RAIL WHEEL INTERACTION

Why study this?

- To increase train speeds
- For heavy haul
- Prevent undue wear – reduce costs
- Safety, guidance and stability of vehicle
- Passenger comfort
- Energy efficiency
- Environment: emissions, noise, particulates

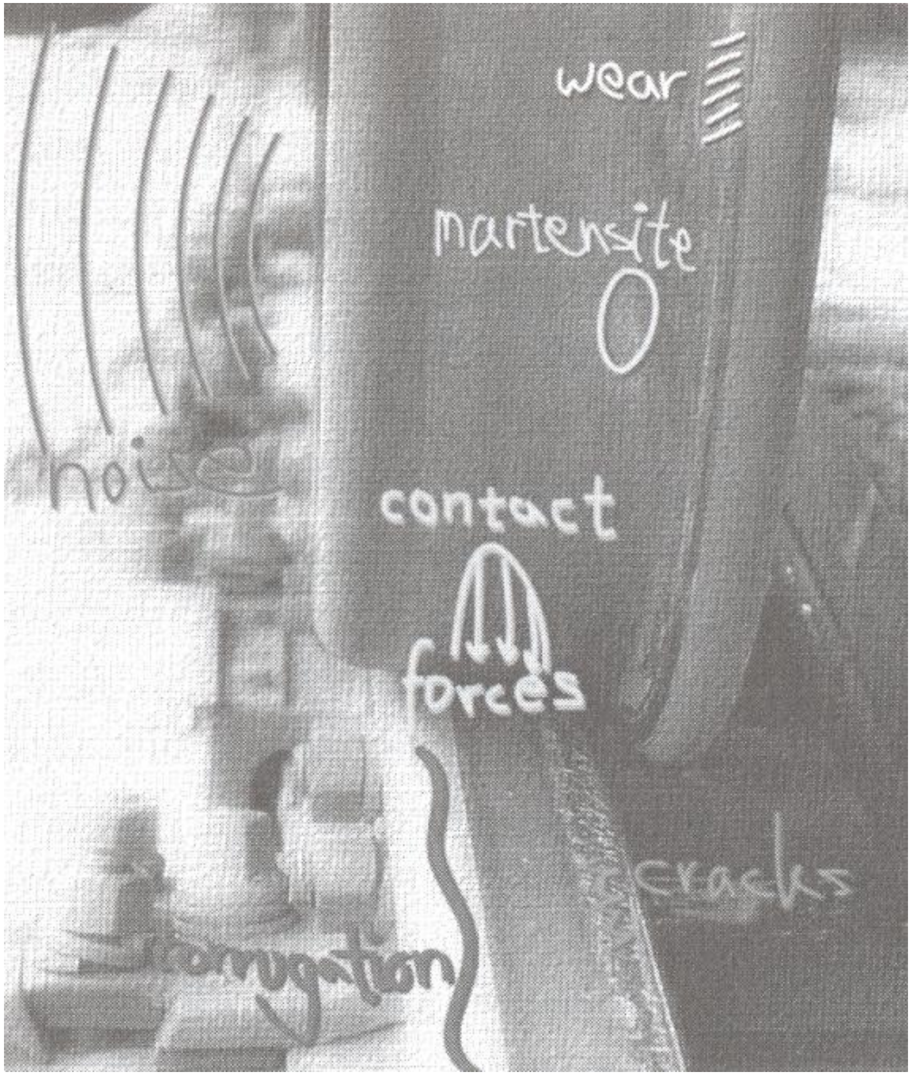
Study Paradigms

- Adhesion and friction
- Fatigue and failure
- Material science approach
- Safety approach

Difficulties

- A highly empirical subject
- Contact area cannot be directly observed
- Every passage is unique, has an effect
- Continuously changing environment
- Continuously changing geometries
- Several factors out of control
- Requires high-level computing
- Many degrees of freedom

Difficulties

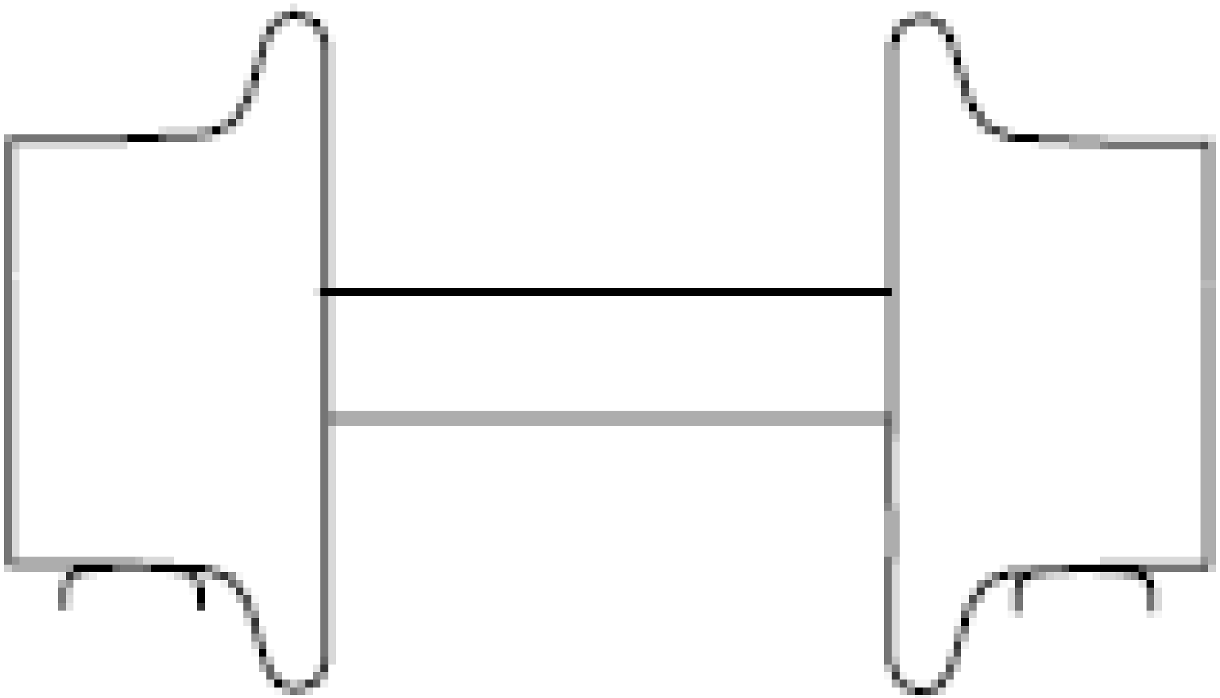


Let us now explore some very basic concepts…

The most basic wheel:

- Coned wheel – 1/20 to 1/40
- Angular velocity constant for both discs
- Flanged wheel: flange on inside
- 7-10 mm flange clearance
- Single piece or tire-on-disc
- Made of steel by casting or forging

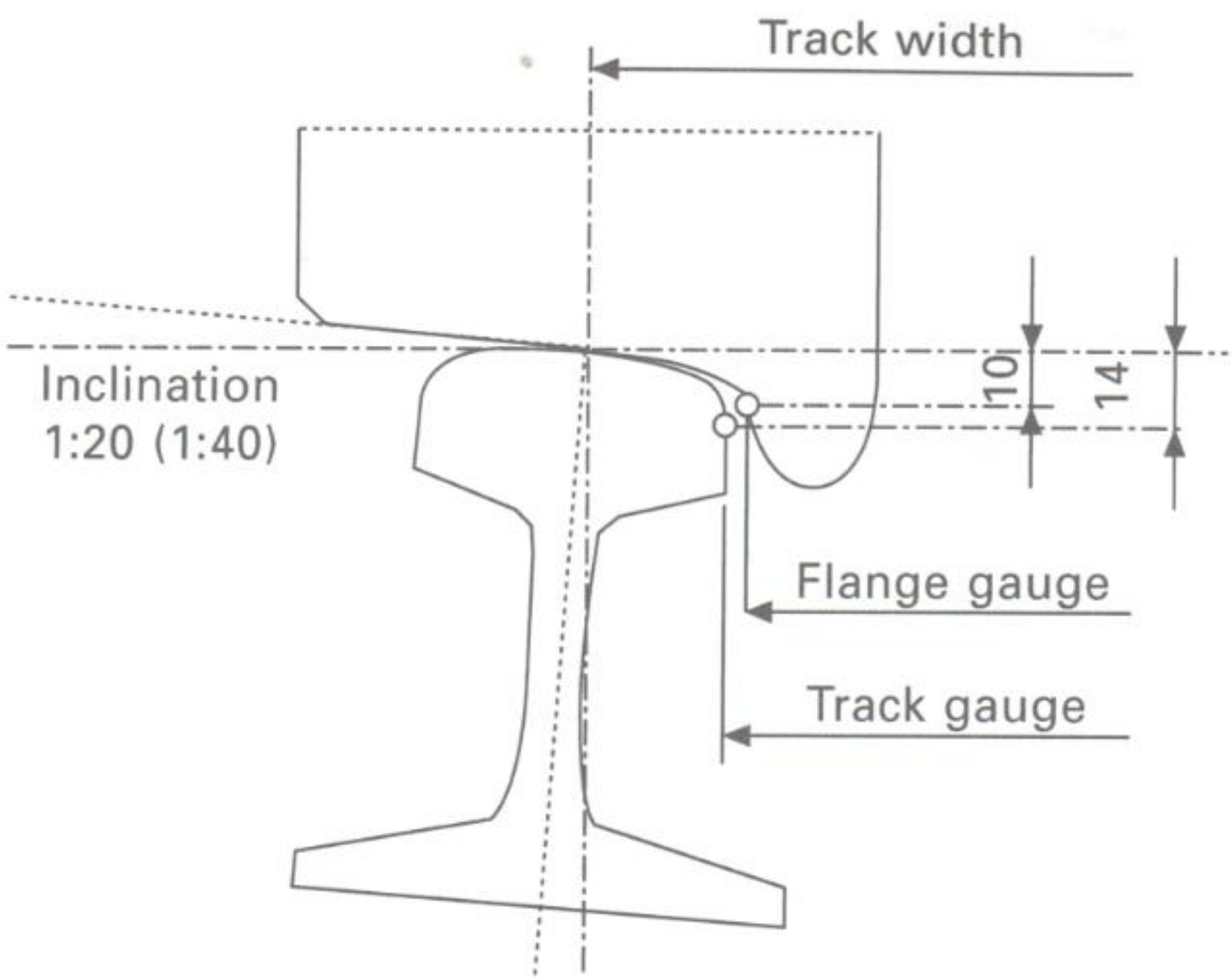
The most basic wheel:



Role of conicity + constant angular velocity

- Provides guidance on straight tracks
- At the cost of stability
- But only solution for non-parallel rails
- Mechanism of motion
- Gives rise to lateral oscillation
- And hunting
- Differential action on curved tracks
- Easy manufacturing by casting

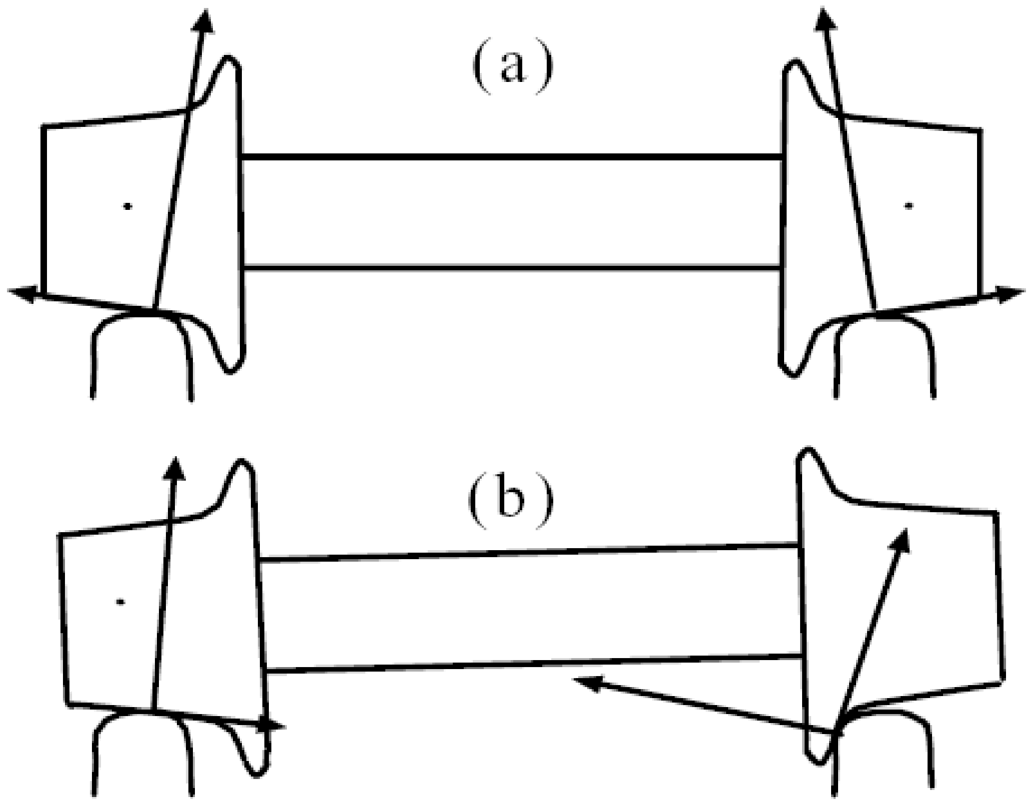
Role of conicity + constant angular velocity



Role of inside flange

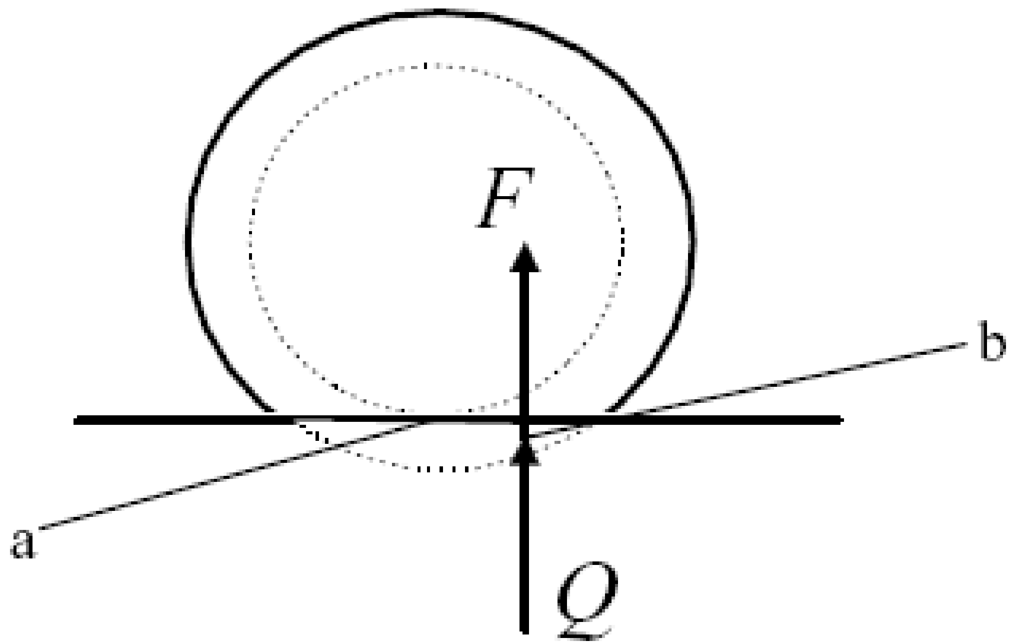
- Final restraint on curves/unusuals
- Gives guidance on curves
- Stability through gravitational stiffness

Gravitational Stiffness



Now we shall use these pieces of information to derive a simplistic derailment model…

Simplistic Derailment Model



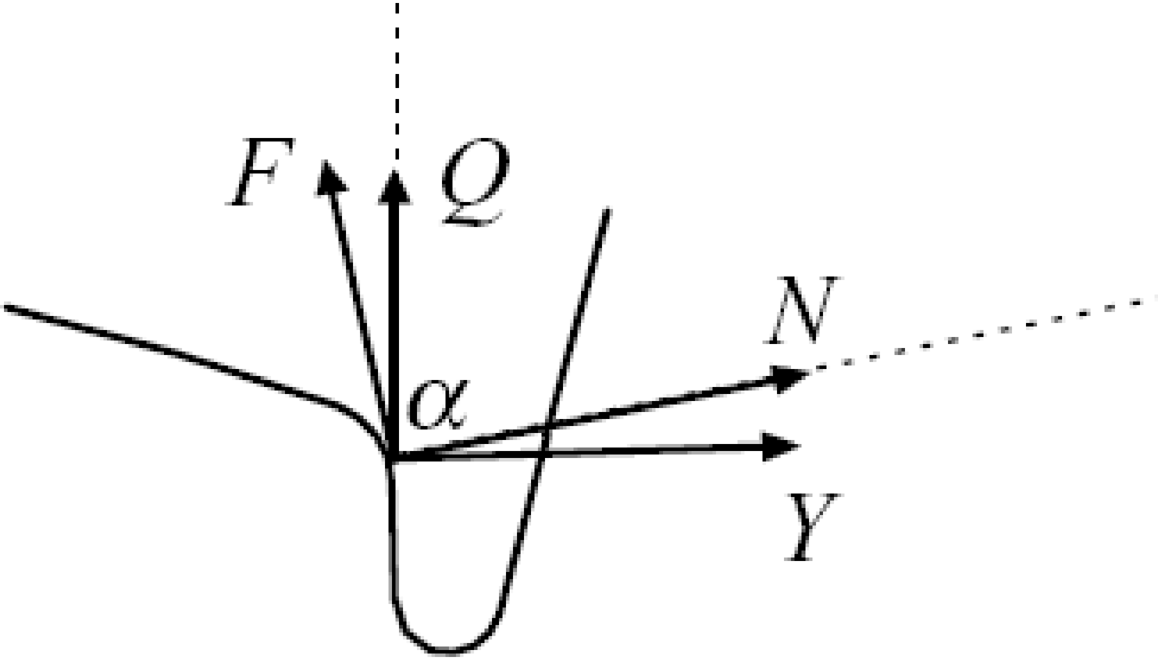
Yawed Wheel – Two Points of Contact

a – on tread

b – on flange

b is ahead of a

Simplistic Derailment Model



Simplistic Derailment Model

- $Y = N \sin \alpha - F \cos \alpha$
- $Q = N \cos \alpha + F \sin \alpha$

$$\frac{Y}{Q} = \frac{N \sin \alpha - F \cos \alpha}{N \cos \alpha + F \sin \alpha}$$

Simplistic Derailment Model

$$\therefore \frac{Y}{Q} = \frac{N \sin \alpha - F \cos \alpha}{N \cos \alpha + F \sin \alpha}$$

Dividing numerator and denominator by cos α

$$\therefore \frac{Y}{Q} = \frac{N \tan \alpha - F}{N + F \tan \alpha}$$

Simplistic Derailment Model

Derailment occurs when Q is carried entirely by point of contact on flange, Y will be least in this case. So,

$$\frac{Y}{Q} < \frac{N \tan\alpha - F}{N + F \tan\alpha}$$

Simplistic Derailment Model

Y/Q is minimum when F is maximum, F cannot exceed μN, So

$$\frac{Y}{Q} = \frac{\tan\alpha - \mu}{1 + \mu \tan\alpha}$$

This is Nadal's Formula

Nadal’s Formula

True when

- Angle of attack is large
- Large lateral force
- Reduced vertical load on wheel
- Track with significant vertical irregularity
- Or high degree of track twist

Now we shall look at a case of catastrophic derailment where the Nadal's formula probably did apply…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Adhesion and Friction-modification

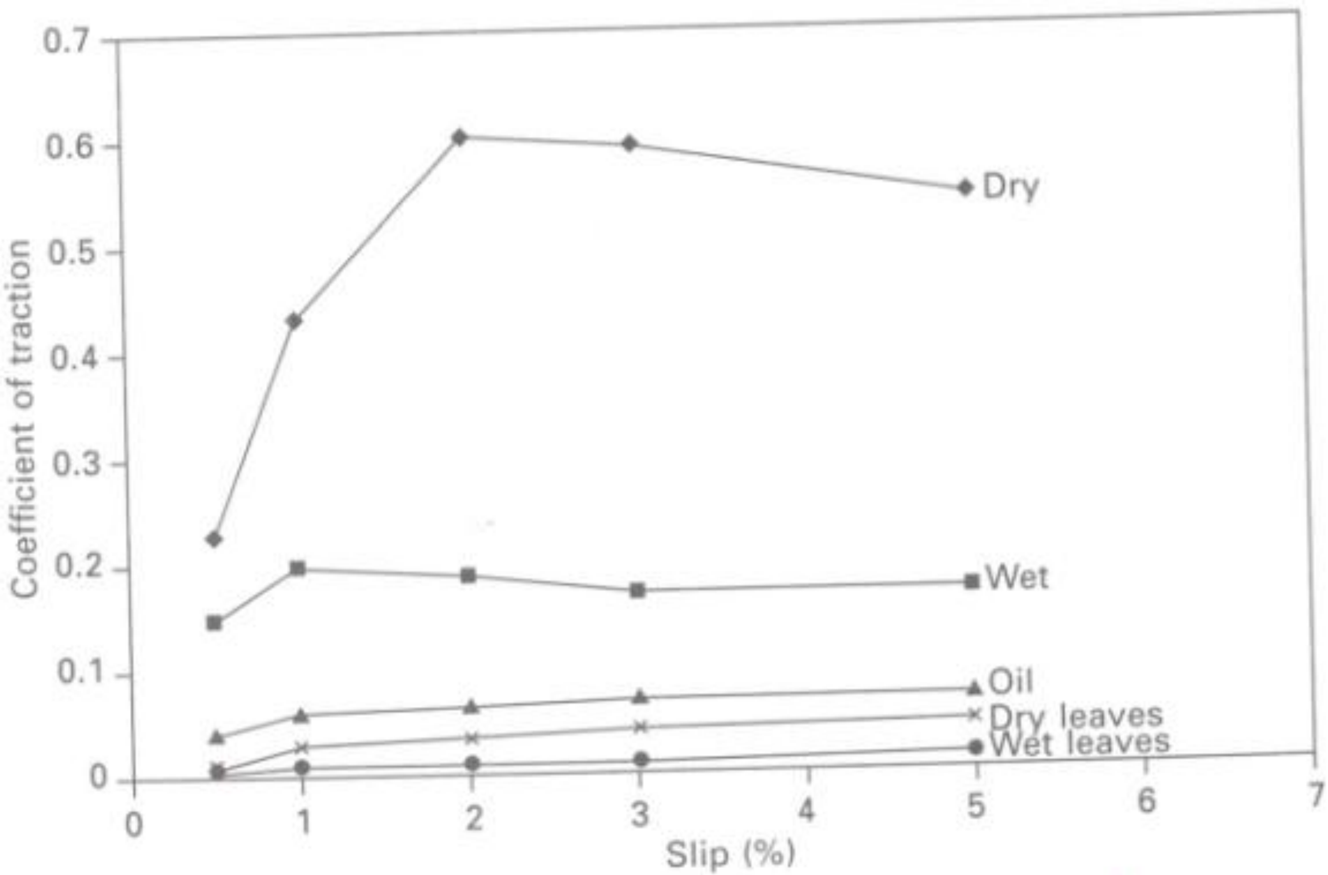
Adhesion & Friction

- Inadequate friction = poor adhesion = unsafe braking (long min stopping distance)
- Less friction = poor adhesion = wheel slip in traction (loss of hauling capacity)
- Rail-wheel contact zone = 1 sq cm
- Exposed to dirt, high humidity, leaves, rain

Effects

- Minimum coeff. of friction required for braking and acceleration = 0.2
- Modern locos = higher coeff. of friction
- Coeff. Of friction > 0.4 means moresurface fatigue of wheels and rail
- Less coeff. Of friction = more slide = sqeal and rail corrugation
- Proper management can lead to 30% savings over natural conditions

How environment affects!

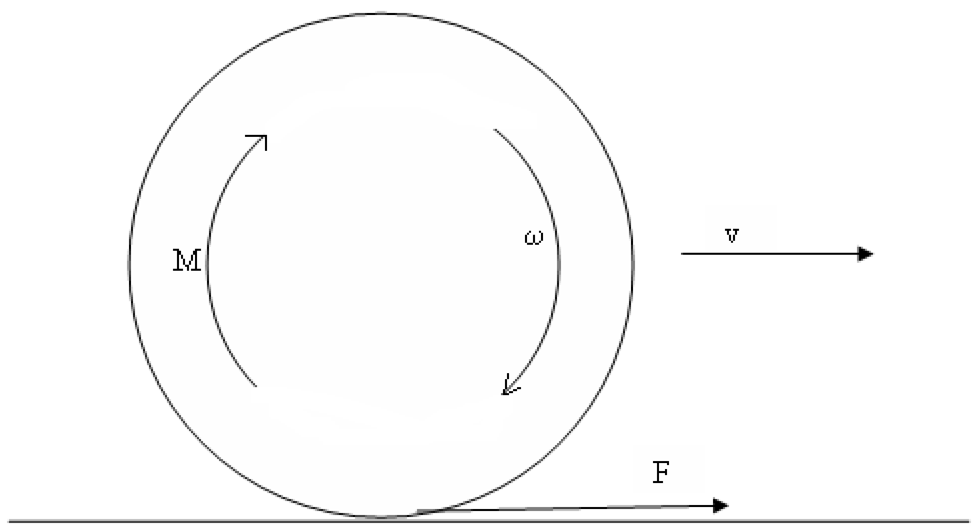


2.23 Creep curves generated during twin disc testing with contaminants applied.

Creep

R= radius, M=torque, ω=ang speed,

F= tangential force



Creep

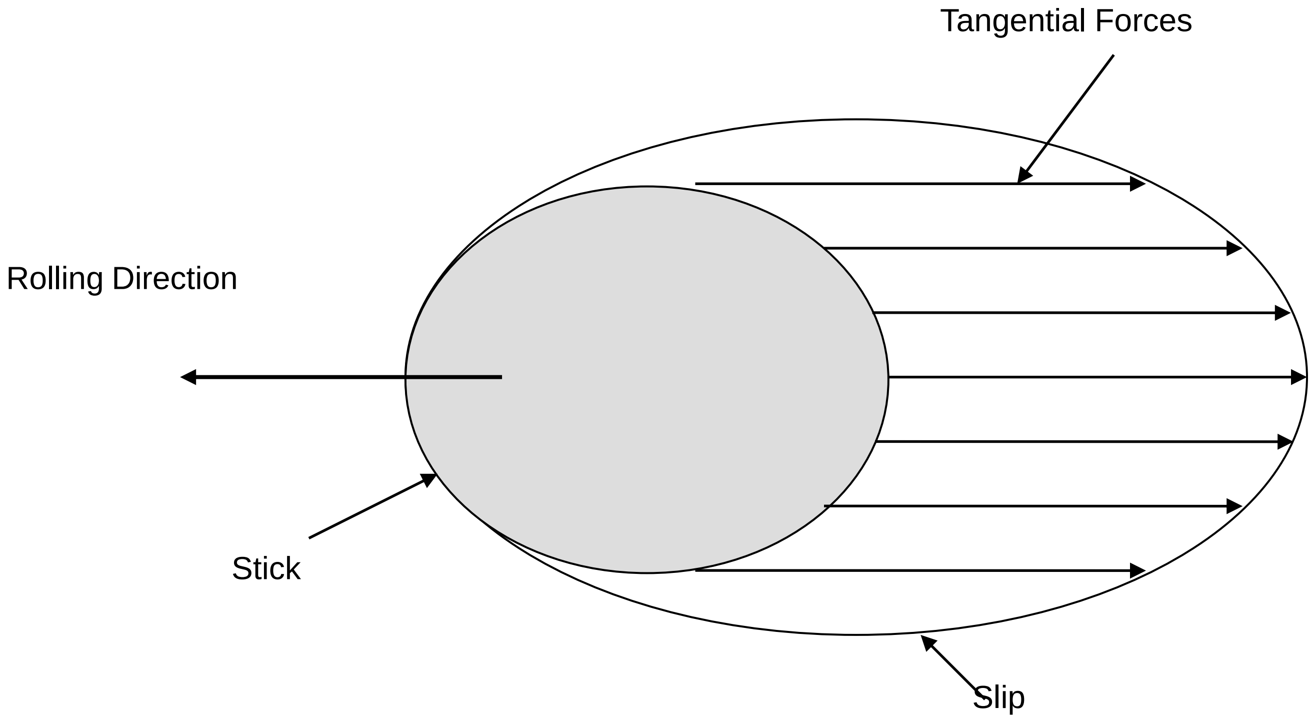
- In pure rolling $v = r.\omega$
- To achieve tangential force F on wheel:

  linear speed of rim > v
- So, $r.\omega > v$
- Creep = $(r.\omega - v)/v$

Adhesion

- Friction
- Available to transfer tangential force
- Between driving wheel and rail.
- Pushes the train forward
- Is called traction
- Limited by coefficient of friction
- If F > limit, wheel slip and rail burn

Rolling and Creep



Rolling and Creep

- Draw Diagram on board for Tangential force to creep qualitative plot

Friction Modification

- Advantageous to control friction
- To get high traction
- Have moderate rolling resistance for braking
- Reduce losses at flange contact to prevent rail-wheel wear and energy losses

Friction Modification

- High friction at wheel tread/rail top contact for locomotives
- Intermediate friction at wheel tread/rail top contact especially for freighy cars
- Low friction in wheel flange/rail gauge corner contact
- We can use friction modifiers for this purpose

Now we shall study applications to artficially modify friction…

Friction Modifiers

- Very high coefficient friction modifiers used to increase adhesion both for braking and traction – use of sand (>0.4)
- High coefficient friction modifiers (0.2-0.4)for wheel tread-top applications
- Low coefficient friction modifiers (<0.1) for flange – gauge corner interface (flane lubricators)

Low Coefficient Modifiers

- Solids, liquids or greases
- Primarily to reduce friction, wear and seizure at curves
- Saves energy (upto 30%) on curves
- Saves mateial from wear (upto 85%)
- Brings down friction coefficient to less than 0.1

Mechanism

- Lubricant transports additives to intended zone
- Additives react to form low shear coating
- Coating reduces friction (low shear)
- Coating prevents metal-to-metal contact (prevents seizure and metal wear)

Disadvantages

- Over-lubrication- migration of lubricant to railtop- loss of adhesion and traction
- Over-lubrication- migration of lubricant to railtop- loss of adhesion and increased braking distance – safety implication
- Increase in crack growth at rail gauge corner by pressurization of fluid as well as by preventing polishing of initial cracks

High Friction Modifiers

- Liquid-borne particles
- Applied by brush or spraying
- Dry into a thin film that alters surface shear stress
- Increase coeff. Of friction with increasing sliding velocity
- Prevents squeal and rail corrugation
- Reduce wheel noise

Defects

- Can affect rail insulation further affecting signalling (as in track-circuiting)
- Are effective for a limited number of wheel passages

High Friction Modifier

- Sand is universally used
- Removes blackish layers formed by leaves
- Leaves as a cause of reduced friction – wet leaves reduce friction coefficient to as low as 0.07
- Lignin, cellulose and pectin cause crushed leaves to stick to rail
- Forms chemically reacted easily sheared surface layer containing P and Ca

Problem with Sand

- Sand is an abrasive
- Reduces rail and wheel life by substantially increasing wear rates
- Alternate methods are Sandite blasting of tracks and Washing with high pressure jets
- Of limited use because of requirements of paths and special trains

Other HF Modifiers

- Raises coeff. of friction to 0.6
- Solids with embedded active components in polymeric matrices
- Applied directly to wheel tread
- Active resin oxidises under high temperature of rail-wheel contact and leaves thin dry film on wheel
- Drawbacks same as that of high friction modifiers

Friction Reduction Model

- Viscous shear model
- Viscous flow
- Boundary lubrication model (Sulphur & Phosphorus)
- Self lubricating alloys like stellites
- Low pressure contact model – PTFE and HDPE – coeff. as low as 0.05
- Multiple layer model