5. Trains Dynamics

**Train Resistance** - The resistance offered by a train to move from stop is called Starting Train Resistance. The resistance offered by it to keep it moving at a specified speed is known as Rolling Train Resistance. In other words force needed to start a train from stationary position is starting resistance and force needed to keep a train moving at certain speed is rolling resistance.

The draw bar pull exerted by locomotive has to be more than the train resistance to keep a reserve force needed for acceleration. Mathematically starting resistance can be expressed by formula. \( R_s = R_{VS} + R_G + R_C + R_A \)

- **Rs** = Total train resistance at start
- **RVs** = Vehicle starting resistance -- Depends on bearing design.
- **RG** = Grade resistance if any
- **RC** = Curve resistance if any (On curves, the friction between rail & wheel increases and hence extra force is necessary).
- **RA** = Acceleration reserve to be divided depending upon acceleration need of the train.

**Rolling Resistance**: The resistance during movement is called rolling resistance. It depends on speed and car body design but does not depend on bearing design. Mathematically it can be expressed as -

\( R_R = R_{VR} + R_G + R_C + R_A \)

Where \( R_R \) = Total rolling resistance \( R_G, R_C, R_A \) are same as starting resistance.

**RVR** = Train rolling resistance on level straight track.

\( R_{VR} = A + BV + CV^2 \)

Where \( A, B & C \) are constants depending on vehicle design, car body designs. ‘A’ Depends on mechanical friction in bearing. ‘B’ Factors include flange friction, swaying and oscillation characteristics of vehicle. ‘C’ Air resistance depends on body design. Aerodynamic design vehicles have less friction than box type vehicles. The values of \( A, B, & C \) are different for different vehicles.
Tractive Effort

The force at rail wheel contact exerted by a locomotive is called Tractive Effort. The tractive efforts at the start get limited by load on driving wheels and limiting frictional co-efficient between rail and wheel. (adhesion) even though the locomotive may be capable of producing much more tractive effort at low speed because of its horse power. On run, however, it depends on speed, loco horse power and wheel diameter.

Adhesion - It depends on rail wheel friction. Adhesive percentage is defined as ratio expressed in percentage of tractive effort at wheel slip and vertical load on driving wheels.

Factors effecting adhesion - Condition of rail and wheel contact surface e.g. wet, dry, oily, slippery, etc. - Type of track and sleeper density - Rate of increase in torque applied to wheel.

Wheel Slip: If torque applied to wheel exceeds the adhesive torque, wheel slip takes place. This reduces the friction between rail and wheel and further wheel slip takes place. Wheel slip reduce the tractive effort and hence haulage capacity and damages rail and wheel. Wheel slip should therefore, be avoided.

Method to improve adhesion - Clean rails regularly - Use sand while starting - Immediately cut off power if wheels slip.

Equilibrium Speed/Balancing Speed

The train will go on accelerating till tractive efforts of power is more than rolling resistance. Once TE & TR( train resistance) become equal, the speed cannot be further increased. This speed is called equilibrium or balancing speed. The loco cannot continuously work on full power and hence potential TE should be substantially higher than TR for better train operation. This also helps in attaining maximum speed quickly. The balancing speed of a WDM2 loco with a load of 4700 ton on level gradient is 59 km/h. So it is desirable to use 2 WDM2 locos in MU for operating such a train.

Determination Of Train Load

The trailing load that can be attached to a locomotive depends upon.

- Ability of locomotive to start the load on steepest gradient on the section.
- Attain maximum permissible speed on most of the route
- Maintain minimum desired speed on steepest gradient.
- Acceleration level desired.
6. TRACTION MODE AND THEIR COMPARISONS

Indian Railways use three traction modes-viz. Steam, Diesel & Electric. However most of steam locomotives have been phased out.

Important desired Locomotive characteristics.

Load- speed relationship

Maintenance requirement – frequency of maintenance should be less.

Riding quality - Disturbances to track should be bare minimum.

Reliability- susceptibility to develop defects on run should be low.

Maintenance time as ratio of running time should be less.

Both side operation - Amenability to both front and back operation .

Pollution- impact on environment should be minimum.

Foreign dependence- in regard to technology, availability of spares should be minimum.

Multiple operation -Amenability for multiple operation.

Steam: The steam loco consists of three systems:-

- Boiler to burn the coal and produce heat energy and to use this energy to heat up- water and produce steam at high temperature and pressure.
- Engine to use steam at high pressure and temperature to produce mechanical energy and transmit it to the wheels to produce torque to pull the train.
- Tender to store water and coal.

The steam engine is very simple in design, easy to maintain and highly reliable equipment. This however, has following drawbacks

- Needs good quality of coal ( high calorific value and low ash contents), a scarce commodity in India
- Low load hauling capacity
- High pollution
- Fire hazard
- Needs frequent stoppages for watering/ filling up coal.
Low Utilization (Kms/day)

**Diesel Locomotive** - This loco also consists of three major systems

- **Diesel Engine** - to convert chemical energy of diesel oil into mechanical energy
- **Transmission** - to transmit the energy produced by diesel engine to obtain rotation of the wheels
- **Control** - to control production of energy/ transmission affection.

**Electric Locomotive** - This also has three main system.

- Pantograph to collect electric energy from overhead wire.
- Transformer/ Rectifiers to step down the voltage and convert into DC.
- Control Circuit to control power into loco wheels.

**Comparison of Steam, Diesel & Electric loco**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Steam</th>
<th>Diesel (Very high with MU)</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load/ Speed</td>
<td>Low Load</td>
<td>High Speed</td>
<td>High Speed</td>
</tr>
<tr>
<td></td>
<td>Low Speed</td>
<td>High Speed</td>
<td>High Speed</td>
</tr>
<tr>
<td>Need for stoppages for loco requirement</td>
<td>High - Every 150 Kms</td>
<td>Low - Every 3000 kms</td>
<td>Very Low</td>
</tr>
<tr>
<td>Riding Quality</td>
<td>Rough</td>
<td>Smooth</td>
<td>Smooth</td>
</tr>
<tr>
<td>Reliability</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Multiple</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Maintenance time</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Forward/Reverse</td>
<td>Only forward.</td>
<td>Both movement</td>
<td>Both</td>
</tr>
<tr>
<td>Pollution</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Foreign Dependence</td>
<td>Nil</td>
<td>Regular ( for HSD oil )</td>
<td>Minimum</td>
</tr>
</tbody>
</table>
7. **Diesel Locomotive**

**Design Features**

A steam locomotive engine is directly coupled to the wheels. This is so because steam engine is capable of producing adequate torque at starting and at very low speeds.

The diesel engine, however, cannot produce high power at start or at very low engine speeds. It is, therefore, necessary that engine is decoupled from wheel while starting and till it attains a minimum working speed. This is achieved by clutch and gear box in automobiles. The clutch gearbox combination is termed as transmission. Transmission is necessary for all IC engines.
In automobile engine, the clutch provides to decouple the engine from wheel, and gearbox helps to increase/ decrease mechanical torque as per requirement of speed/torque. The horse power of automobile engines are low and hence mechanical clutch with mechanical gear box are quite suited for transmission.

The engine power is very high for rail locomotive engine. Mechanical transmission is, therefore, not suitable as it becomes very bulky and difficulty to operate. The transmission of diesel locomotives is therefore either hydraulic or electrical.

In hydraulic transmission, hydraulic coupling with reversing gear box is used.

Hydraulic torque converter acts as clutch and gearbox combined into one with infinite gear ratios. The output torque can be varied from infinitely from zero to more than engine torque. One side of torque converter (impeller end) is connected to engine and continuously rotates while other side (turbine end) is connected to wheel by suitable gear train. The hydraulic transmission attains peak efficiency at a specific speed, and falls steeply on either side of it. By multi-staging the converter, high efficiency can be maintained in the entire working range.

On most of our mainline diesel locos, IR have gone in for electric transmission. In this type of transmission, the engine is permanently coupled to a DC Generator. The output of the generator is fed to traction motors through a control circuit which varies the torque- speed relationship. The traction motors are directly mounted on the axles and drive the axles through gears.

Various types of Transmissions

![Transmission Diagram](image-url)
Some of the major components are:

- Engine or power pack to produce power for transmission.
- Governor to regulate fuel input according to Generator demand and to maintain constant engine RPM at each notch.
- **Throttle** - to vary engine RPM and power output.
- **Traction Generator** - to convert mechanical energy into electric energy.
- **Expressor** - to produce compressed air for locomotive braking and to operate various contractors in the control circuit, and vacuum for the train brake system.
- **Radiator Fan** - to cool engine cooling water
- **Traction Motor** - to convert electric energy to mechanical energy (for driving the wheels)
- **Turbo Super Charger** - to compress air before input into engine for combustion
WDM2 Locomotive Bogie

- **Motor**
- **Centre Pivot**
- **Bogie Frame**
- **Side Bearer**
- **Traction**

- **Roller Bearing Box**
- **Equalising Beam**
- **Helical Springs**
Some of the Safety Components are:

**Over Speed trip mechanism** – it trips the power if engine RPM exceeds the predetermined limit.

**Wheel slip relay** – it reduces the power to traction motor if wheel slip takes place.

**Hot engine alarm** – it gives alarm if cooling water temperature exceeds the predetermined limit and cuts off the power if engine remains hot for a specific time.

**Sand gear** – to sprinkle sand on the rail to improve adhesion.

**Classification and Codification of diesel locos.**

Diesel loco are classified on wheel arrangement by 2-4 letter codes.

- **B** Bi-axle bogie with mechanical coupled axles
- **C** Tri-axle bogie with mechanical coupled axles
- **BO** Bi-axle bogie with independently driven axles
- **CO** Tri-axle bogie with independently driven axles

Diesel locos are coded to indicate gauge, traction mode, end use and model number. This is four letter code.

- **1st letter** : Gauge (W-BG,Y-MG,Z-NG(2′6") and N-NG(2′)
- **2nd letter** : Traction Mode (D-Dsl, A-AC, C-DC)
- **3rd letter** : Service (P- Pass, G- Goods, S-Shunting, M-Mixed)
- **4th letter** : Suffix number; Design/ Model no.

**e.g. WDM2** – A broad Gauge Diesel Locomotive suitable for mixed services i.e., both passenger & goods train operation.

**Classification, code & wheel arrangement of IR diesel locos are shown in table below :**

<table>
<thead>
<tr>
<th>Locomotive Code</th>
<th>Classification</th>
<th>Horse Power</th>
<th>Transmission</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Configuration</th>
<th>Power</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>WDM2</td>
<td>CO-CO</td>
<td>2636</td>
<td>Electric</td>
</tr>
<tr>
<td>WDM3A</td>
<td>CO-CO</td>
<td>3100</td>
<td>Electric</td>
</tr>
<tr>
<td>WDG3A</td>
<td>CO-CO</td>
<td>3100</td>
<td>Electric</td>
</tr>
<tr>
<td>WDP3A</td>
<td>CO-CO</td>
<td>3100</td>
<td>Electric</td>
</tr>
<tr>
<td>WDP1</td>
<td>BO-BO</td>
<td>2300</td>
<td>Electric</td>
</tr>
<tr>
<td>WDG4</td>
<td>CO-CO</td>
<td>4012</td>
<td>Electric</td>
</tr>
<tr>
<td>WDP4D</td>
<td>CO-CO</td>
<td>4500</td>
<td>Electric</td>
</tr>
<tr>
<td>WDG4D</td>
<td>CO-CO</td>
<td>4500</td>
<td>Electric</td>
</tr>
<tr>
<td>WDG5</td>
<td>CO-CO</td>
<td>5500</td>
<td>Electric</td>
</tr>
<tr>
<td>WDS 4</td>
<td>O-C-O</td>
<td>600</td>
<td>Hydro-mech</td>
</tr>
<tr>
<td>WDS 4A or B</td>
<td>O-C-O</td>
<td>660/700</td>
<td>Hydraulic/Hydro-mech</td>
</tr>
<tr>
<td>WDS 5</td>
<td>O-C-O</td>
<td>1065</td>
<td>Electric</td>
</tr>
<tr>
<td>WDS 6</td>
<td>O-C-O</td>
<td>1400</td>
<td>Electric</td>
</tr>
<tr>
<td>YDM 4</td>
<td>CO-CO</td>
<td>1400</td>
<td>Electric</td>
</tr>
<tr>
<td>ZDM 5</td>
<td>B(^1) - B(^1)</td>
<td>490</td>
<td>Hydraulic</td>
</tr>
</tbody>
</table>

Cost of Diesel Locos

WDG3A – ` 9 crores, WDG4 – ` 12.5 crores, WDM2 - Rs. 4.5 crores (Indicative Price)

**Codal life of Diesel Locos**: 36 Years (with a Re-powerpackaging after 18 years, Viz. Mid-life rehabilitation/ Rebuilding done at DMW/Patiala)

### 8. Operation & Maintenance Of Diesel Loco

#### Haulage capacity of a WDM2 Locomotive

Starting Tractive Effort = 30.4 tonnes

Continuous Rated Tractive Effort = 24.6 tonnes

It can haul a train of 4700 tonnes on level track with a balancing speed of 59 kmph.

**Fuel & Lubricating Oil Consumption Targets** - The bulk of main line B.G. diesel Locos on Indian Railways are WDM2 Locos. The fuel consumption of a WDM2 loco under idle conditions is 20-25 lit/ hrs, but at 8th notch fuel consumption is about 450 litres / hr. But specific fuel consumption on IR is generally measured in terms of litres/ 1000 Gross Ton Km which depends upon load, average speed, grade & curvature of section etc.
The target for level section is 2.5 lit/ 1000 GTKM for goods operation & 4 lit/ 1000 GTKM passenger for Passenger operation.

Lubricating oil consumption is generally measured in terms of percentage of fuel oil consumption and its target is less than 1.5% of Diesel Oil.

**Diesel Loco Maintenance**

When steam locomotives were introduced, India was lagging in engineering industries and hence the concept of having Railway Workshops was created. The stress was on repair of sub-assemblies rather than replacement and discarding of old components. This concept has undergone a revision for diesel loco maintenance. Most of the items are purchased from trade and the worn-out parts are replaced rather than repaired. This has emerged due to the nature of parts, viz. rubber fittings, gaskets, filters, electrical contactors, precision machined valves, etc. Even for major assemblies, the concept is to change the complete assembly in shed rather than repair in position. The assembly is then sent to the particular section for overhauling and testing. For this purpose, a pool of important sub-assemblies (unit exchange spares) is kept in each diesel shed/shops for this purpose.

Diesel locos are allotted a specific homing shed, which is responsible to maintain it properly. Suitable preventive maintenance schedules, specifying part to be checked, repaired and replaced are specified to ensure trouble free service on line.

Various locomotive maintenance schedules, the periodicity and time required for undertaking them is given below:

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Periodicity</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip</td>
<td>20/30/40 days*</td>
<td>Any shed</td>
</tr>
<tr>
<td>M4</td>
<td>4 months</td>
<td>Home Shed</td>
</tr>
<tr>
<td>M8</td>
<td>8 months</td>
<td>Home Shed</td>
</tr>
<tr>
<td>M12</td>
<td>12 Months</td>
<td>Home Shed</td>
</tr>
<tr>
<td>M24</td>
<td>24 months</td>
<td>Home shed</td>
</tr>
<tr>
<td>M48</td>
<td>48 months</td>
<td>Home Shed</td>
</tr>
<tr>
<td>POH</td>
<td>8 years</td>
<td>Workshop</td>
</tr>
</tbody>
</table>
Rebuilding 18 years DMW

* As per RB letter 2003/M(L)/466 dated 27.6.08, Loco with pure air brake, microprocessor control system and roller suspension bearing. Loco should be kept under monitoring. Also as per RDSO letter no. SD.WDM.2.9 dated 24/27.05.13

After 18 years, locomotive is sent to DMW/ Patiala for rebuilding/ remanufacturing.

**Diesel shed records** - Important records maintained by diesel sheds are:

- **Daily position sheet** - gives details of loco outage, dead locos on lines, locos undergoing schedules, locos expected to go out and come into shed

- Repeated Booking Register

- Wheel profile register

- History of Repairs carried out - Locowise

- Load test results.

- Diesel oil Consumption /Specific fuel consumption Register

- Lub oil consumption Register.

**Availability**

A Rolling stock is said to be 'ineffective' if it is not available for the whole day i.e. from O hrs to 24 hrs. The present target for ineffectiveness of WDM2 locos is 10% (earlier it was 12.5%). However, its outage (availability for train operations) is also watched on 4-hourly basis for which a further allowance of 10% is given for running repairs. So, the sheds are required to maintain on 4-hourly basis an outage of 81% of Diesel Locos for Train operations. However for Passenger Locos the outage is to be maintained as per Locos Links.

**Target Outage calculation**

Total holding of diesel shed ------ = X

10% allowance for heavy repair----10% of X = 0.1X

Available for traffic= X-0.1X = 0.9X
Passenger link say = Y
Available for freight operation = 0.9X-Y
Running repair 10% = 0.1(0.9X-Y)
Net target freight outage = (1-0.1)(0.9X-Y)

**Multiple Unit Operation**

The Diesel-electric locos are capable of being coupled together to work in Multiple Unit Operation in which only Leading Loco is required to be manned, whereas all the trailing locos are controlled by Leading Loco to run at the same notch and produce power accordingly. In case of multiple loco operation trailing locomotive can be notched up or down from the same controls available with the driver of leading locomotive. Similarly Brake application on trailing locomotive will be as per brake aspects on the leading locomotive.

**GM/EMD Locomotives:**

Indian Railways have purchased the following:

1. 13 assembled WDG 4 locomotives
2. 9 partly knocked down WDG 4 locomotives.
3. 10 assembled WDP 4 locomotives.
4. Technology for manufacturing of these locomotives at DLW/Varanasi from M/s General Motors, USA.

DLW has started manufacturing this loco,
Features of GM/EMD Locomotives:

1. 4000 HP locomotive equipped with 16-710 G 3B engine.
2. 540KN starting Tractive Effort.
3. 270 KN Braking Effort.
4. 4% improvement in fuel efficiency.
5. AC-AC technology.
6. Micro processor based traction control.
7. Electronic brake system.
8. High adhesion and high speed bogie.
9. 90 days trip schedule.
10. Bogie overhauling after 1.6 Million kms.

COMPUTERS

GM locomotive is provided with 3 computers:

1. Main computer named as EM 2000 which –
   a. Does total control over diesel engine performance including safety aspects.
   b. Does trouble shooting and self diagnosis.
   c. Alpha numeric display.
   d. Archive memory and data logging.
2. Siemens computers which controls converters.

Comparative Performance of WDM2 and WDG4 (GM) is as under:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Indices</th>
<th>WDM2</th>
<th>WDG4 (GM)</th>
<th>% Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weight of train that can be hauled on level track (Tons)</td>
<td>4500</td>
<td>9400</td>
<td>109</td>
</tr>
<tr>
<td>2</td>
<td>Weight of train that can be hauled on 1:200 gradient</td>
<td>3085</td>
<td>5455</td>
<td>77</td>
</tr>
<tr>
<td>3</td>
<td>Balancing speed with 4700 ton</td>
<td>59</td>
<td>85</td>
<td>44</td>
</tr>
</tbody>
</table>
TECHNOLOGY PROGRESSION:

Remote Monitoring and Management of Locomotives:

LocoNet

![Diagram of LocoNet technology]

- **trailing load**
- **Availability (Locos on line/locos owned)**: 81% >90% 12
- **Trip Schedule**: 20 to 30 days 90 days
- **Shop attention**: 8 years 16 years 167
- **Reliability (Track KMs)**: 1 lacs 4 lacs 300
- **Lube Oil consumption (% of Fuel oil consumption)**: 1.5 0.5 66
- **SFC (gms/ bhp/hr)**: 164.24 151 9
- **HP Output**: 2600 4000 54
- **Starting adhesion**: 27% 42% 55%
- **Starting Tractive effort**: 30.4 T 52T 74
With the help of remote monitoring (ALCO) following are the advantages:

1. On line health monitoring and fault diagnostic of locomotives is possible.
2. Conditional maintenance of locomotive can be done resulting in increased periodicity of shed recall power.
3. Feasibility of advanced train control is possible.

Introduction of IGBT Traction Control Converter: EMD Locomotive

1. Traction Control Converter, the heart of AC-AC traction system, is basically a computer controlled inverter. High voltage GTO is used in existing TCC as main switching device. IGBT has been recently introduced in these applications because of better efficiency, characteristics and reliability.
2. Indian Railways Diesel Traction has timely adopted this new technology and manufactured first locomotive equipped with IGBT based converter in Nov ‘06.
3. After successful field trials, IGBT has been introduced in series locomotive production from Sept ‘07 onwards.

4500 HP Power Upgradation:

1. 1st 4500 hp loco (12114) with EMD IBT was commissioned in field in May ‘2007.
2. Two more locomotives equipped with IGBT were commissioned subsequently.
3. Series production of 4500 hp EMD locomotives has started.
4. Existing fleet with GTO TCC is also being planned to be upgraded to 4500 hp.

Operational advantages:

<table>
<thead>
<tr>
<th>Load</th>
<th>Balancing speed (KMPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4000 HP</td>
</tr>
<tr>
<td>Freight</td>
<td>85</td>
</tr>
<tr>
<td>Coaching</td>
<td>130</td>
</tr>
</tbody>
</table>

Improvements in EMD Passenger Locomotives:

Introduction of EMD IGBT has lead to new series of EMD passenger version named WDP_{4B} with 4500 HP and 6 TM configurations. WDP_{4B} will have maximum speed potential of 130 kmph.
3. Hotel Load:

Hotel load module of 500 kVA capacity, 750 Volts, 3 phase for BOG rake is being developed.

Benefits:

1. Significantly higher efficiency.
2. Reduced tare weight of train. Additional Passenger capacity will be generated by replacement of power cars.

Two WDP4 locomotives with hotel load have been turned out in 2010 and trials are on.

Further improvements planned in EMD locomotives are as under:

1. Electronic Fuel Injection System
   a. Fuel saving upto 2%
   b. Engine emission Tier – 2 complaint.

2. Enabling Distributed Power Operation: Following are the advantages:
   a. Long haul operation of freight trains.
   b. Train set operation for passenger trains.
   c. Support 200 Car trains or longer.
   d. Allow increased average speed, reduced cycle times.
   e. Reduce coupler forces.
   f. Push pull train operation.
   g. Reduce energy consumption, derailment risks, wheel wear.
   h. Improve safety based upon reduced stopping distance.