DRS-10

BLOCK-1

Unit 3 Horsepower and other design parameters of GM locomotive

Objective: After going through this unit you will understand the Horsepower and other design parameters Of GM locomotive.

Structure:

Locomotive Design

There have been significant changes in locomotive technology during past 10-15 years. Modern electric and diesel-electric locomotives have sophisticated control systems that allow precise control for power application to the rails. These locomotives, therefore, have the ability to significantly out-perform older technology locomotives. Introduction of AC-AC technology ensures that the locomotives are dispatched to gain the maximum benefit of the increased dispatchable adhesion.

The following mechanical principles and mathematical formulas that govern locomotive power application need to be clearly defined:

1 Locomotive Horsepower

There are four different horsepower ratings on a locomotive:

1.1 Brake horsepower.

Brake horsepower is measured at the engine crankshaft and is a measure of the **TOTAL horsepower available for conversion to electrical energy at the main generator plus the power required for driving accessory loads.**

1.2 Traction Horsepower

Traction horsepower = Brake horsepower - Accessory loads

GT46MAC locomotive has the following accessory horsepower demands:

- Auxiliary Generator.
- Traction Motor/Main Generator Blower.
- Air Compressor - mechanically driven by engine, but has a zero horsepower load when unloaded and is disengaged. GT46MAC has a clutch which disengages when no compressed air is required.
- Inertial Filter Blower Motor.
- Radiator Cooling Fans - electrically driven by the companion alternator. GT46MAC utilises two speed-cooling fans to lessen the horsepower demands for engine cooling when full cooling is not required.
- AC Inverter Blowers - electrically driven by the companion alternator.

Traction HP rating is the most commonly used rating when quoting locomotive horsepower. When railroads dispatch loads on hp/ton basis, they in almost all cases use traction hp for calculations.

1.3 Net Traction Horsepower

Net Traction Horsepower = Traction Horsepower x Generator Efficiency

In case of GT46MAC locomotive, 0.94 is the efficiency of the main generator.

1.4 Rail Horsepower

Rail horsepower, the power delivered by the locomotive wheels at the rails, can be expressed by **Rail Horsepower = Traction Horsepower x Transmission Efficiency**

Transmission efficiency is through:

- Main Generator
- Switch Gear
- Cables
- Traction Motors
- Traction Motor Axle Gears.
- Inverters

1.5 Draw Bar Horsepower

The power developed at the draw bar called Draw Bar Horsepower and is the actual horsepower used to pull a trailing load. It is the engine to generator horsepower minus electrical transmission losses minus horsepower necessary to move the locomotive only.

Drawbar Horsepower =

$$\frac{\{(\text{Engine to Generator H.P. x Transmission Efficiency}) - (\text{Loco weight x locomotive resistance x kmph})\}}{270 \text{ kg km per hour}}$$

Due to the fact that the formula includes "locomotive resistance" and kmph, it is necessary to specify the grade and curve condition as well as the speed of movement to obtain draw bar hp value. The resistance for each one percent of grade requires an additional 9.2 kg/t. Each degree of curvature requires and additional about 0.37 kg/t. The influence of Rolling Resistance on DB horsepower will be explained later. It should be clear that the Draw bar horsepower decreases with increased speed.

1.6 Horsepower Required to Pull a given Train Load

The calculations to find the Drawbar horsepower to pull a given train up a specified grade and curvature can also be made.

Drawbar HP required =

$$\frac{\text{Resistance X Wt. of Freight Car X No. Of Freight Cars X kmph}}{270}$$

Draw bar horsepower requirements will increase with increased speed.

2 Resistance

2.1 Rolling Resistance

The rolling resistance of a train can be determined by formula is generally is taken from tables and curves based on formula. The most widely used of such formulae is the "Davis Formula". **Rolling resistance is generally expressed in kg/t and is summation of Flange Resistance, Journal Resistance and Air Resistance.**

Other things being equal, total Rolling Resistance increases as speeds increase.

2.2 Grade Resistance

Grade resistance, expressed in kg/t , is independent of and unrelated to train speed. It is due to the force of gravity. It is always equal to 10 kg/tonne for each percent of grade as illustrated in the calculations below.

$$1\%\ \text{Grade} = \frac{1\ \text{m rise}}{100\ \text{m distance}}$$

when Weight, W = 1 tonne = 1000 Kg

Comment [D1]:

R_G = 1/100 x 1000 Kg = 10 Kg

Grade resistance = 10 Kg per 1 % of grade.

$$\text{Total Grade Resistance} = \frac{\text{Rise in elevation} \times 100 \times R_G\ (10\ \text{kg/t})}{\text{Distance travelled}}$$

2.3 Curve Resistance

A one-degree curve is a curve whose central angle extends to a chord of 30.48 m (100 feet). A 30.48 m (100 feet) chord is 1/360 of a complete circle; the radius of a 1' curve is 1746.5 m (5730 feet). Curve resistance is expressed in kg / t / degree.

Degree of curvature = 5730 / Radius in feet or 1746 / Radius in m

3 Tractive Effort

Tractive effort is defined as the turning force produced at the rails by the driving wheels. Tractive Effort can be expressed mathematically as follows for an AC locomotive.

Tractive Effort = Traction Horsepower x 315 mile-lbs/hr / Speed in miles per hour

or

Traction Horsepower x 230 km-kg/hr / Speed in km per hour

a. **Tractive effort depends on five major factors:**

I. Horsepower of the diesel engine.
II. Ability of the main generator.
III. Ability of the traction motors.
IV. Gear ratio.
V. Adhesion
   - Weight on driving wheels.
   - Rail condition.
   - Wheel Slip Control System.
   - Inverter System.

b. The effect of the above factors on tractive effort is explained below:

i) **Horsepower of the Engine**

HP of the diesel engine primarily determines the possible TE a locomotive can develop at the rims of the driving wheels. T.E calculations use the Traction HP for calculation purposes.

With an increase in the horsepower of the engine, either T.E. of the locomotive will increase for the same speed or speed will be increase with the same T.E.

ii) **Ability of the Main Generator**

The main generator is the first step in the transmission of engine horsepower to the wheels. The main generator converts the mechanical power into electrical energy, referred to as kW. This electrical energy is then used by the traction motors to turn the locomotive wheels. kW are measured by the following formulas :

$$\text{Main Generator Kilowatts} = \frac{\text{Main Generator Voltage x Main Generator Current}}{\text{1000 W per kilowatt}}$$

$$\textbf{Tractive Horsepower} = \frac{\textbf{Main Generator Kilowatt}}{\textbf{0.746 HP per kilowatt}}$$

The generator can produce any combination of amperage and voltage within the rated power range of the locomotive.

iii) **Ability of the Traction Motors**

Traction motors transform the electrical energy of the main generator into mechanical force to turn the locomotive wheels. At low speeds, the traction motors must be capable of operating at their thermal limit. Maximum locomotive speed is limited by the safe rotational speed of the armature. In a DC motor, the armature windings limit the maximum speed of the armature to approximately 2400 RPM. In an AC motor for the GT46MAC, the induction rotor allows the operating RPM to increase to 3600 RPM.

The ratings of the traction motors also affect the "Minimum Continuous Speed" of a DC locomotive, as well as the tractive horsepower available for transmission to the motors. With an AC locomotive, however, "Minimum Continuous Speed" is not a consideration. With AC traction motors, the locomotive can be put to full throttle at standstill without any damage to the motors.

iv) **Effect of Gear Ratio**

At full load, a given power output will produce a corresponding rotor speed regardless of gear ratio. The effect of changing gear ratio is to change the train speed at which full load can be applied continuously without thermal damage to the motors.

Therefore:

1. Increasing the gear ratio reduces the minimum speed (hence increases tonnage) at which a given locomotive can operate without heat damage to the motors.

2. Reducing the gear ratio, the maximum speed at which a given locomotive can operate without mechanical damage to the motors.

v) **Adhesion**

Adhesion can be defined by the following locomotive formula:

$$\% \text{ Adhesion} = \frac{\text{Tractive Effort (kg) X 100}}{\text{Locomotive Weight}}$$

There are three classes of adhesion:

- Required (Train Weight and Grade dependent)
- Available (Operation under a given set of rail conditions)
- Developed (Locomotive capability through enhancements-wheel slip control)

The adhesion rating of a locomotives depends upon confidence level. This means that at a confidence level of 98%, the user can count on the locomotive developing the given adhesion factor 98% of the time. This is also termed as "All Weather Adhesion".

There are cases where trains can be dispatched with a lower confidence level and a higher adhesion requirement. For example, trains may be dispatched during the summer months at a lower confidence level i.e. the user is counting on higher adhesions because of good weather conditions. Under inclement weather conditions, the locomotives can be dispatched at a higher confidence level of making a successful trip as the rail conditions deteriorate. There is a large gain in dispatchable adhesion as the confidence level drops to say 80 %. This means that if one counts on the locomotive to produce 43% adhesion, it will probably make the run successfully only 80% of the time without help.

- **Weight on Driving wheels**

The weight on the driving wheels is that portion of the entire weight supported by the wheels driven by traction motors. The weight on driving wheels is in an important factor in the locomotive's "adhesion". Adhesion is the grip produced by friction between the steel wheels and steel rails. Adhesion is required to keep the wheels from slipping. In the modern locomotives which allow "wheel creep" (controlled wheel slip), however, the maximum tractive effort can be much higher due to the precise control of the wheel creep systems.

- **Rail Conditions**

With a given weight on rails, adhesion depends on rail conditions. Dampness, water, leaves, rust, ice, frost, and oil cause rails to be slippery. With GT46MAC locomotive, the adhesion may TEMPORARILY reach as much as 45% (with ideal rail conditions). Practical year round adhesion factor may be as low as 33 %.

- **Wheel Slip Control System**

The wheel slip control system used on a locomotive can have a dramatic effect on the adhesion level achieved. Until the introduction of the "Super Series" wheel slip control system, all wheel slip control systems were "corrective" type systems. In other words, they operated under the principle that all wheel slip is bad and would reduce power to traction motors to control the slip.

The introduction of "Super Series" improved dispatchable adhesion. The "Super Series" wheel creep control system allows the wheels to exceed ground speed by a certain percentage, depending on rail conditions, to improve adhesion. Super Series is activated automatically through the control system.

The introduction of AC technology also improves the wheel creep control system due to its rapid response. In a DC locomotive, power is modulated by varying the DC field current of the main generator. There is an inherent lag time as the main generator's magnetic field requires time to collapse. With the AC locomotive, the wheel creep corrections are far more rapid as the devices that control the power output to the AC traction motors (called Gate Turn Off Thrystors, or simply GT0s) can have their switching sequence changed almost instantaneously. Power corrections are much more rapid and smoother with the AC traction equipped locomotive.

- **Inverter System**

GT46MAC locomotive utilizes a system called "truck control", where one inverter controls all of the axles within a truck unlike GE which uses single axle inverter system i.e. one inverter per axle.

While "truck control" system has less number of physical components to maintain, this has the disadvantage of the power reduction in the event of an inverter failure.

4 Dynamic braking effort

Dynamic braking effort may be considered as negative tractive effort. It is useful for controlling train speed. Dynamic Brakes are normally not used to stop a train but are used to assist deceleration.

Dynamic Brakes are the preferred tool to control train speed on, many railroads for the following reasons:

i) It saves considerable brake shoe wear, the subsequent reduction in air brake use minimizes the chance of stuck brakes on the train.

ii) It eliminates the fuel inefficient practice of 'Stretch braking' a train with air brakes.

5 Brake Effort

Braking effort for a train can be calculated by the Following formula:

Brake Effort = ($-G_R$ r+ C_R + Car_R) x (Trailing load in tonne + Locomotive Wt. in tonne)

Where G_R = Grade resistance

C_R = Curve resistance

Car_R = Car resistance

6 Comparison between Four Axle & Six Axle Locomotive

Six axle locomotive has 50% more Traction Motors than a four axle locomotive resulting in:

- Six axle locomotive has about 50% more tractive effort than a four axle locomotive.
- Six axle locomotive weighs about 50% more than a four axle locomotive.
- Six axle locomotive's minimum continuous speed is approximately 40% more than a four axle locomotives with equal horsepower.

With equal trailing tonnage, six axle locomotive's running time on a given run over the railroad is slightly longer than the four axle locomotive. This is because of the increased rolling resistance with the additional two motors / axles.

As a general rule, if the locomotive's primary mission is to haul trains at high speeds (inter-modal use), four axle locomotive is better suited. If the locomotive's primary responsibility is heavy service over terrain with grades and curves, six axle locomotive is better suited.