Adhesion Limitation and Tractive Requirements

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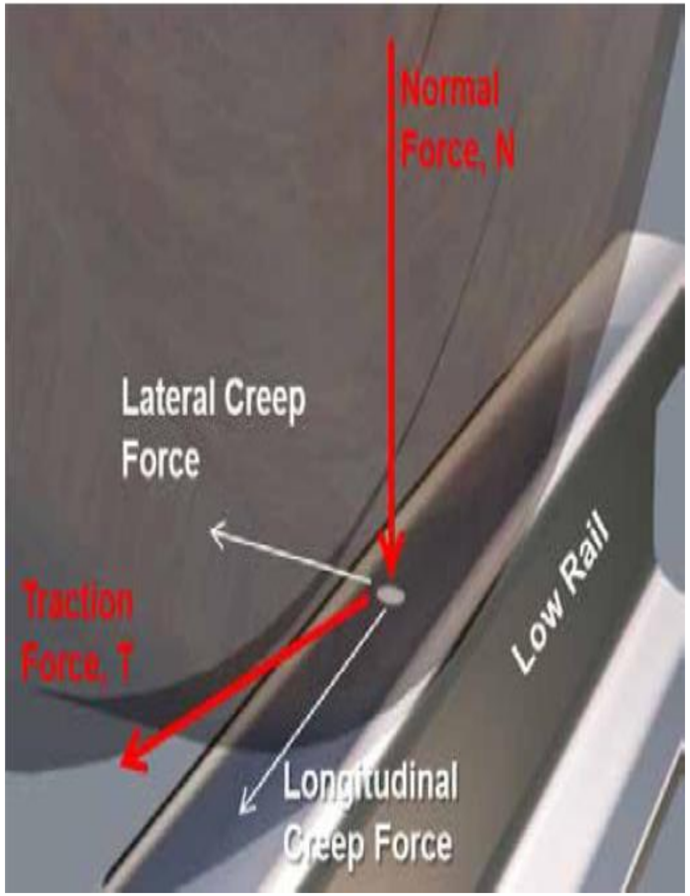
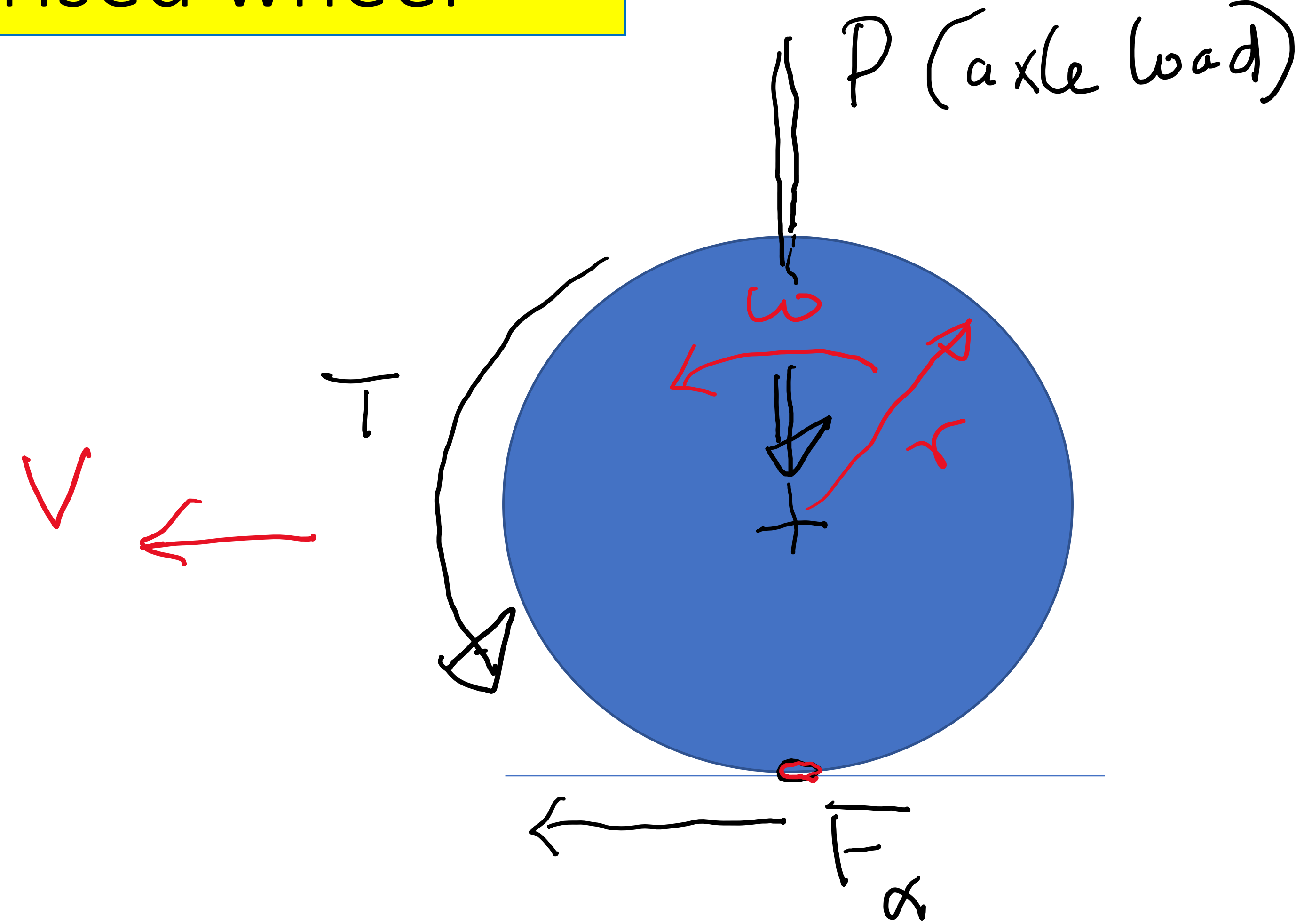
The Wheel/Rail Interface

Rail Wheel Contact

- The contact patch typically forms an **elliptical area** where the wheel touches the rail and transfers longitudinal, vertical and lateral forces.
- In normal centre tracking conditions, the wheel tread and rail contact at a single contact patch.
- Contact area, displacement and normal contact force : ***Hertz contact theory.***
- In the tangential direction, the creepages and the creep forces :***Kalker's creep theory***.

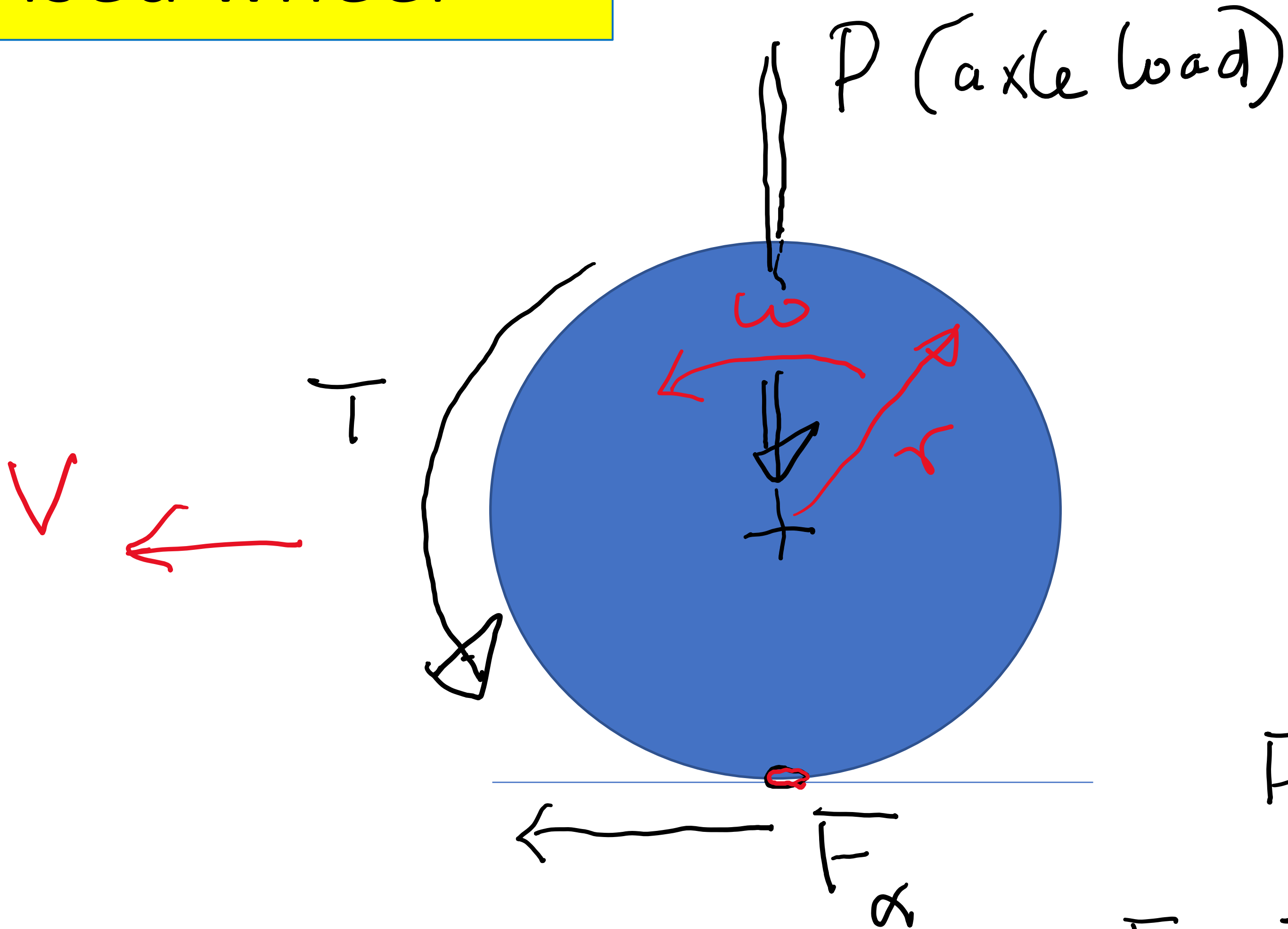


Motorised wheel



$v < \omega r$

Motorised wheel



$$v < \omega r$$

$$S = \frac{v - \omega r}{v}$$

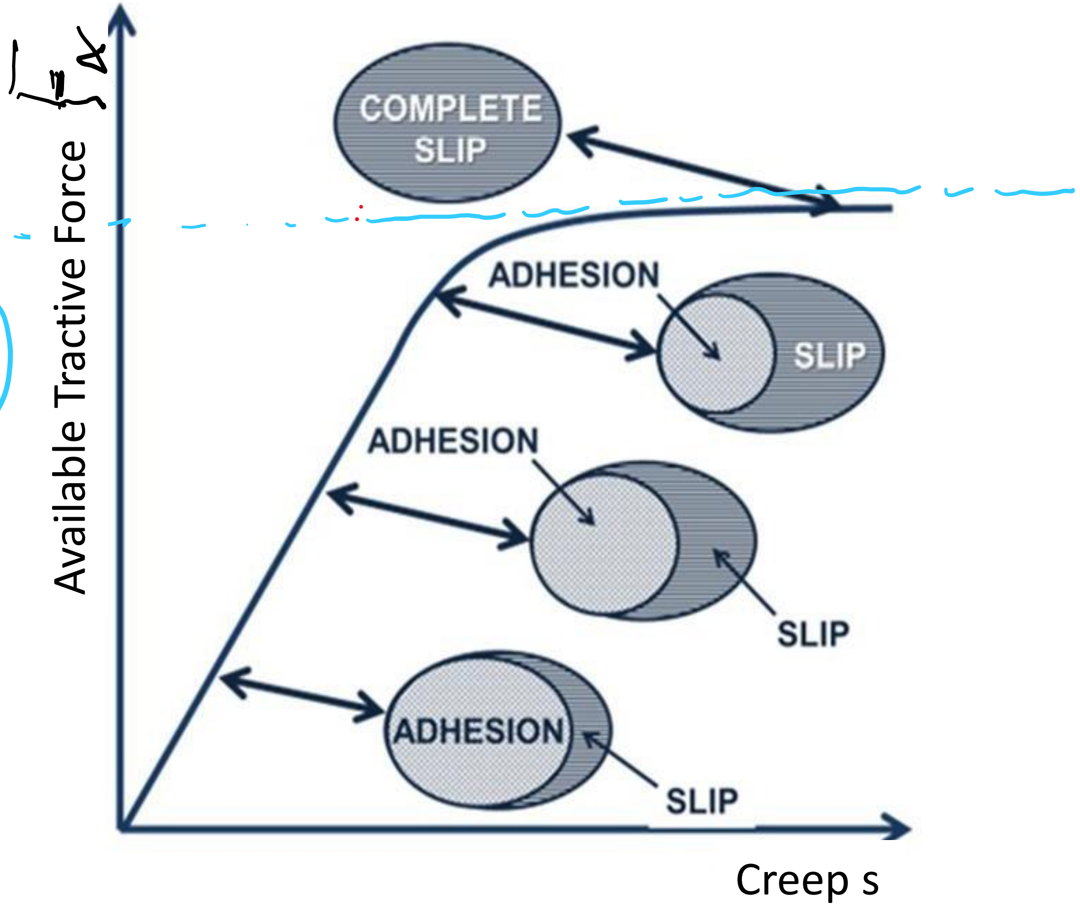
$$F_\alpha = Fn\{P, s\}$$

$$F = T/r \leq F_\alpha$$

Available Tractive Force/Available Adhesion

μP

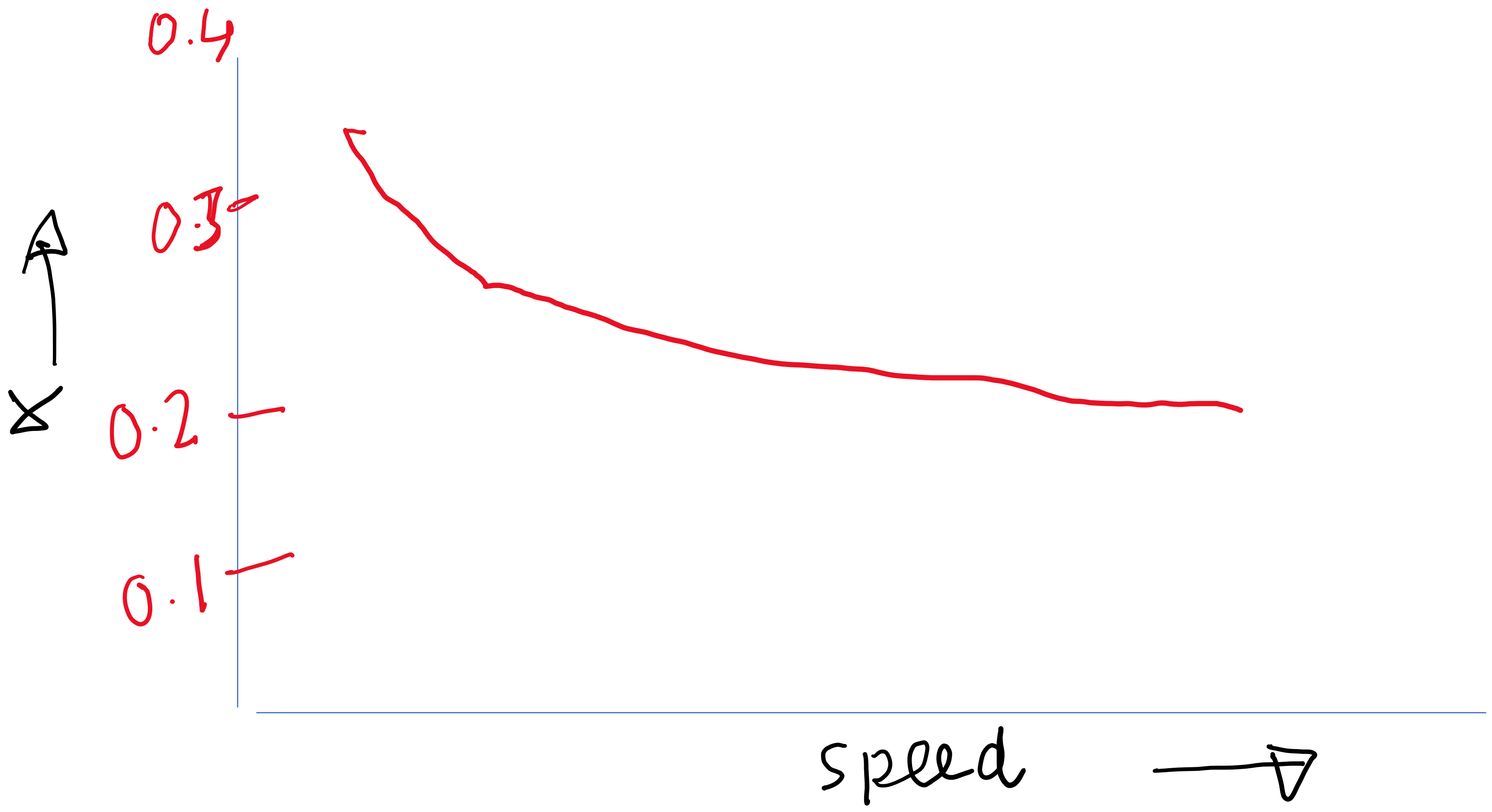
$(0.4P)$



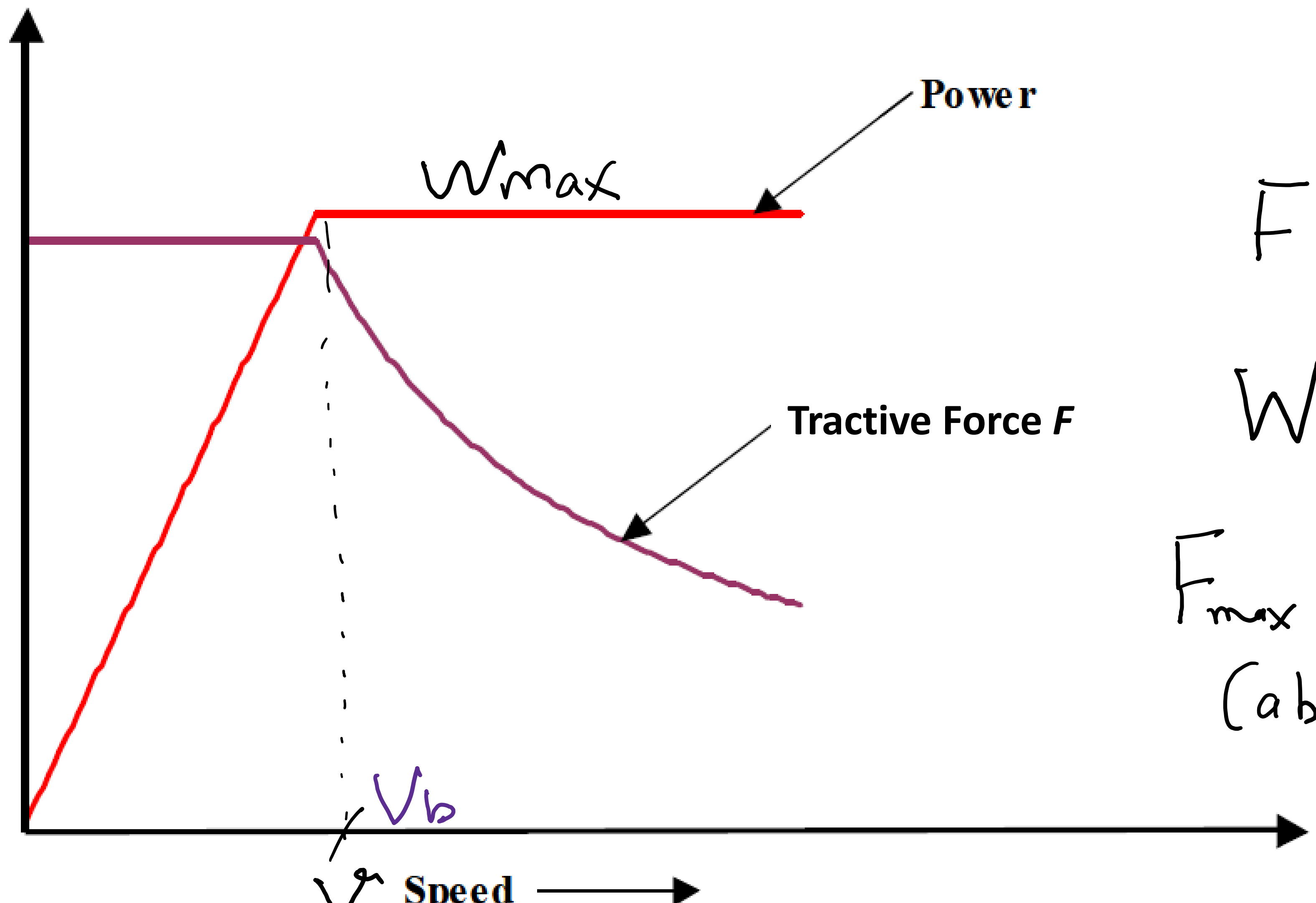
For a given P

$$\alpha = \frac{F_\alpha}{P}$$

Available Adhesion; Variation with speed



TE and Speed Curve



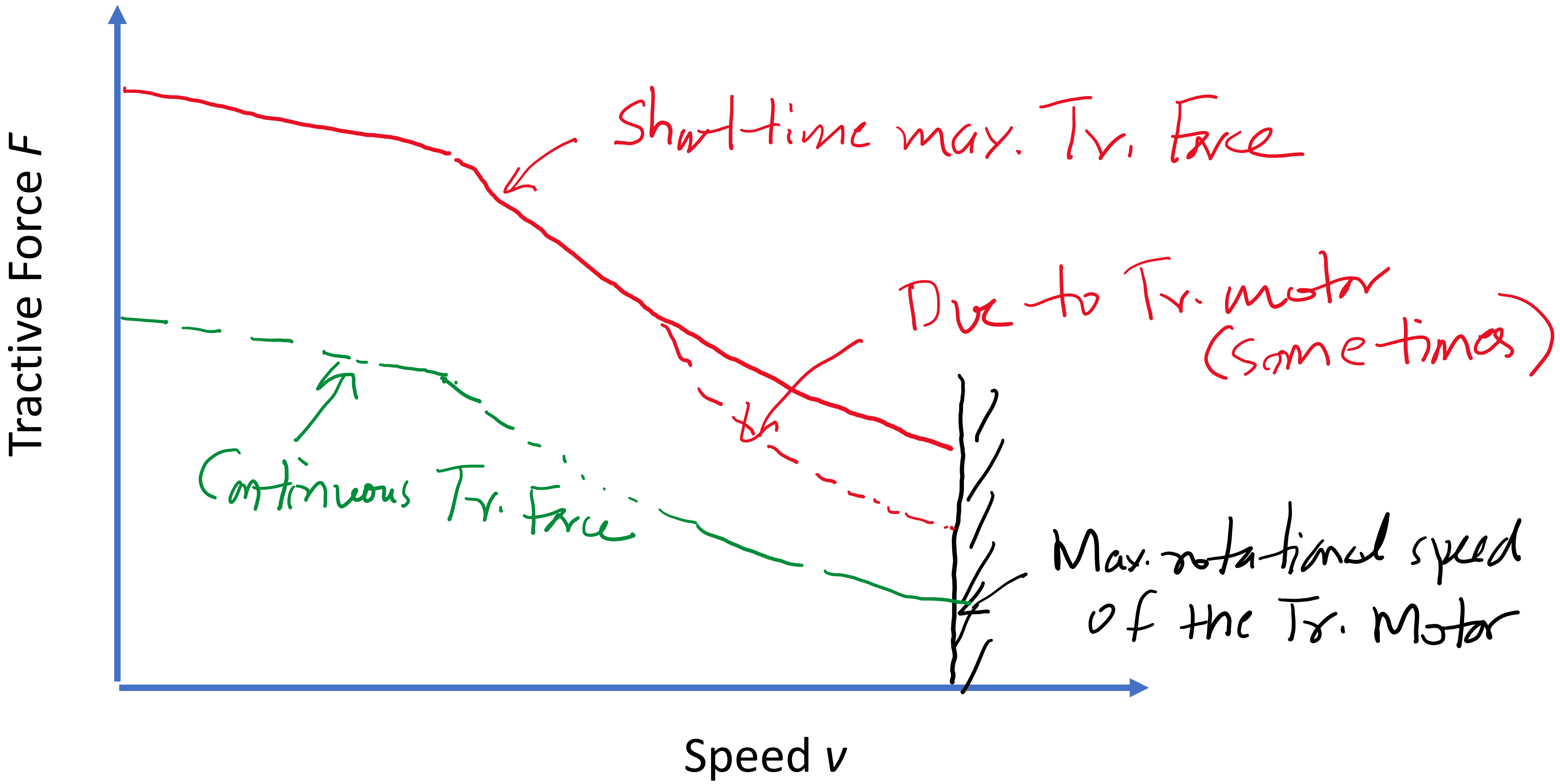
$F = T/r$

$W = F.v$

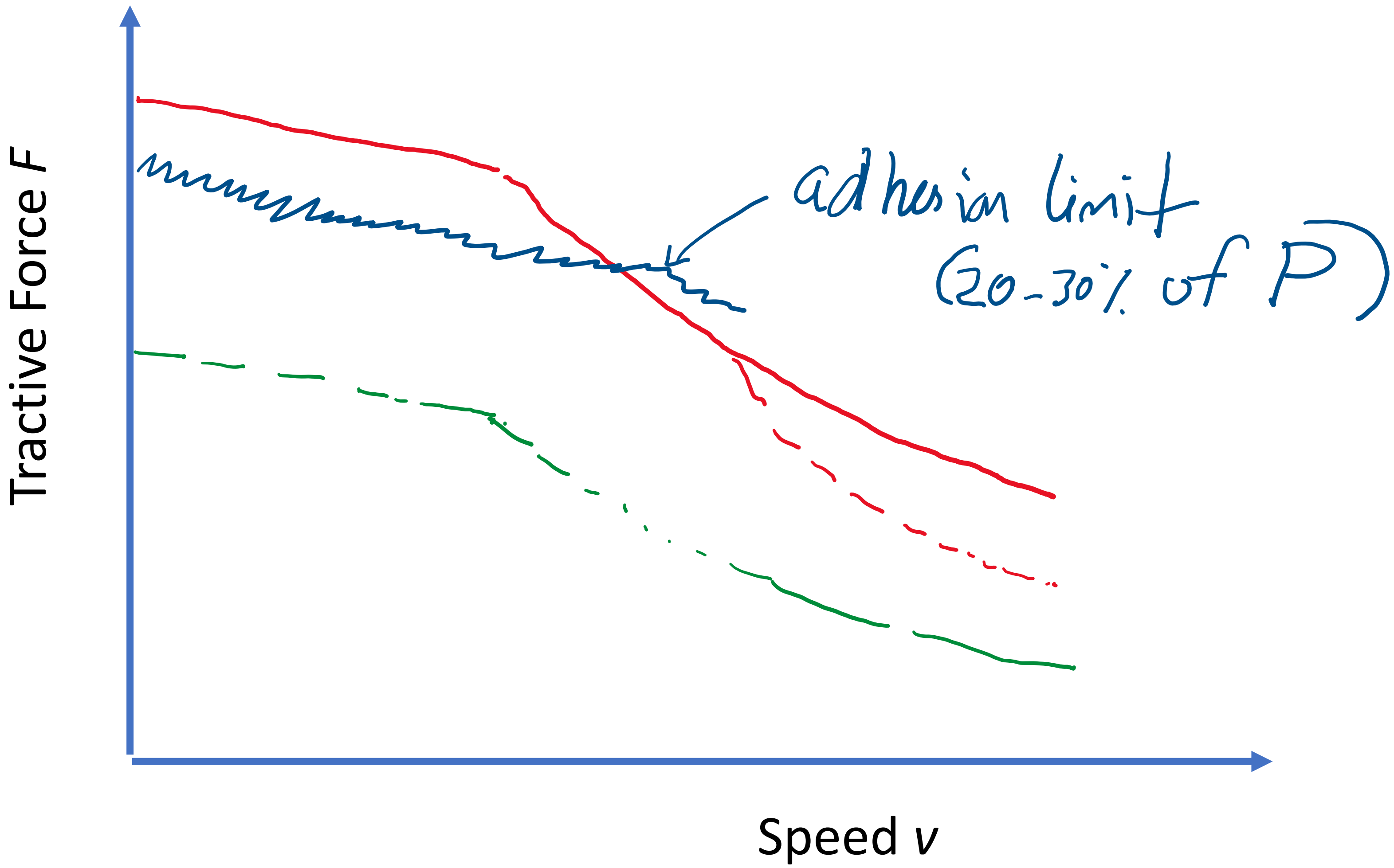
$F_{max} = W_{max}/v$

(above the base speed)

Short term rating/ Continuous rating



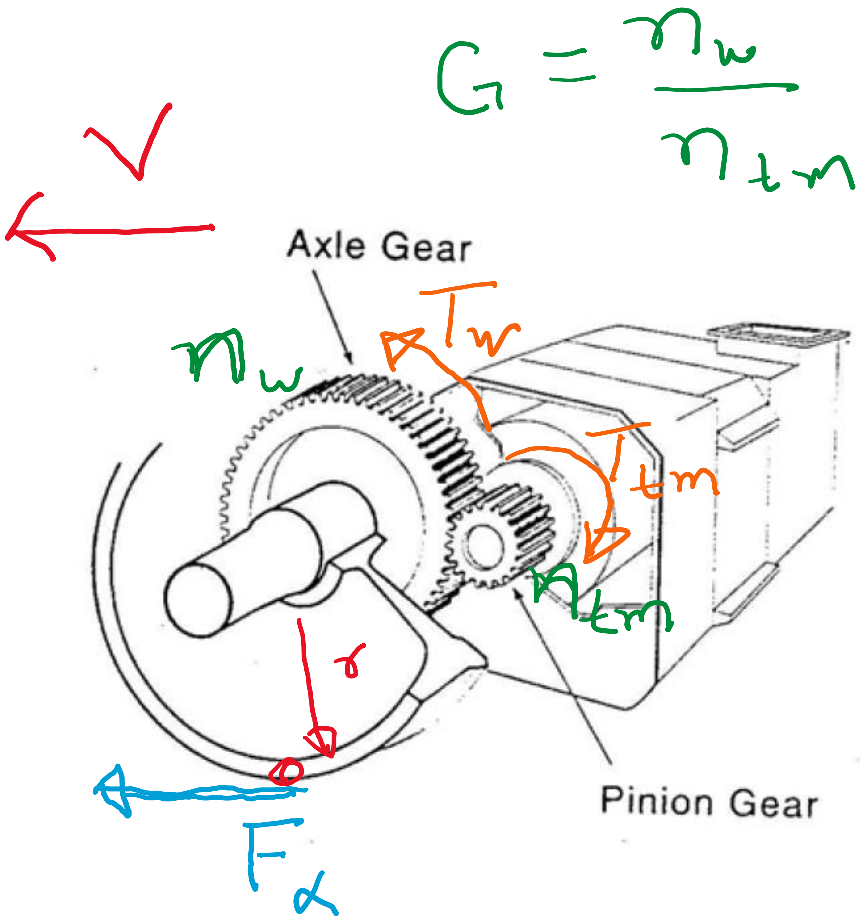
Adhesion limits



Factors affecting Tractive Effort

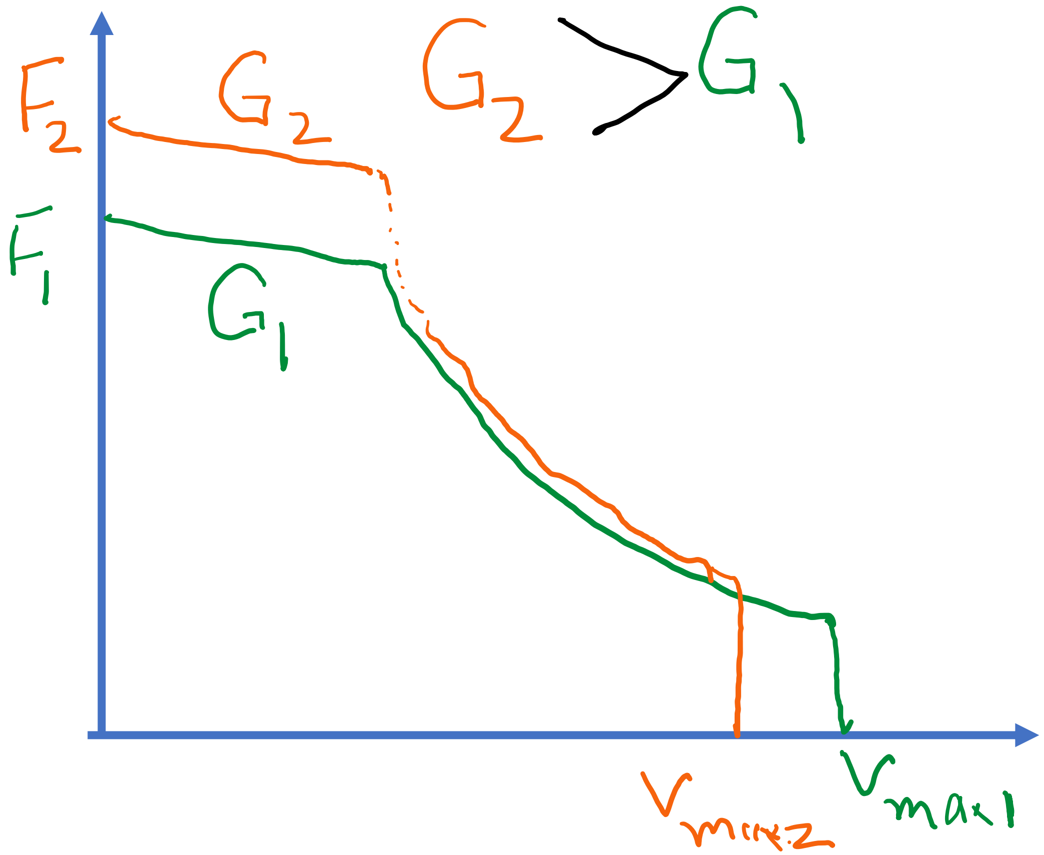
- Power Rating and ability of the traction motor
- Gear Ratio
- Weight on the driving wheels
- Rail condition
- Wheel slip control system
- Power Converter System

Gear Ratio



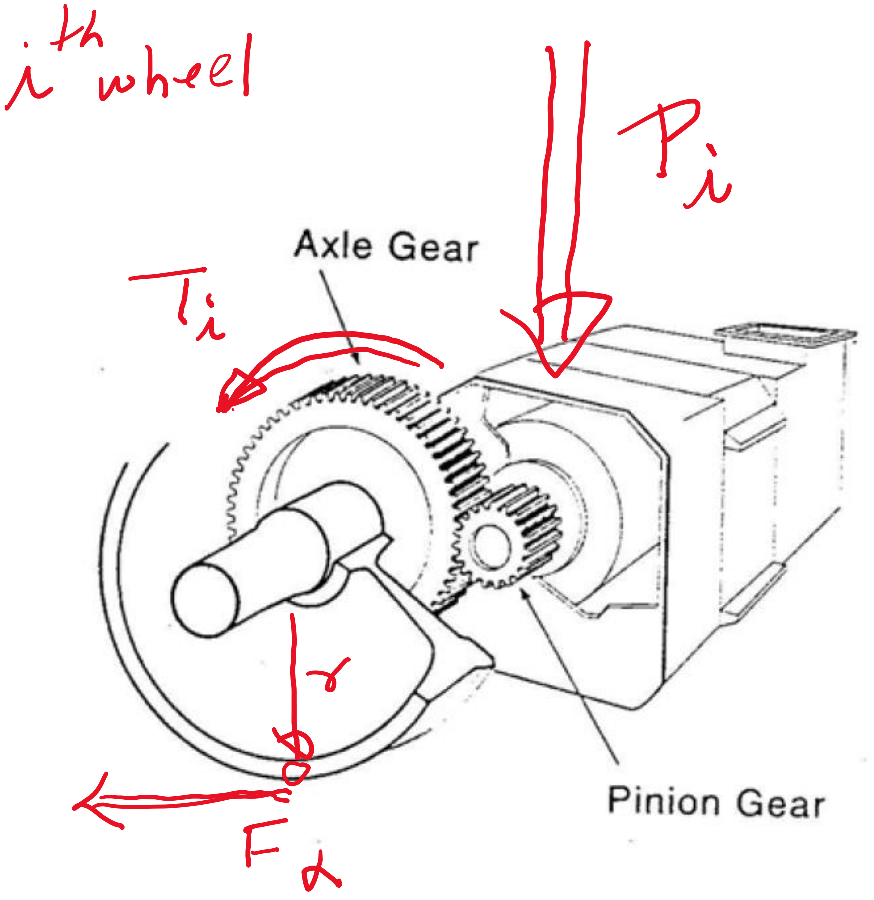
- $F_{\alpha} = \frac{T_w}{r} = \frac{T_{tm} * G * \eta_g}{r}$
- $Power\ W\ = T_{tm} * \omega_{tm} = T_{tm} * \frac{2\pi N}{60}$
- T_{tm} is approximately proportional to the volume of the rotor
- High W can be achieved by high torque or high rotational speed or both
- Motor speed $N\ = G * \frac{v}{r} = G * \frac{2.65\ V}{r}$

Gear Ratio



- Increasing the gear ratio
  - increases the maximum TE but reduces the maximum speed.
- Decreasing the gear ratio
  - increases the maximum speed but decreases the maximum TE
- $\frac{F_1}{F_2} = \frac{G_1}{G_2}$
- $\frac{v_{max1}}{v_{max2}} = \frac{G_2}{G_1}$

Wheel Slip Control System



- If $T_i > \propto_{max} * r * P_i$, then rapid slipping
  - Coupling of wheels by mechanical rods
  - Control by different speed of the axles (taking the actual wheel dia into account)
  - Control by real overspeed of the vehicle (radar based)
  - Control by rate of change individual axle speeds
  - Control by the number of occurred slip indications
- In AC motors, supply frequency and/or voltage to the stator is reduced which reduces the motor torque

Traction Vehicle

$6F_\alpha$- $(D+T_r)= m_{tr}\ a_x$

$6\alpha P_i$- $(D+T_r)= m_{tr}\ a_x$

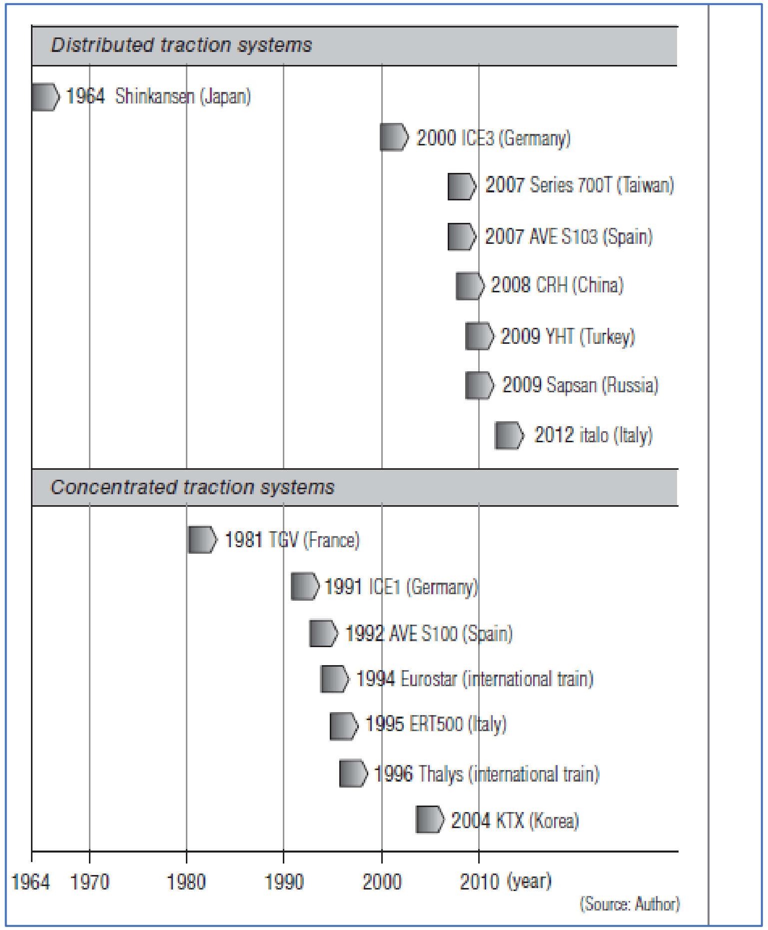
$n\alpha P_i$- $(D+T_r)= m_{tr}\ a_x$

$\alpha \boldsymbol{nP}_i$- $(D+T_r)= m_{tr}\ a_x$

More adhesive mass in case Of DPRS

Distributed Power/Concentrated Power

- The distributed traction system has many advantages
  - energy efficiency
  - light axle weight
  - high acceleration and deceleration due to large number of driving axles
  - more cabin space as there are no locomotives
  - and ability to utilize the energy of regenerative braking efficiently



Ref: Akiyama et al.

Use of Tractive Force

- Running Resistance

$(D = D_R + D_A + D_C + D_G)$

- $D_R + D_A = \mathbf{A} + \mathbf{B}\, v + \mathbf{C} v^2$

- Acceleration of the train

Rolling Resistance

- Rake Rolling resistance in kg/t
    - r_1= Journal Resistance + Flange Resistance + Air Resistance
- r_1 *increases as speed increases and it decreases when weight increases*.
- For loaded BOXN wagons at speed of ***v*** Kmph

r_1= 0.6438797 + 0.01047218 v + 0.00007323 v^2

- For loaded ICF coach

r_1 = 0.6854599 + 0.0211244 v + 0.000082 v^2

- $R_1(Kg) = r_1 * weight\ of\ the\ rake\ (Tonnes)$
- Locomotive Resistance (r_2) in kg/t

r_2 = 0.647+ (13.17 / W) v + 0.00933 v + (0.057 / WN) v^2
where N is number of Axles, W is axle load of the locomotive in tonnes

- $R_2(Kg) = r_2 * weight\ of\ the\ locomotive\ (Tonnes)$
- $D_R + D_A = R_1 + R_2$

Rolling Resistance

- Starting rolling Resistance of BOX N wagon is taken as 4.0 kg/t including Acceleration Reserve.

- Starting Rolling Resistance of a locomotive/ICF coach is taken as 6.0 Kg/t including Acceleration reserve.

Curving Resistance and Grade Resistance

- D_C(kg) = 0.4 * Degree of curvature S * (rake load tonnes+loco wt.in tonnes)

Where Radius of curvature (mtrs) = 1747/S

- D_G(kg) = (1 / G) * 1000 * (rake load in tonnes +loco wt. in tonnes).
- Curving Resistance and Grade resistance are independent of speed.

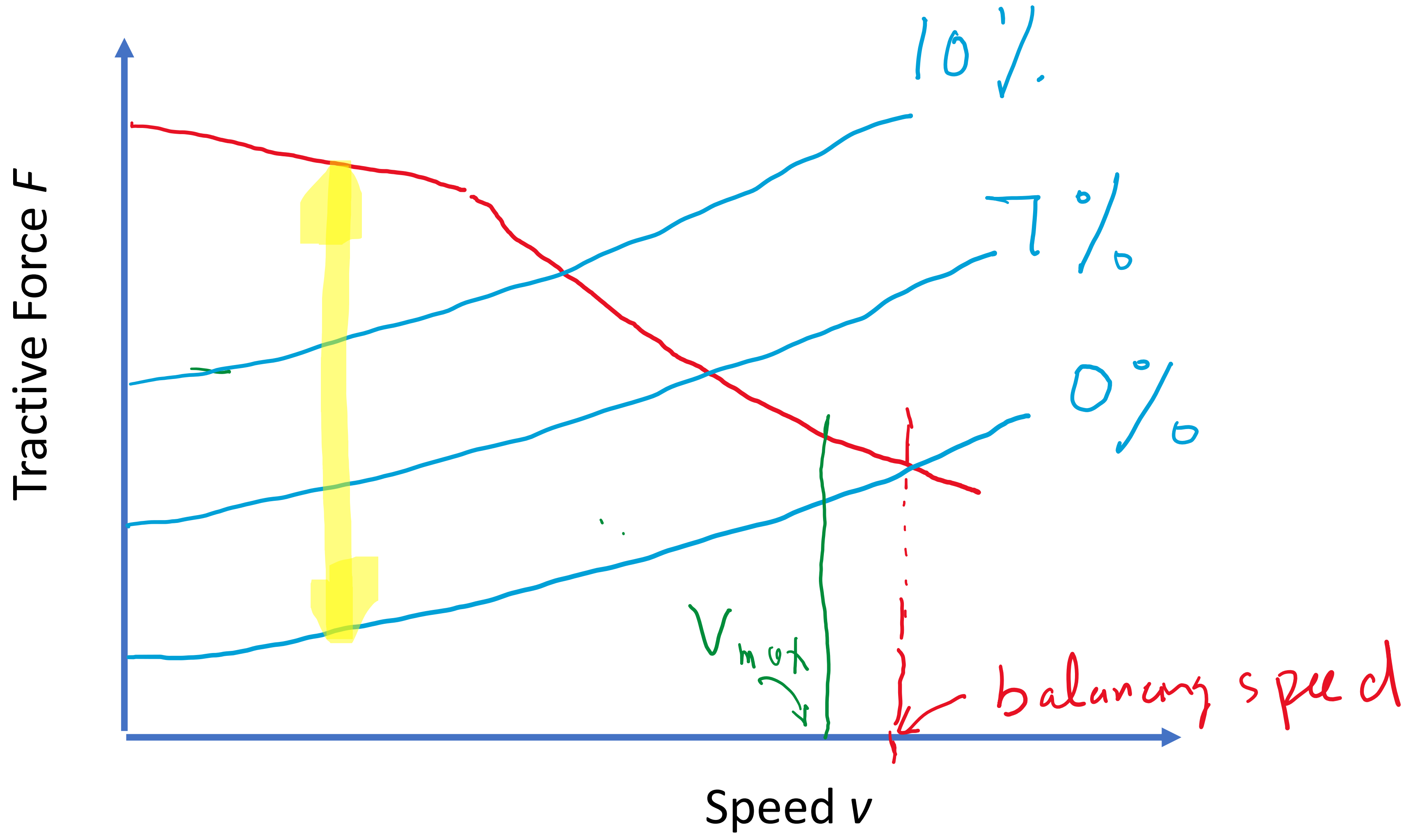
Running Resistance example

- Load = 4700T (BOXN), Grade= 1/200, Curvature= 2 degree, Speed = 50 km/h,

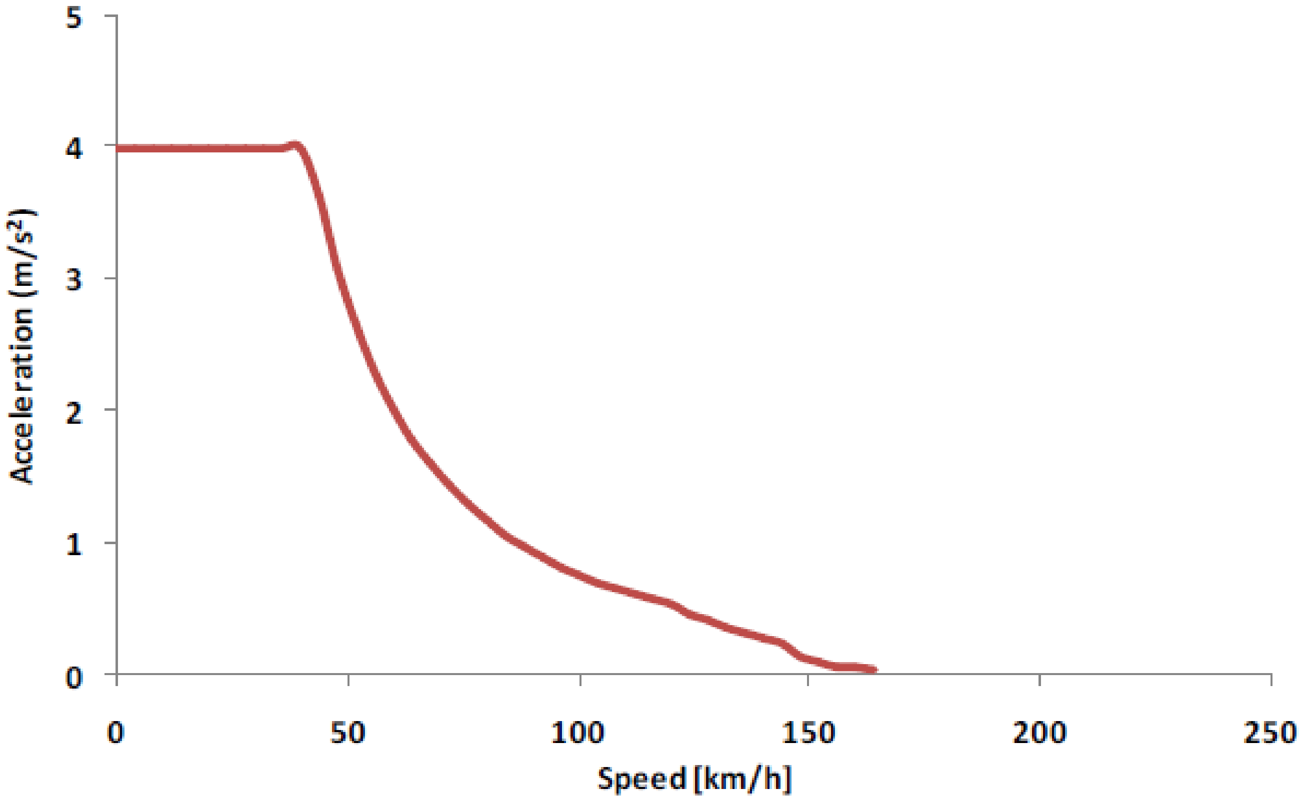
Locomotive= WAG9 (123t)

- **Starting load**
- $D_R + D_A = D_R$= 4700*4 + 123*6= 18800+738= 19538 kg
- D_C= 0.4*2*4823= 3858.4 kg
- D_G= (1/200)*4823*1000 = 24115 kg
- D = 47511.4 kg = 47.51t
- **At 50 km/h**
- $D_R + D_A$= 4700*1.3505 + 123*2.913= 6347.35+358.3= 6705.65 kg
- D_C= 0.4*2*4823= 3858.4 kg
- D_G= (1/200)*4823*1000 = 24115 kg
- D = 34679 kg = 34.679t

Running Resistance



Acceleration vs Speed



Traction Requirements of different Traction Stocks

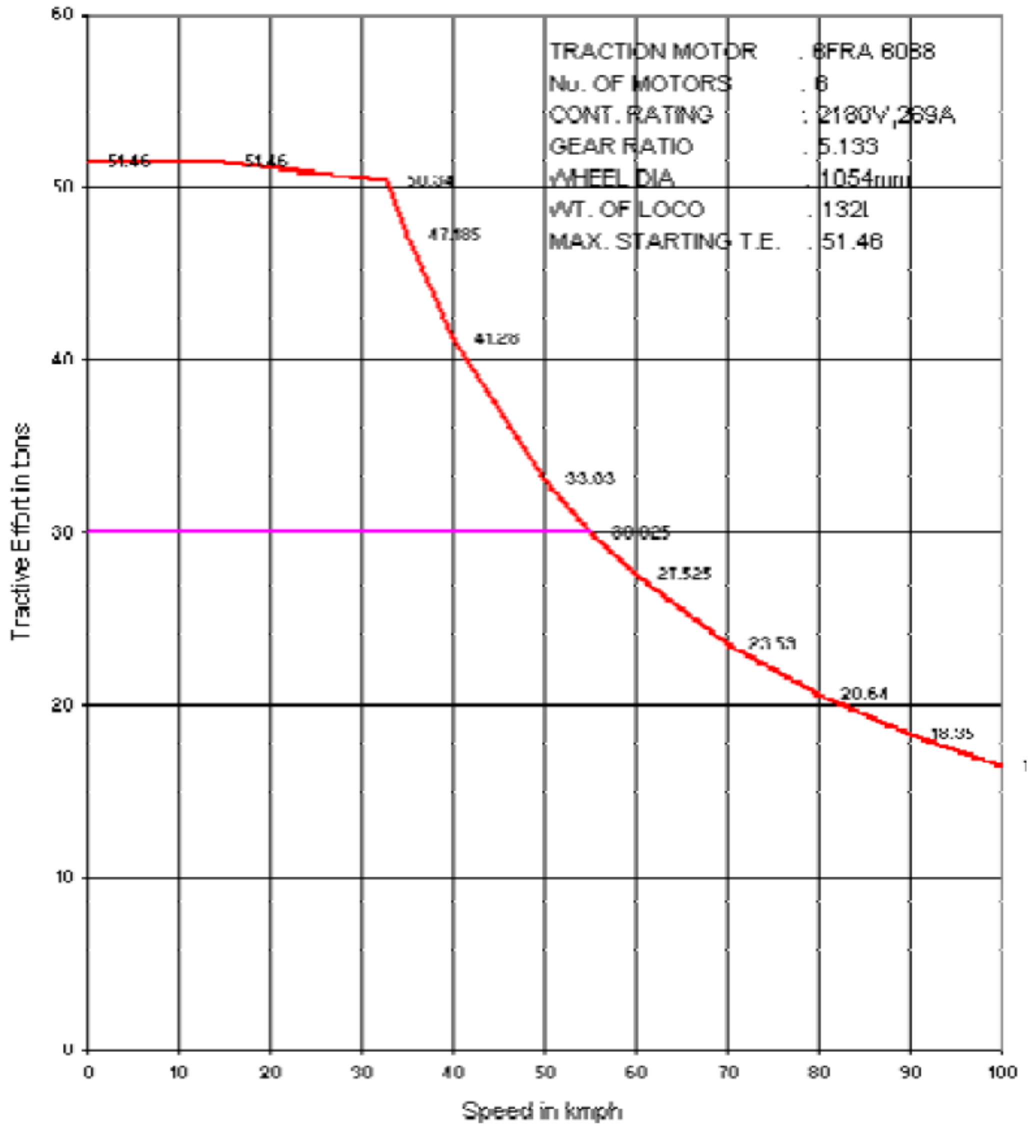
Requirement of Tractive Effort for different applications

- Starting Load
- Running Resistance (Grade and Curve)
- Short term load (Magnitude and Duration)
  - Stoppage Intervals, Grade and Curves
- Continuous load (Magnitude and Duration)
  - Span
- Maximum Speed
- Maximum Starting Acceleration

TE vs Speed Curves for Locomotives

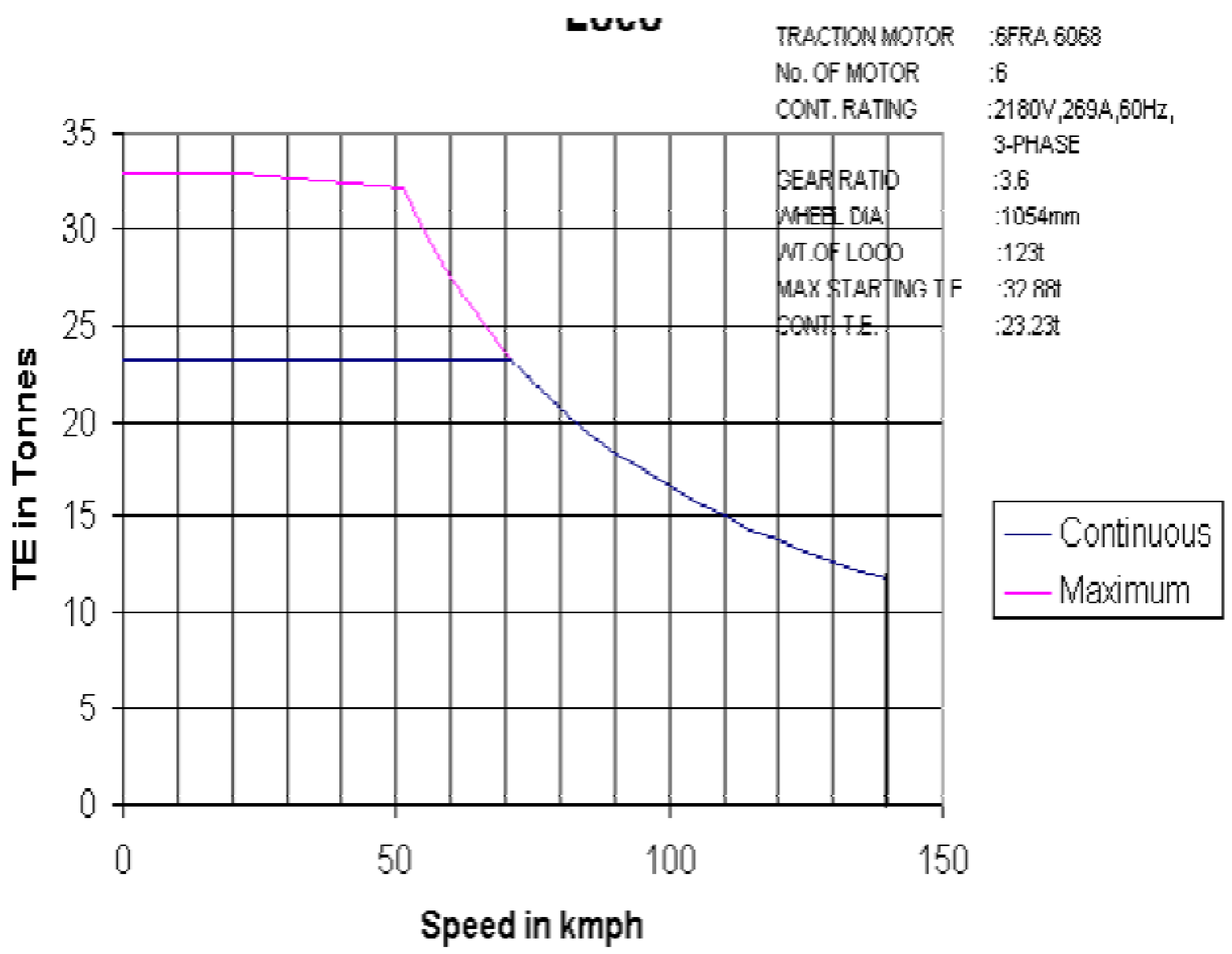
Freight Locomotives

WAG9H

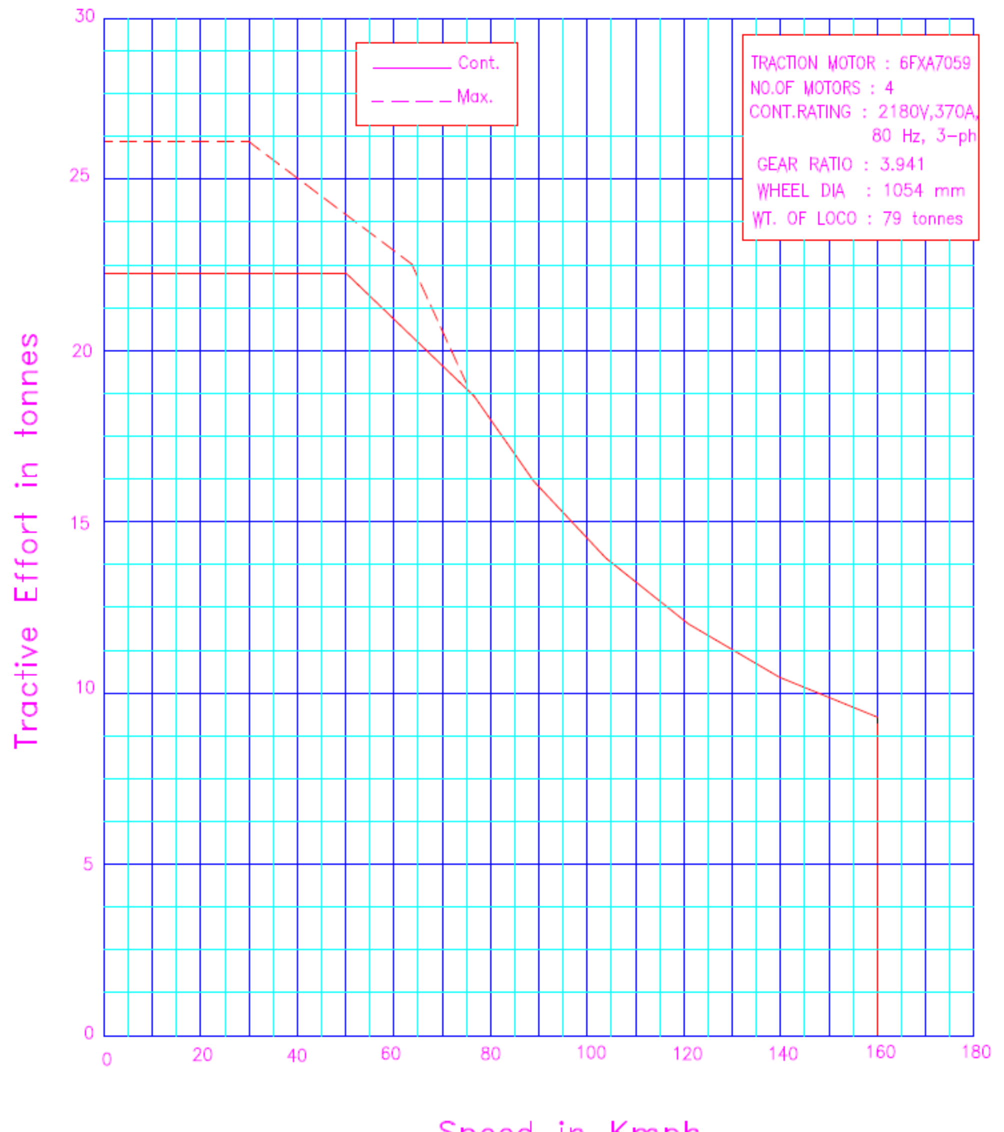


Passenger Locomotives

WAP 7



WAP 5



Locomotives: A comparison

Loco	TM	Gear Ratio	New wheel dia	*Max. designed current limit for TM (Amp)*	*Short term current rating for TM*	*1 hr rating*	*Continuous rating*	Max. designed TE (t)	Short term rating TE (t)	1 hr rating TE (t)	Continuous rating TE (t)	Power/ Loco (KW)
WAG-9H (132t)	FRA 6068, **100 kmph**	5.133	1092	***393A***	***370A***	***290A***	***270A***	50.85 t	50.3 t	35 t	35 t	**4736 KW**
WAP-5 (78 t)	FXA7059, 160 kmph	3.941	1092	***593A***	***540A***	***396A***	***370A***	28.29 t	28.06 t	20.99 t	19.6 t	**4210 KW**
WAP-7 (123t)	FRA 6068, **140 kmph**	3.6	1092	***393A***	***370A***	***290A***	***270A***	35.66 t	35.28 t	27.68 t	24.54 t	**4736 KW**
E40AC Siemens, Germany	Heavy haul,Multi, **80 kmph**	5.41	Adhesive mass = 132 t					52.5 t			45 t	**4000 KW**
Oresund link, Sweden	Medium freight, **140 kmph**	Adhesive mass = 132 t						40 t				**6500 KW**
Iron ore line, Sweden	Heavy freight, Multi, **80 kmph**	Adhesive mass = 300 t						120 t	135 t			**10800 KW**

Distributed Power Traction Stock

European Scenario

Service	Features	Eg.	Max TE	Max short term power	Powered axles	Train mass	Starting accn	Max speed
Fast regional and intercity EMU's	Frequent stops (10-30 km) Have to accelerate to high speeds (180-220 kmph)	Class BM71 (Norway)	15.8 t	3535 KW	8/16	215 t	0.65 m/s^2	210 km/h
Regional and Intercity DMU's	Frequent stops (10-30 km) Have to accelerate to high speeds (140-200 kmph)	Class 172 Turbostar (UK)	11.5 t	1086 KW	6/12	135 t	0.75 m/s^2	160 km/h
Commuter EMU's for heavy city service	Frequent stops (2-6 km) Have to frequently accelerate 10-40 km span Speed often maintained up to 40-60 kmph top speeds (120- 160 kmph)	Class X60 Sweden	34.3 t	4300 KW	12/14	206 t	1.2 m/s^2	160 km/h
Metro cars	Frequent stops (0.7-2 km) Span 15 km Have to frequently accelerate Speed often maintained up to 40-50 kmph top speeds (80- 100 kmph)	Class C20 Sweden	12.7 t	1592 KW	8/8	70 t	1.3 m/s^2	90 km/h

Indian Scenario

Service	Eg.	Consist	New wheel dia	Max TE	Powered axles	Train mass	Starting accn	Max speed	Balancing Speed	Gear Ratio
Fast regional and intercity EMU's	Onboard Equipment MEMU	DMC+ 3TC 2 basic units	952 mm	42 t	8/32	720 t	0.5 m/s^2	110 km/h	132.5 km/h	
Regional and Intercity DMU's	1600 HP DMU	1DPC+4TC	952 mm	16 t				110 km/h		
Commuter EMU's for heavy city service	Bombay EMU	12 car train Four units of 03 cars	952 mm	52.5 t	16/48	884 t	0.54 m/s^2	110 km/h		
Metro cars	DMRC	4M2T	820 mm	51.1 t	16/24	401 t	1.24 m/s^2	85 km/h		6.789
Train 18		16 coaches 4 basic units	952 mm	80 t	32/64	958 t	0.7 m/s^2	160 km/h	184 km/h	5.158

An overview of Shinkansen HSR

Shinkansen in operation

Name	Operators	Manufacturer	Power supply	MaxSpeed (km/h)	Nos of cars	Operation Since
E4 Series	JR East	Hitachi,Kawasaki	25kV 50Hz AC	240	8	1997
E3 Series	JR East	Kawasaki,Tokyu Car	20/25kV 50Hz AC	275	6	1997
E2 Series	JR East	Hitachi,Kawasaki, Nippon Sharyo, Tokyu Car	25kV 50/60Hz AC	275	8	1997
500 Series	JR West	Hitachi, Kawasaki Kinki Sharyo, Nippon Sharyo	25kV 60Hz AC	300	8/16	1997
700 Series	JR Central JR West	Hitachi, Kawasaki, Kinki Sharyo, Nippon Sharyo	25kV 60Hz AC	285	16	1999
800 Series	JR Kyushu	Hitachi	25kV 60Hz AC	260	6	2004
N700 Series	JR Central JR Kyushu JR West	Hitachi,Kawasaki Kinki Sharyo Nippon Sharyo	25kV 60Hz AC	300	16	2007
E5 Series	JR east	Hitachi, Kawasaki Heavy Industries	25 kV AC, 50 Hz	320	10	2011

Technological trajectory

- The series 300 has applied lightweight technologies, such as AC drive system, aluminum alloy body, bolster-less bogie,
- The series 700 and N700 achieved further weight reduction by application of IGBT device. IGBT realized compact and lightweight traction system.
- Weight reduction is also effective on reduction of kinetic energy, which increases in proportion of mass and square of velocity.
- When velocity increases from 220km/h to 270km/h, kinetic energy becomes 150% more.
- However, 30% of weight reduction realized, like the series 300, kinetic energy increases only 5%.

Shinkansen

Train	Max TE	Max short term power	Powered axles	Train mass	Starting accn	Max speed
N 700 (16 cars)	60 t	17080 KW	56/64	715 t	0.7 m/s^2	300 km/h
E5 (10 cars)	25 t	9600 KW	32/40	453 t	0.48 m/s^2	320 km/h

Thank You