Tractive effort of locomotives-Resistances-DBP

Dr. Ahmed A. Khalil

4th Year Civil

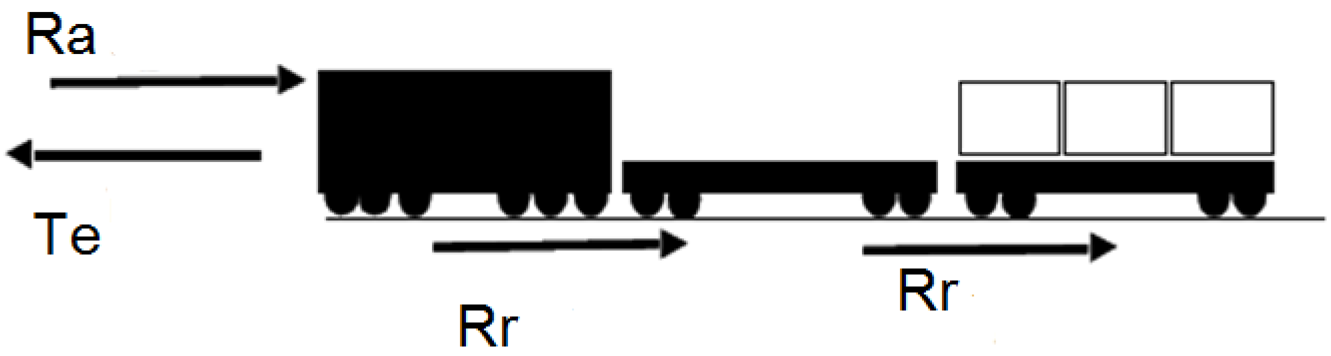
Weeks 2 – 3 - 4

Train Resistances

1- Running Resistance (Rr)
2- Air Resistance (Ra)
3- Starting Resistance (Rs)
4- Acceleration Resistance
5- Grade Resistance
6- Curve Resistance
7- Tunnel Resistance

Tractive Effort

Running & Air Resistances



Te = قوة الجر

Ra = مقاومة الهواء

Rr = مقاومة السير

*** عند السير بسرعة منتظمة**

Te = Ra + Rr

A railway vehicle moving upon level, tangent track, in still air and at a constant speed encounters certain resistances that must be overcome by the tractive effort of the locomotive.

$$\mathbf{Ra} + \mathbf{Rr} = k_0 + k_1 \cdot v + k_2 \cdot \left(\frac{v}{10}\right)^2 \ [\mathrm{kg/t}]$$

v … speed [km/h]

k_0 … constant 2.5

k_1 … constant 0.0025

k_2 … constant 0.025 (according to the *UIC*)

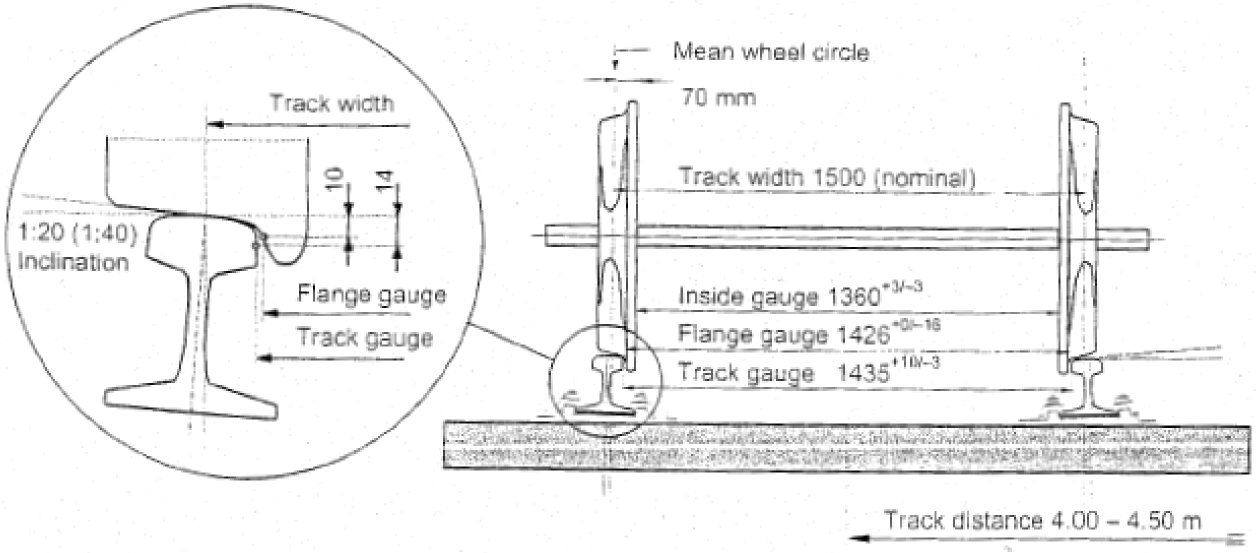
k_0 = rolling resistance component independent of train speed

k_1 = coefficient used to define train resistance dependent on train speed

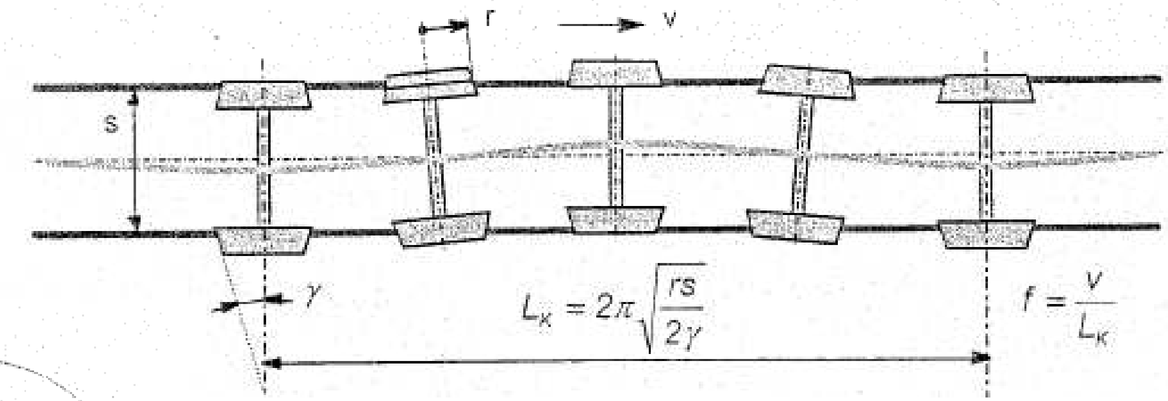
k_2 = aerodynamic coefficient or polynomial function used to further define train resistance

k_0	k_1	k_2
Journal resistance Rolling resistance Track resistance	Flange friction Flange impact Rolling resistance wheel/rail Wave action of the rail	Head-end wind pressure Skin friction on the side of the train Rear drag Turbulence between cars Yaw angle of wind tunnels

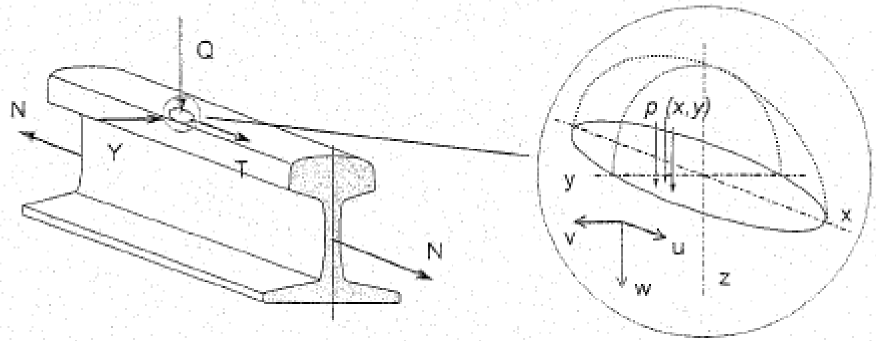
Group K_1



Track width
10
14
1:20 (1:40)
Inclination
Flange gauge
Track gauge
Mean wheel circle
70 mm
Track width 1500 (nominal)
Inside gauge 1360+3/-3
Flange gauge 1426+0/-16
Track gauge 1435+10/-3
Track distance 4.00 – 4.50 m



r
v
s
γ
$L_K = 2\pi\sqrt{\frac{rs}{2\gamma}}$
$f = \frac{v}{L_K}$



Q
N
Y
T
N
p (x,y)
y
x
v
u
w
z

Group K_2

The air resistance is expressed by the coefficient c_w, the vehicle cross section A, the specific mass of the air and by the vehicle speed relative to the wind velocity:

$$k_2 \cdot \left(\frac{v}{10}\right)^2 = c_w \cdot A \cdot \rho \cdot v_r^2 \cdot 0.6361 \text{ [kg/t]}$$

v_r … relative speed [km/h]

A … vehicle cross section [m²]

ρ … specific mass of the air [kg/m³] 0.001204

c_w … air resistance coefficient (0.6 – 1.15 for locomotives, closed wagons 0.25 – 0.4)

k_2 … constant 0.025 (according to the *UIC*)

Strahl Formula

Ra + Rr of complete train loads is calculated according to *Strahl*

$$Ra + Rr = 2 + (m + 0.07) \cdot \left(\frac{v}{10}\right)^2 \ [kg/t]$$

m … correction values:

0.033	for passenger wagons and freight wagons in complete train loads
0.04	for fast trains
0.05	for mixed freight trains
1.0	for empty stock

Grade Resistance RG

$R_G = W \sin\alpha$ ton

$R_g = \dfrac{W \sin\alpha}{W}$

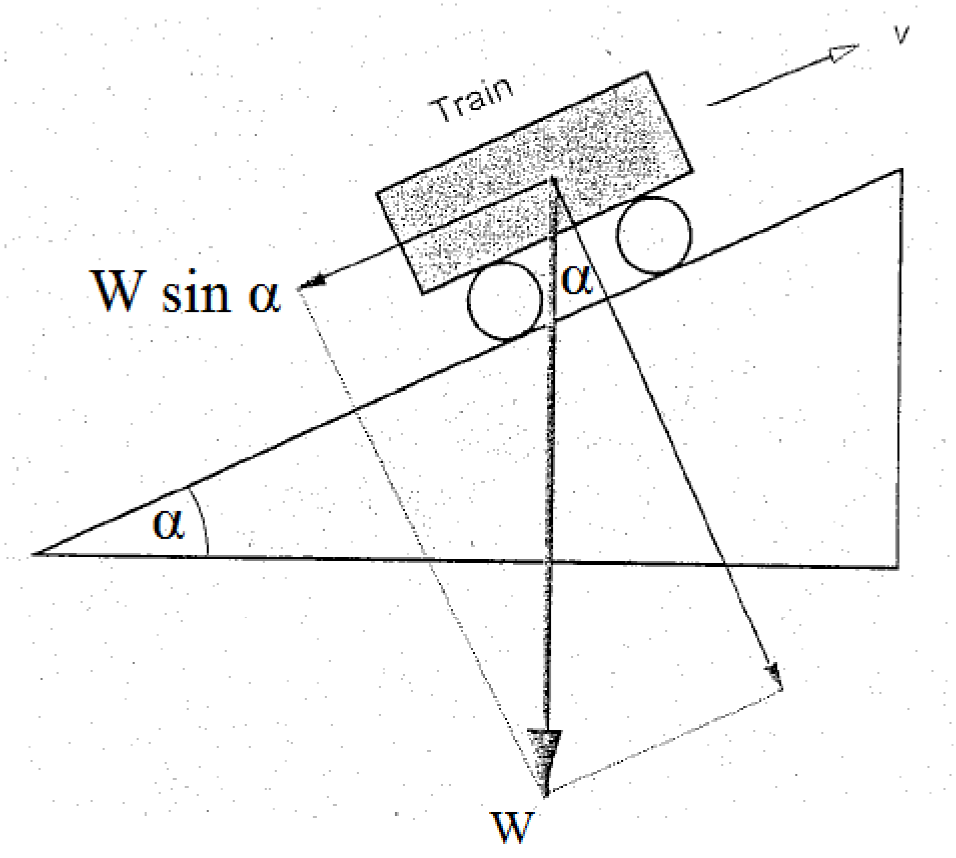
$= \sin\alpha$ t/t

$= 1000 \sin\alpha$ kg/t

$= 1000 \tan\alpha$

$= 1000$ * gradient / 1000

$= 1$ kg/t/1‰ grade



Curve Resistance R_C

إن حركة العجلة على القضيب لا يمكن اعتبارها حركة دوران خالصة بل هي عبارة عن حركة دوران مصحوبة بحركة انزلاق في الاتجاه الطولي والاتجاه العمودي ، وبذلك يمكن القول بأن مسير الوحدة المتحركة على منحنى ما يتكون من :

أ. حركة دوران في الاتجاه الطولي .

ب. حركة انزلاق في الاتجاه العمودي .

ج. حركة انزلاق في الاتجاه الطولي.

ومقاومة الاحتكاك الناشئة عن الانزلاق في الاتجاه العمودي والانزلاق في الاتجاه الطولي نتيجة للسير على المنحنى هي المسماة بمقاومة المنحنى :

ويسبب الانزلاق العمودي حوالي ٨٥% من هذه المقاومات ، وحوالي ١٥% للاتجاه الطولي وتعتمد مقاومة المنحنى على نصف قطر المنحنى والمسافة بين محوري البوجي الخارجيين .

Curve Resistance R_C

Curvature resistance is calculated according to the following *Röckl* formulas:

$$R_C = \frac{k_1}{R - k_2} \quad [kg/t]$$

R … radius [m]

$R > 350$ m	$k_1 = 650$	$k_2 = 55$
$R \approx 300$ m	$k_1 = 530$	$k_2 = 35$
$R < 200$ m	$k_1 = 500$	$k_2 = 30$

Degree of Curve (D)

Where :

D^o = The degrees that subtend an arc of 100 ft

R = 5730 /D ft

R = 1746 / D m

Starting resistance (Rs)

Starting resistance (Rs) = 10 to 25 kg /ton

= 15 kg/ton

هي مقاومة السير عند لحظة القيام وتكون كبيرة نظراً لتماسك مادة التشحيم مع محاور العجلات وكمرة الفخذ .

حيث تبلغ هذه المقاومة حوالي ١٥ كج/طن ، وإذا ما سار القطار لمسافة صغيرة حوالي ٢سم فإن هذه المقاومة تهبط إلى النصف تقريباً وبعد مسافة أكبر تبدأ مادة التشحيم في القيام بوظيفتها وهي تقليل مقاومة الاحتكاك بين العجلة والمحور فتصل مقاومة السير إلى معدلها الطبيعي

$$R_{acc} = 102 \cdot \xi \cdot a \ \ [kg/t]$$

R_{acc} … acceleration resistance [kg/t]

ξ … coefficient of rotating masses [1 … 1.1, typical value 1.05]

a … starting acceleration [m/s^2] (typical value 0.05 … 0.1)

Tunnel Resistance

Tunnels can increase the train resistance considerably. Factors which affect tunnel resistance are train length, tunnel length, the ratio of the cross-sectional area of the train to the cross-sectional area of the tunnel, and tunnel roughness

Tunnel Length (Feet)	Train Type	q = 0.40	q = 0.65
2000	Passenger	4.0	6.0
5000	Passenger	6.3	12.0
2000	Freight	8.0	12.3
5000	Freight	12.6	24.0

Tractive effort

• هو القدرة اللازمة أو الشغل اللازم للتغلب علي المقاومات التي تقابلها القاطرة ويجب أن تكون أكبر من جميع هذه المقاومات لاعطاء القطار السرعة والعجلة اللازمة للحركة

• Tractive effort is the propelling force which a locomotive exerts at the rims of its driving wheels. It is usually expressed in pounds

• The relation between tractive effort, rail horsepower, and speed in miles per hour is

$$\text{* Tractive effort} = \frac{270\ (\text{Rail horsepower})}{\text{Speed}} \quad \text{kg}$$

Note: efficiently factor = 0.85

- Locomotives are generally rated in terms of their horsepower.

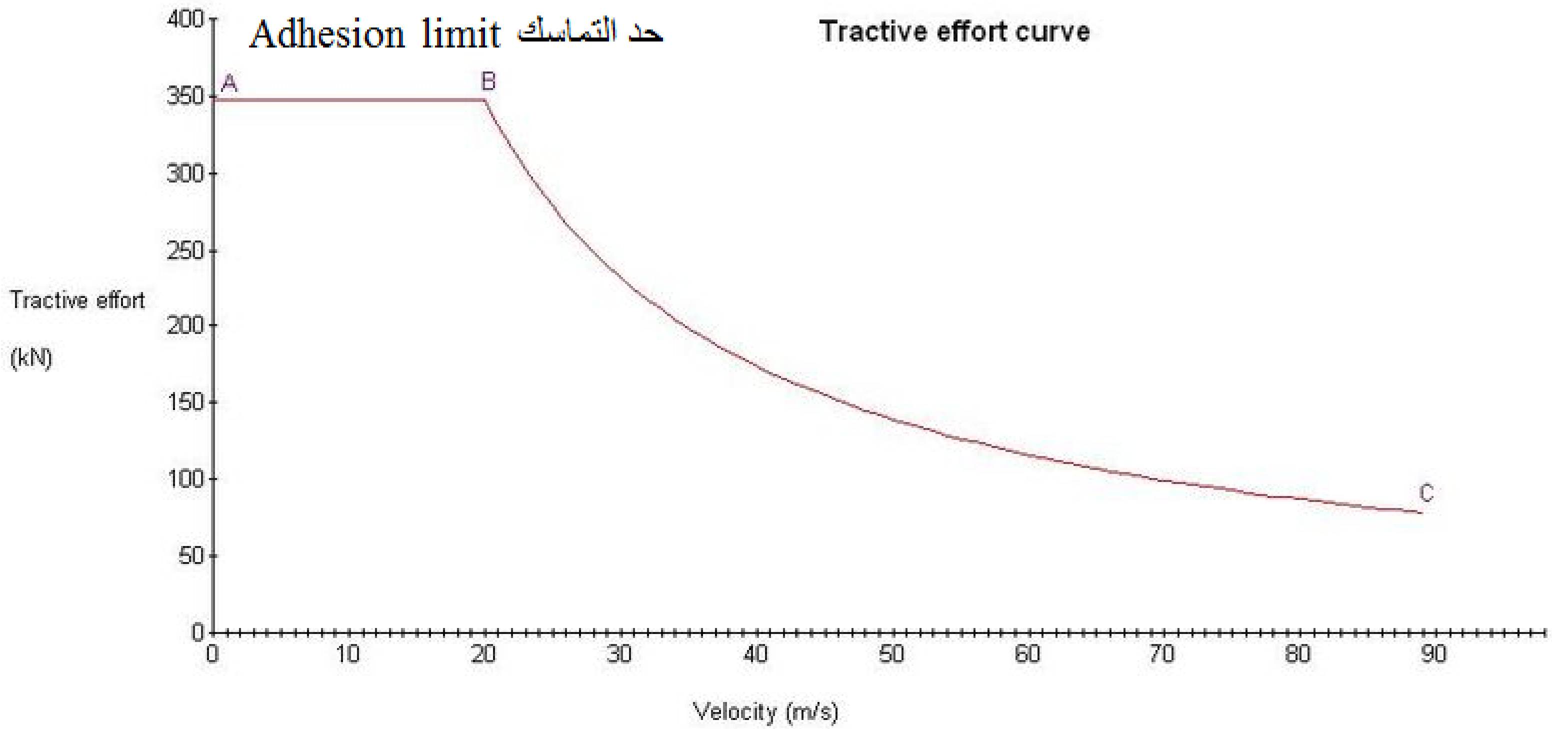
- In electric locomotives the rated horsepower is the power available at the rims of the drivers.

- In diesel- or turbine-electric locomotives the rated horsepower is that which is input to the main generator for propulsion.

- The power exerted by a locomotive at the rims of the drivers is called rail horsepower.

Adhesion

-The adhesion of a locomotive is the ratio of the tractive effort needed to slip the drivers to the weight on the drivers. It is usually expressed in percent.



The line AB shows the operation at the maximum tractive effort, the line BC shows the relationship of continuous tractive effort being inversely proportional to speed

العلاقة التى تربط بين حد التماسك والسرعة هى :

$$\text{Adhesion force} = \mathbf{w}\ (\text{for driving wheels of loco.}) \times \mu$$

$$= \mathbf{w} \times [(9000/(42+ v)\ ) + 116]$$

- هذه العلاقة توضح أن هناك تناسب عكسي بين حد التماسك والسرعة بدرجة أقل من التناسب العكسي بين قوة آلات القاطرة والسرعة ،

-يتضح أن قوة آلات القاطرة تكون أكبر من حد التماسك عند السرعات القليلة وأقل من حد التماسك عند السرعات العالية ،

- ولأن حد التماسك يعبر عن مقدار القوة التي يمكن الاستفادة منها ، لذلك فعند السرعات القليلة لا يمكن الاستفادة من قوة الآلات إلا بمقدار يساوي حد التماسك أما عند السرعات العالية فيمكن الاستفادة من كل قوة آلات القاطرة حيث أنها تقل عن حد التماسك .

w = Weight on tracking wheels *(ton)*

v = Speed *(km/hr)*

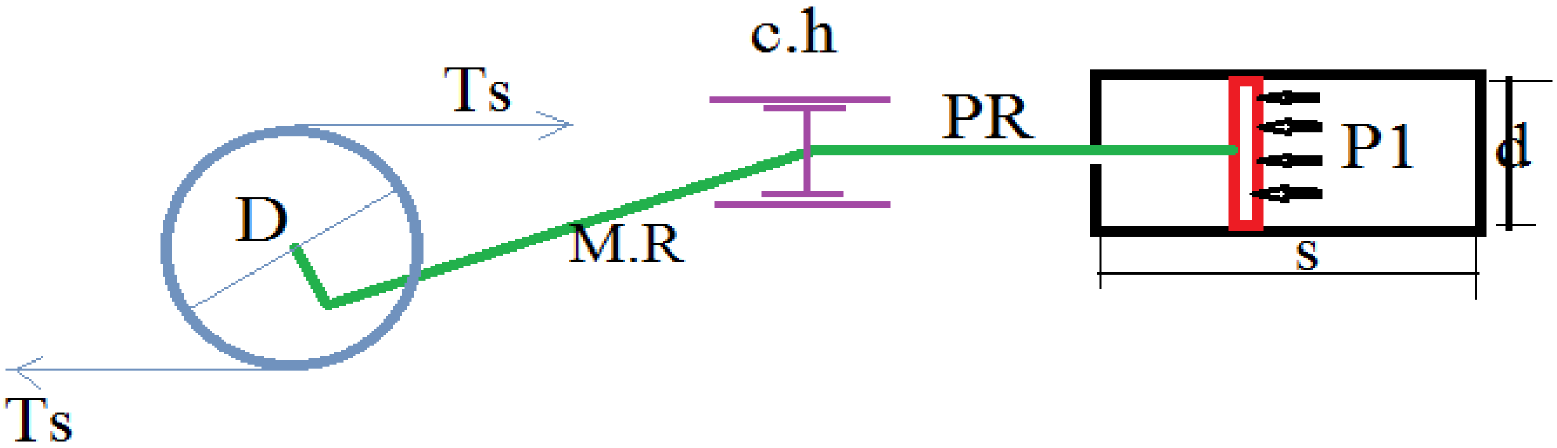
-Under poor rail conditions (when the rail is both oily and wet) it may amount to less than 5%, whereas under exceptionally good conditions it may exceed 40%.

Poor rail conditions can be improved by the use of sand or by chemical treatment, so that it may be assumed that maximum tractive efforts of 25 to 30% of the weight on drivers can normally be exerted without slip and will thus be available for starting trains.

- With the train in motion, wheel slip may occur at tractive efforts well below the starting maximum, due to imperfections in track alignment and wheel bouncing. That is, adhesion becomes smaller as speed increases.

At 60 mph, for instance, adhesion may be 15% or lower, even with good rail conditions.

STEAM lOCOMOTIVE



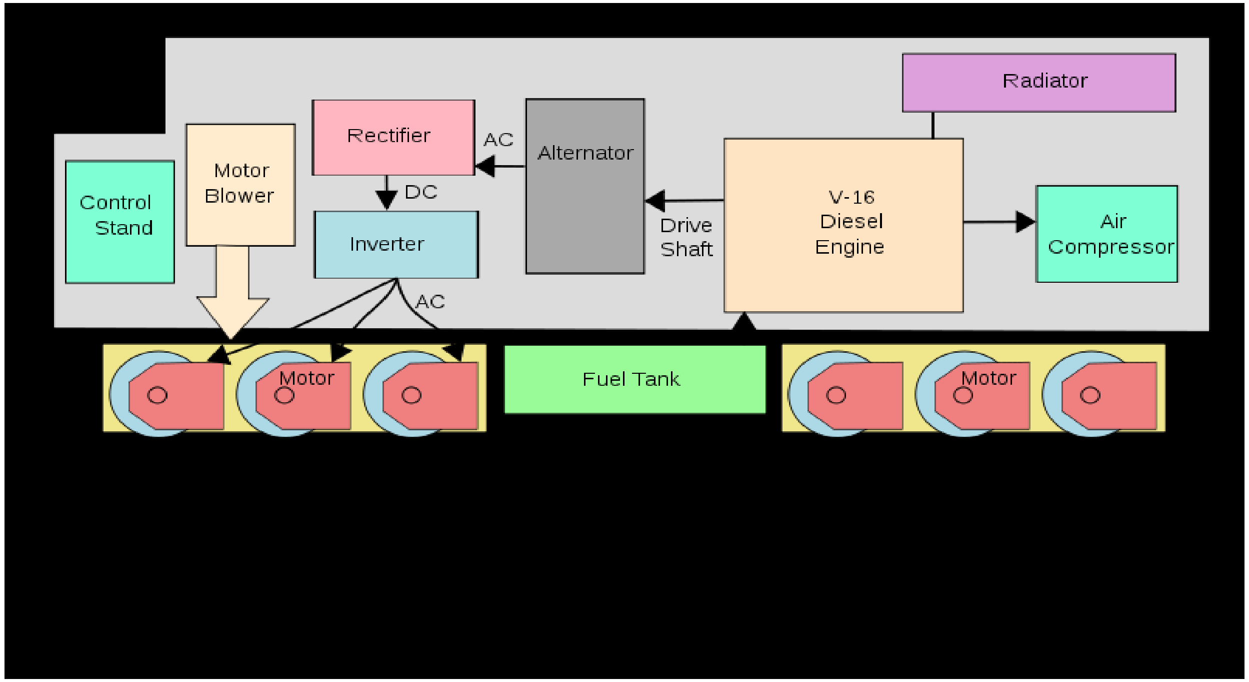
$W = P1\ .\ \Pi\, d^2\ .\ \frac{2\ .\ S\ .\ 2}{4} = P1\ .\ \Pi\, d^2\ .\ S = 0.85\, P\, \Pi\, d^2\ .\ S$

$W = Ts\ .\ \Pi\ .\ D$

$Ts = \frac{0.85\, P\ .\ d^2\ .\ S}{D}$

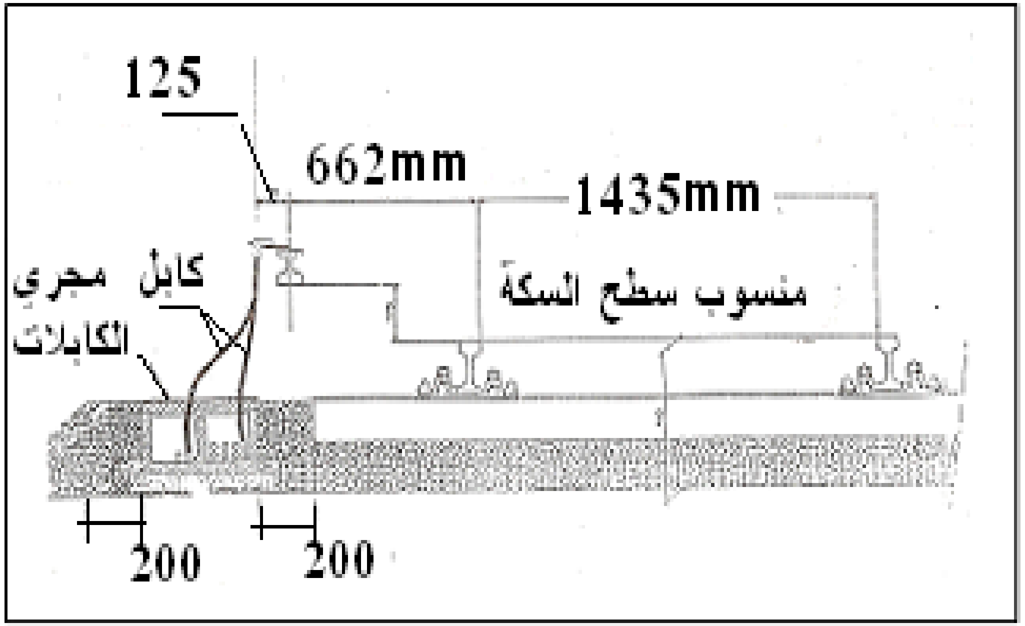
Where: W= work done in one revolution of the driving wheel (equivalent to 2 strokes of the piston), P1= cylinder pressure = 0.85 of boiler pressure P, S = stroke length, d= piston diameter

ELECTRIC lOCOMOTIVE

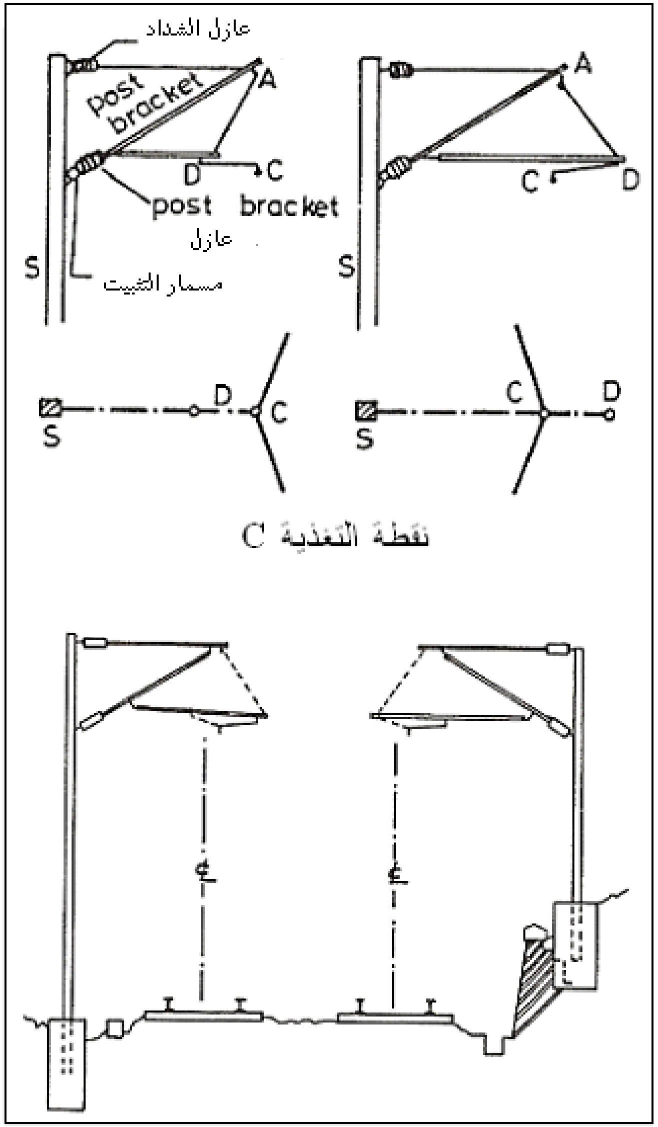


Two general power distribution systems are used on the electrified railways ; namely, the direct-current and the alternating-current systems. Current collection may be accomplished through the medium of collector shoes sliding on a third rail, or by use of a pantograph or trolley wheel in contact with an overhead trolley wire

$$Te = \frac{T \, . \, 24}{D} \quad \frac{G}{g} \, . \, \eta \, . \, N \qquad lb$$



Power rail



Catenary

$$Te = \frac{T \cdot 24}{D} \cdot \frac{G}{g} \cdot \eta \cdot N \quad lb$$

Where:

Te = tractive effort

T = torque of a single motor in lbs, it is taken at one foot radius from the motor armture shaft center, placing it on the circumference of a circle with 24 in diameter

G= number of teeth of the gear

g= number of teeth of the pinion

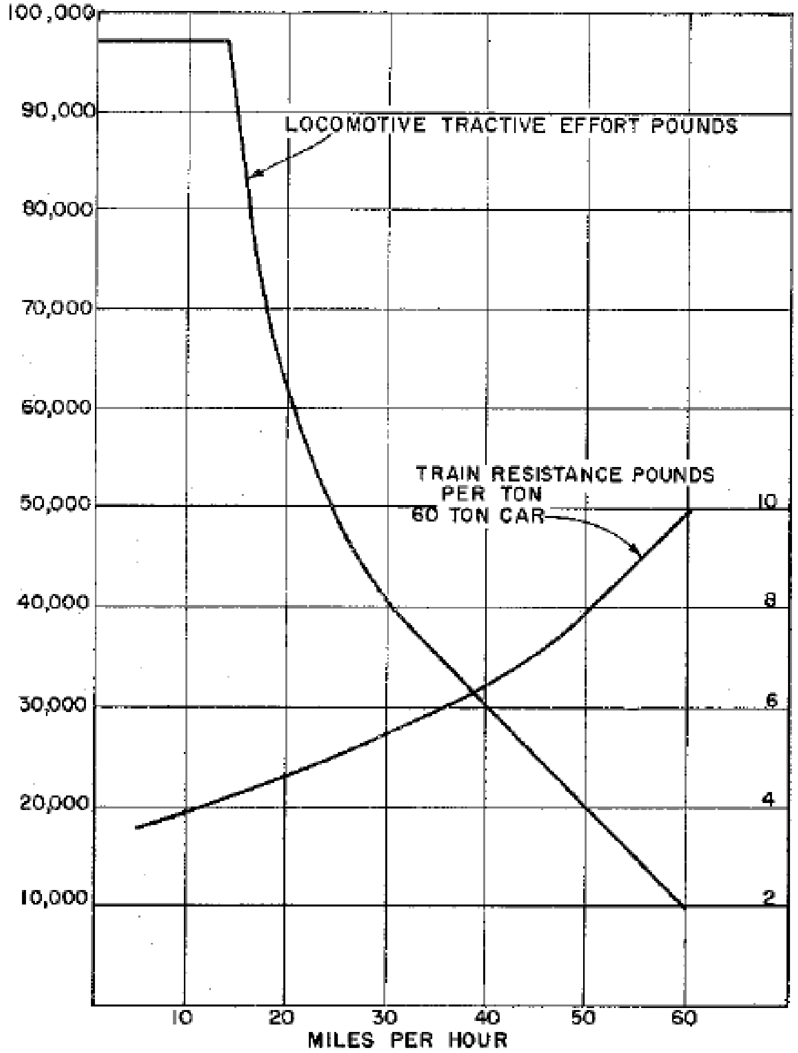
η = mechanical efficiency of gear transmission = 96%

N = number of motors

Draw Bar Pull

DBP $= P_a$ = Tractive effort – Total resistances

DBP= Te - Rt



Ruling grade

the grade which limits the maximum weight of train which can be hauled by a given locomotive and which may not be the same as the maximum gradient if the latter is so short that an entire train is not on it at the same time or if its effect is reduced by momentum

$$Te \geq (Rt + Rg + Rc) \cdot W$$

$$\text{Ruling grade} = Rg + Rc$$

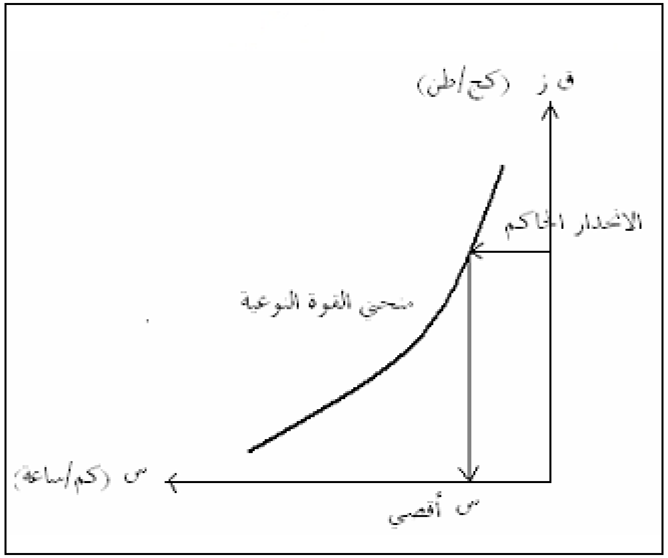
$$Te = Rt \cdot W + Rg \cdot W$$

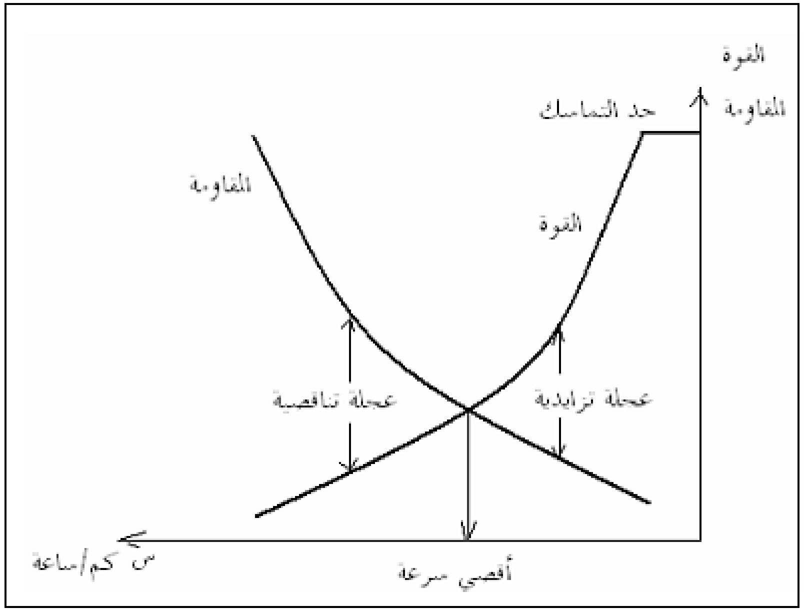
$$Rg = \frac{Te}{W} - Rt$$

تحديد أقصى سرعة :

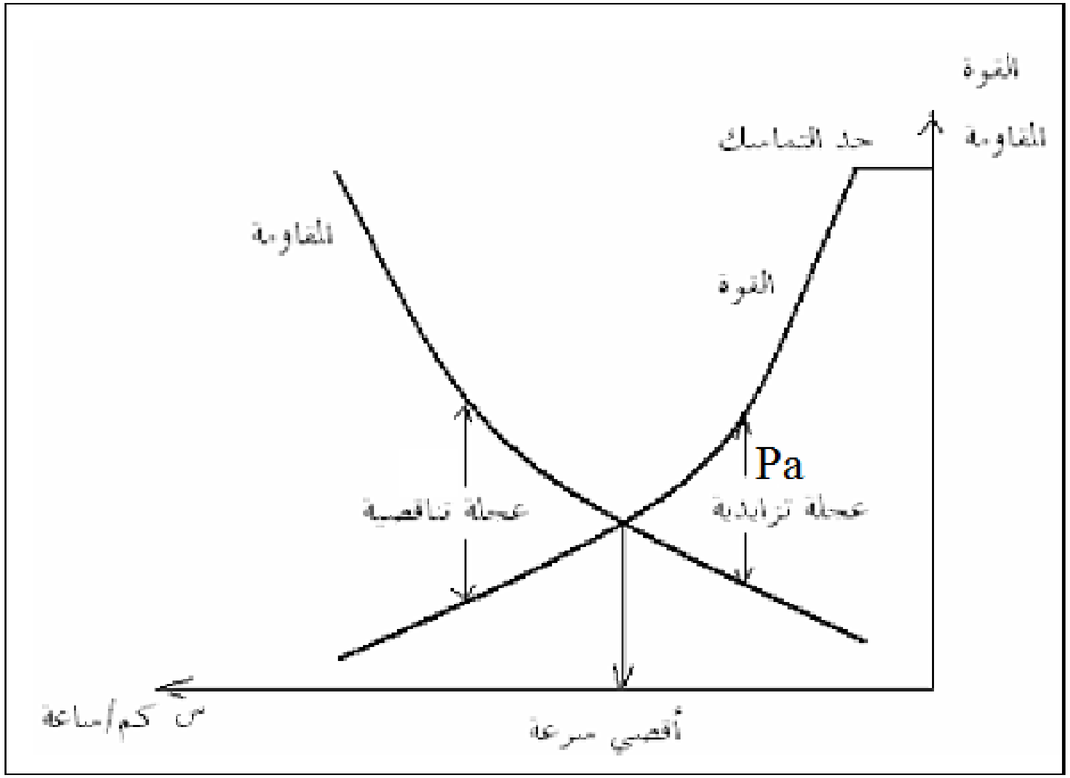
أ- للحصول علي أقصي سرعة علي الانحدار بمعلومية الانحدار الحاكم ومنحني القوة النوعية: نرسم العلاقة بين السرعة والقوة الزائدة ، ونضع الانحدار الحاكم يساوي القوة الزائدة فنحصل من المنحنى على أقصى سرعة .

ب- للحصول علي أقصي سرعة علي الانحدار بمعلومية منحني قوة الجر ومنحني المقاومة: نرسم العلاقة بين القوة والسرعة ثم على نفس المحاور نرسم العلاقة بين المقاومات الكلية والسرعة ومن نقطة تقاطع المنحنيين نحصل على أقصى سرعة.





Force of Acc. & Deceleration



$$Pa = \frac{70}{L} \left(V_2^2 - V_1^2\right) \qquad \text{lb/ton}$$

$$Pa = \frac{70}{L} W \left(V_2^2 - V_1^2\right) \qquad \text{lbs}$$

$$L = \frac{70}{Pa} W \left(V_2^2 - V_1^2\right) \qquad \text{ft}$$

Time and distance needed for Acc. & Deceleration

$$t` = \frac{95.6}{Pa} (V_2 – V_1) \qquad \text{sec}$$

$$L= 1.3 \left[\frac{70}{A} (V_2^2 – V_1^2) +1.467\, V \,.\, t_b \right] \qquad \text{ft}$$

$$t = 1.3 \left[\frac{95.6}{A} (V_2 – V_1) + t_b \right] \qquad \text{sec}$$

t_b = 1 sec for passenger trains

= 6 for freight trains

A = sum of forces acting on the train during braking from V_1 to V_2 in lb/t

$$A = \frac{W_e \cdot R \cdot e \cdot f + R_t}{W} \pm R_g$$

Where:

- W= total weight of train in lbs
- R_t = total train resistance on a level straight
- R_g = grade resistance lb/t
- R= braking ratio
- W_e = empty weight in lbs
- e = efficiency factor
- f= coefficient of friction between revolving wheel and brake shoe

V_1 mph	ef %
10	22.5
20	19.2
30	15.8
40	13.5
50	12.5
60	12.25
70	12.10