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# **UNIT M 6-TRANSMISSION IN DIESEL LOCOMOTIVE**

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## **OBJECTIVE**

The objective of this unit is to make you understand about

- the need for transmission in a diesel engine
- the duties of an ideal transmission
- the requirements of traction
- the relation between HP and Tractive Effort
- the factors related to transmission efficiency
- various modes of transmission and their working principle
- the application of hydraulic transmission in diesel locomotive

## **STRUCTURE**

1. Introduction
2. Duties of an ideal transmission
3. Engine HP and Locomotive Tractive Effort
4. Factors related to efficiency
5. Rail and wheel adhesion
6. Types of transmission system
7. Principles of Mechanical Transmission
8. Principles of Hydrodynamic Transmission
9. Application of Hydrodynamic Transmission ( Voith Transmission )
10. Principles of Electrical Transmission
11. Summary
12. Self assessment

## 1. INTRODUCTION

A diesel locomotive must fulfill the following essential requirements-

1. It should be able to start a heavy load and hence should exert a very high starting torque at the axles.
2. It should be able to cover a very wide speed range.
3. It should be able to run in either direction with ease.

Further, the diesel engine has the following drawbacks:

- It cannot start on its own.
- To start the engine, it has to be cranked at a particular speed, known as a starting speed.
- Once the engine is started, it cannot be kept running below a certain speed known as the lower critical speed (normally 35-40% of the rated speed). Low critical speed means that speed at which the engine can keep itself running along with its auxiliaries and accessories without smoke and vibrations.
- The engine cannot be allowed to run above a certain speed known as high critical speed. It is 112 to 115% of rated speed. The high critical speed is the speed at which the engine can keep itself running without damaging itself due to thermal loading, and centrifugal forces.
- It is a constant torque engine for a particular fuel setting irrespective of its speed. It can develop rated power at rated speed and fuel setting only.
- It is unidirectional.
- To de-clutch power, the engine has to be shut down, or a separate mechanism has to be introduced.

To satisfy the above operating requirements of the locomotive, it becomes necessary to introduce an intermediate device between the diesel engine and the locomotive wheels. This device, called transmission, should accept whatever the diesel engine gives, with all its limitations mentioned above and be able to feed the axles in such a way that the locomotive fulfills the essential requirements.

Any transmission should fulfil the following requirements.

1. It must transmit the power from the diesel engine to the wheels.
2. It must have a provision to connect and disconnect the engine from the axles for starting and stopping the locomotive.
3. It must incorporate a mechanism to reverse the direction of motion of the locomotive.
4. It must provide a permanent speed reduction, as the axle speeds are normally very low when compared with the speed of the crankshaft of the diesel engine.
5. It must provide a high torque multiplication at start, which should gradually fall as the vehicle picks up speed and vice-versa.

The requirements of traction are-

1. It requires high starting torque at zero speed so that the train can start without jerk.
2. Once the train is started, torque should reduce quickly, uniformly, and speed should increase with high acceleration.

3. The speed and power characteristics should change automatically & uniformly depending on the road requirements so that the power transmission is jerk free.
4. The power transmission should be reversible with identical speed and torque characteristics with easy reversibility in both directions.
5. There should be a power de-clutching arrangement whenever required.

## **2. DUTIES OF AN IDEAL TRANSMISSION**

1. It should be able to multiply the torque and reduce the speed to such a level that the train can be started without a jerk.
2. Once the train has started, it should decrease the torque and increase the speed as required, automatically.
3. The torque & speed characteristics should be varied uniformly throughout the traction depending upon the road requirements, so that the power transmission is jerk free.
4. It should be capable of reversing the power transmission easily, with identical torque & speed characteristics in both the directions.
5. It should be light, robust, and should occupy very little space.
6. It should be reliable and ask for minimum maintenance.
7. It should be approachable easily for maintenance and ask for low minimum nos. of consumable.
8. It should not transmit road shocks and vibrations to the engine.
9. It should have good efficiency, good utilisation factor, and good degree of transmission.
10. It should be capable of starting the engine, if required.
11. It should be able to apply brakes, if required.

## **3. ENGINE HP AND TRACTIVE EFFORT**

The power produced by the diesel engine at its crankshaft is the horsepower, which is proportional to the multiplication of torque and the speed of the engine. In any diesel engine torque and speed are the two independent quantities- the torque produced by the engine is proportional to the load to overcome the resistance for its rotation, and the speed of the crankshaft depends on the HP produced by the engine.

Tractive effort of a locomotive is the effort or force exerted by the driving wheels on the rails. The torque produced at the crankshaft of the diesel engine is multiplied by the transmission system, and is available at the axle as the axle torque. The wheel on the rail applies this torque, divided by the radius of the wheel gives the effort at the wheel-rims is called Tractive effort. As the horsepower of the diesel engine is constant for a fixed throttle setting and speed, the horsepower available at the axles will also be constant from zero to the maximum vehicle speed when using an ideal transmission system. Depending on the speed of the vehicle, the tractive effort is varied automatically (increased torque at decreased speed, and vice-versa). In other words, the tractive effort-speed curve of a diesel locomotive obtained by using an ideal transmission system would be a rectangular hyperbola. In this case the full installed horse-power at site is available at the rails from zero to the maximum track speed, but in actual practice, the tractive effort curve falls well below the theoretical curve mainly due to three reasons-

1. Power consumed by auxiliaries such as cooling fan, compressors, exhausters, dynamo etc.
2. Power utilisation factor of the transmission.
3. Transmission efficiency at the rails.

## **4. FACTORS RELATED TO EFFICIENCY**

### **Power Utilisation Factor**

The diesel engine when viewed as a constant torque engine is capable of developing its full rated horsepower only when running at its maximum speed and maximum fuel setting. Therefore to utilise its full power from zero to hundred percent of vehicle speed, the engine must run always at its maximum speed with full fuel setting. But this is not the case in actual practice. When the engine is coupled to the wheels through a transmission system such as a coupling or a multi-stage gearbox, the engine speed is directly governed by the inherent characteristics of transmission and hence its power varies proportionately. The ratio between the horsepower input to the transmission in peak notch operation at any instant of the vehicle speed and the maximum horsepower installed at the site conditions is known as power utilisation factor.

### **Transmission efficiency**

This is defined as the ratio between the rail horsepower and horsepower input to the transmission at any vehicle speed.

### **Degree of transmission**

This is a very important factor for selecting a transmission system for a diesel locomotive. This is defined as a product of power utilisation factor and the transmission efficiency. In other words, this is the ratio between the rail horsepower at any instant, and the installed horsepower at the site.

## **5. RAIL AND WHEEL ADHESION**

The locomotive wheels run on a metal track. Any tangential force exerted at the wheel rims will cause a linear movement of the vehicle only if the driving wheels have a grip on the rails, as otherwise the wheels will slip and the vehicle will not advance. The maximum force that can be exerted by the driving wheels without causing a slip is called the adhesive limit of the locomotive. This depends primarily on the adhesive weight of the locomotive as well as friction between the contact surfaces of the rail and wheels. The coefficient of adhesion at start, between the rail and wheel rim, generally lies between 0.25 and 0.33, depending upon the type of transmission, axle configuration, bogie design etc. The selection of a transmission system for a locomotive should be in such a way that the tractive effort at start should always be well above adhesive limit of the locomotive, so that the starting load is limited by the adhesive factor and not by the engine power.

## **6. TYPES OF TRANSMISSION SYSTEM**

### **MECHANICAL TRANSMISSION**

- Gear
- Friction Clutch
- Belt and Pulley
- Chain and sprocket.

### **HYDRODYNAMIC TRANSMISSION**

- Fluid coupling
- Torque converter

## **ELECTRICAL TRANSMISSION**

- DC electrical
- AC/DC electrical
- AC electrical
- Linear motor etc.

## **7. PRINCIPLES OF MECHANICAL TRANSMISSION**

In this system of transmission, a clutch and a multi ratio gearbox are employed. The multi ratio gear box consists of several gear trains. The engine power is transmitted through one gear pair at a time. As the engine is rigidly connected to the wheels through a fixed gear ratio in each gear, the vehicle speed varies directly with the engine speed. As the power output of the engine is proportional to the engine speed, the power delivered by the vehicle also varies with the engine speed.

The transmission efficiency of the mechanical transmission is the highest, as there is no conversion of energy during the power transmission process. But the other parameters are inferior when compared with other types of transmission systems.

## **8. PRINCIPLES OF HYDRODYNAMIC TRANSMISSION**

In hydrodynamic mode of transmission the velocity / the momentum of the fluid is the contributing factor for transmission of power. The rate of change of momentum of the fluid from driving to the driven member decides the amount of torque being transmitted in this system. Hydrodynamic drives are of two types.

## **FLUID COUPLING**

### **HYDRAULIC TORQUE CONVERTER.**

#### **Fluid coupling**

It is a device employed in a power transmission system simply to transmit torque from one end to the other through a fluid medium. There are two principle members. Those are-

- 1 Impeller or pump, generally connected to the input side of the power transmission system.
- 2 Turbine or runner, connected to the output side.

All the blades or wings in both the members are straight and radial. In most of the cases, these two elements are produced by Aluminium castings.

#### *Working principle:*

The power output of the engine is supplied to the impeller. The speed of every particle of the fluid that passes through the rotating impeller increases. In a turbine the reverse action takes place. The high speed fluid exerts a push on the turbine blades. This

causes the turbine to produce an output power. In this way, the coupling transmits power to the external load.

The two members of the coupling are identical with respect to the inside to their inside and outside diameters, design and positioning of blade diameters etc. Therefore, the kinetic energy or torque absorbed by the impeller is equal to that released in the turbine. Hence, there can be no torque conversion in a fluid coupling, and impeller torque is always equal to the turbine torque.

#### Slip

This is the difference between impeller and turbine speeds. When there is no slip, there is no transfer of fluid from impeller to the turbine and hence no torque is transmitted. This is because the turbine sets up a head of fluid equal and opposite to the head of the fluid set up by the impeller. To transmit any torque, a fluid coupling must necessarily have some slip depending upon its size and speed. Torque can be transmitted either way depending upon the speeds of its two members. The higher speed member automatically becomes the torque receiving or input side.

#### **Hydraulic torque converter**

The principle components are three. Those are-

1. Impeller or pump, connected to the input side of the transmission system.
2. Turbine or runner, connected to the output side.
3. Reaction member or guide-wheel, which is placed in the fluid circuit to guide the fluid coming from the turbine into the impeller, and is normally connected to the casing. This remains stationary.

The general working principle and the basic characteristics are very similar to those of fluid coupling, as described above, but for the following variations.

The principle members are not identical in construction and the wings or blades provided in them are shaped and positioned to form various angles with respect to the axis of rotation to obtain required performance. The torque condition of the impeller and turbine are not the same due to the existence of a reaction member in the fluid circuit. Therefore, the impeller torque undergoes a change in turbine, and is either increased or decreased according to the speeds of the two members.

#### *Some facts about torque converter*

1. In transmitting power, a torque converter behaves like a gearbox having infinite gear ratios, and hence provides a stepless variation of torque at the turbine end for a constant input torque. This inherent characteristic suits very well with the output torque requirement of a locomotive.
2. Due to the conversion of energy from mechanical to hydraulic in the impeller, and hydraulic to mechanical in turbine, there is a loss of power in the transmission. Hence its transmission efficiency is poorer than a mechanical transmission. However, it compares well with the electrical transmission.
3. For a definite output speed, its transmission efficiency is superior, when working under part load. Hence, it is ideal for shunting locomotives.
4. It does not transmit shocks and vibration from either side due to the presence of a hydraulic medium.
5. It permits the selection of a high-speed diesel engine as its prime mover. Thus, it reduces its gross weight of the locomotive.

## **9. APPLICATION OF HYDRODYNAMIC TRANSMISSION**

### **REVERSIBLE HYDRAULIC TRANSMISSION (VOITH TRANSMISSION)**

### *Advantages of reversible transmission*

1. Separate torque converters are provided for each direction of running of locomotive. A change in the direction of travel of locomotive is effected by filling /emptying the appropriate converter.

2. Mechanical components such as claw/clutches, external/internal splined components, shifting fork, slide blocks, pneumatic cylinders and linkage mechanism, tooth on tooth safety devices etc. are dispensed with.

3. While the vehicle is in motion, by engaging the converter intended for the opposite direction of the travel, hydrodynamic braking can be achieved till the vehicle comes to a standstill position. The retardation of the vehicle will be very smooth, and sharp without any wear and tear of brake blocks, brake-rigging components.

4. The controls and monitoring devices in the locomotive are much simplified when compared with the conventional type of mechanical reversible transmission.

5. The transmission can be instantaneously switched on to either direction of travel at any time, while the locomotive is stationary or is moving, unlike in mechanical reversible transmission where the shifting of the claw clutch is to be carried out only when both the primary and the secondary rotating components are absolutely standstill.

### *MERITS OF HYDRODYNAMIC TRANSMISSION OVER CONVENTIONAL ELECTRIC TRANSMISSION*

#### **Efficiency**

Transmission efficiency of any hydraulic transmission using torque converter is comparable to any electrical transmission. The efficiency of hydro-mechanical transmission is about 10 % higher. The comparative saving in fuel costs will be substantial especially in high horsepower super-fast train locomotive.

#### **Power to weight ratio**

The horsepower to weight ratio of a diesel hydraulic locomotive is comparatively higher due to the use of high-speed diesel engine and lower weight of transmission. For example, the power to weight ratio of the WDM<sub>2</sub> (Electrical transmission) is 23 hp/tonne, as against 33 hp/tonne for the WDM<sub>3</sub> (hydraulic transmission). One of the main reasons is that the hydraulic transmission permits use of high-speed (low weight) diesel engine, as power absorbing capacity of the torque converter is proportional to the cube of its impeller speed. In case of an electrical transmission, the peripheral speed of the generator -armature becomes a limitation for choosing the engine speed.

#### **Adhesion**

Coefficient of starting adhesion is comparatively higher owing to coupled axles of the diesel hydraulic locomotives as against the independently driven axle hung traction motors of the diesel electric locomotives.

#### **Part load efficiency**

The part load efficiency of the hydraulic transmission, whether using a converter, or using a coupling, is comparatively higher at lower vehicle speed than electric transmission, where generator and traction motor efficiency remain more or less constant, and independent of horse power transmitted. This advantage is predominant especially in shunting locomotives, where the diesel engine operates most of the time at part notches at low vehicle speeds.

## 10. PRINCIPLES OF ELECTRIC TRANSMISSION

### GENERAL

Most of the Diesel Electric Locomotives serving in Indian Railways are single engined with one D.C. self ventilated, separately excited, single bearing main generator.

This supplies power to six nose suspended, force ventilated, series wound D.C. motors connected in three series pairs.

Power for electrically driven auxiliaries and control circuits is obtained from a self-excited, self ventilated auxiliary generator mounted on the end of main generator. This also supplies the battery charging current. Output of auxiliary generator is maintained constant at different speed by a voltage regulator. It also takes care about the limit of current going out to avoid damage to the generator. 8 lead acid batteries in series with four cells per battery, being provided for starting the engine by motoring the main generator, and to supply all the control circuits and the locomotive lighting.

The locomotive is provided with electrical end jumper cables to enable it to work in multiple with a number of other locomotives.

### POWER CIRCUITS

The main generator is separately excited with or without a differential series field to give the required characteristic form.

Each traction motor has separate reversing switch contacts for reversing the field current, and field diverting arrangements.

Wheel slip sensing arrangement is provided between all three motor pairs using three relays. Ground fault sensing arrangement is provided in the generator circuit using a relay, to avoid damage to the electrical machines and circuits.

### FIELD WEAKENING AND TRANSITION

As has already been mentioned the series type dc motors are used as traction motors. This type of motor draws a high current at low speed and a low current at high speed. If its load is heavy, it runs at low speed; if light, it runs at high speed.

The generator delivers electrical power. When the load resistance is low, the amperes are high and when resistance is high, the amperes are low. To achieve maximum fuel efficiency, the engine should be loaded in such a way so that it gives constant horsepower for a particular speed setting, and accordingly the fuel for each throttle setting is scheduled.

So to get most of the engine, one should stay on the constant horse power curve. As the traction motors are the load, and current changes with change in speed of the motor, the voltage also changes accordingly power being constant.

When the train accelerates, i.e. the motor speed increases, the voltage output of main generator goes on increasing and at a particular train speed, generator voltage reaches its limit and horse power is reduced by the excitation system. With this situation more train speed can't be achieved.

To get higher train speed, either the motor fields are weakened or the motors are rearranged in the circuit. This increases traction motor current. With higher current now the motor speed starts increasing.

Normally the motor field is made weak, connecting resistor in parallel to the field, and rearrangement is done by changing the motors from series-parallel to parallel grouping. An automatic regulator, on getting signal about locomotive speed does the change in motor circuit.

## **11. SUMMARY**

In a diesel engine an intermediate device is used to transmit the power of the engine upto wheels. This intermediate device is called transmission. It is essential to have a transmission in a diesel engine because of certain inherent limitations in it. An ideal transmission has to fulfil many a requirements: like, torque multiplication during starting, automatic picking up of speed with the submission of torque just after starting, modifying torque and speed characteristics automatically as per load and road condition and also to facilitate reversing facility to the train etc. There are various modes of transmission like mechanical, electrical, hydraulic etc. Amongst them suitability of transmission is based on the requirement of traction and their operating efficiency. Overall transmission efficiency, percentage utilisation of rail wheel adhesion and power to weight ratio should be given due consideration while selecting the type of transmission for a locomotive In consideration to the above facts, electrical transmission is widely used in the railways. But in shunting locomotives hydraulic transmission is also used, because of its relative merit over electric transmission on the areas like, - part load efficiency, coefficient of starting adhesion and power to weight ratio being high.

Hydraulic transmission works on hydrodynamic principle. Previously, Suri transmissions were in use. It was a hydro- mechanical transmission, in which a reversing gearbox was in use to reverse the direction of movement of the locomotive. But in recent days, Voith transmission, the hydraulic transmission itself takes care of reversing facility. It is a superior version of hydraulic transmission over Suri Transmission.

## **12. SELF ASSESSMENT**

1. Why transmission is necessary for a diesel engine?
2. What should be the duties of an ideal transmission?
3. What do you understand by Tractive Effort? What is its relation with rail wheel adhesion?
4. Explain the working of fluid coupling and torque converter in hydrodynamic transmission?
5. Based on what merits hydrodynamic transmission is applied in some shunting locomotives?
6. Explain the principle of working of an electrical transmission?