the advantage that it does not freewheel at any speed as other overdrives do.

When the overdrive is to be engaged, a knob near the driving wheel is pulled, and it is pressed down when the overdrive is not required. When the overdrive is engaged and the speed of the car is in the overdrive range, the automatic overdrive can be disconnected by either depressing the accelerator pedal or by pressing the clutch pedal slightly. The overdrive works according to the movement of the accelerator pedal. When the knob is pulled in the overdrive range and the accelerator pedal is released, a torque reversal occurs, which automatically locks the planetary, giving a direct drive. When the pedal is again pressed, the torque is in the positive direction, and a ratio of 1:1 is obtained.

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