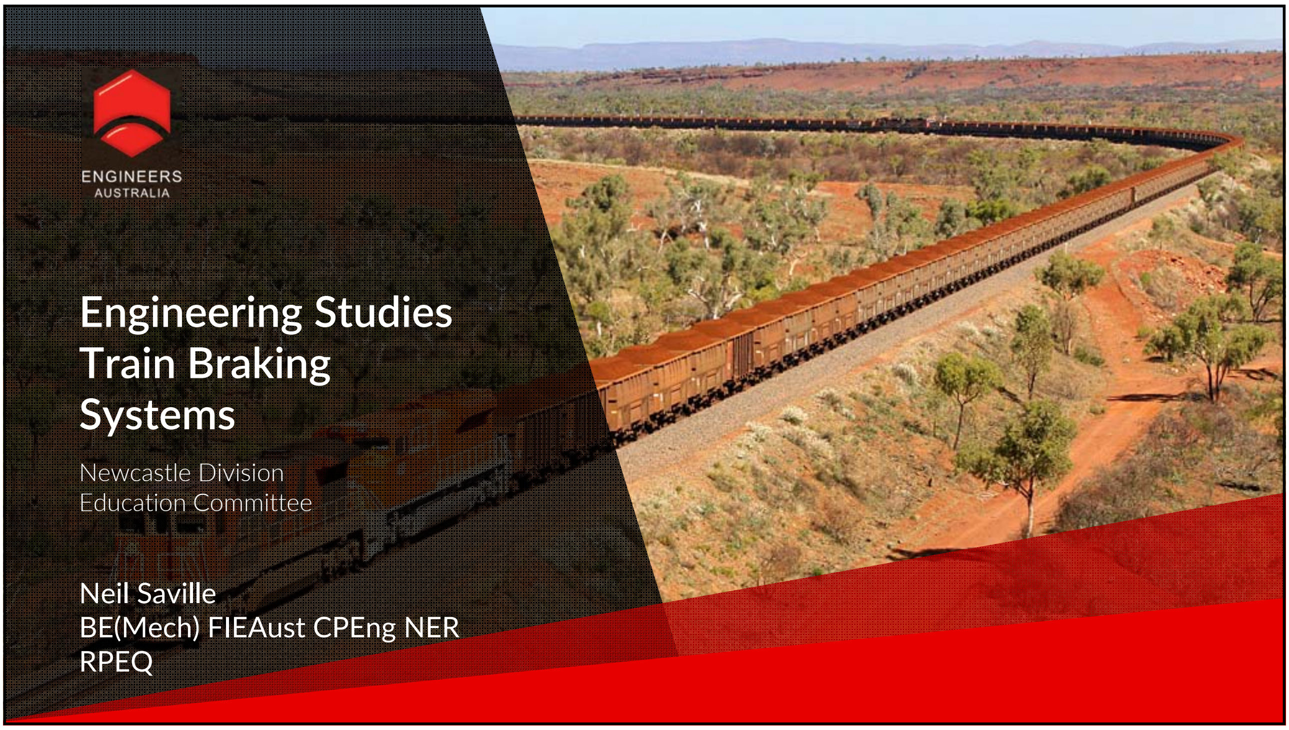

Engineering Studies Train Braking Systems

Newcastle Division
Education Committee

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Train Braking Systems

- Introduction
- Historical and Social Influences
- Engineering Mechanics and Hydraulics
- Engineering Materials
- Brakes and the Safety imperative

Introduction

- Braking Systems – why are trains different?
  - Length, mass, speed & grade
  - Iron ore and coal trains may comprise hundreds of vehicles, lengths over 3km & weigh over 40,000 tonnes
  - High speed trains may run at speeds over 350 km/h and weigh hundreds of tonnes
  - Descents (downhill grades) can be km in length

Introduction

- Moving trains have significant kinetic energy (can be measured in hundreds of MJ or GJ) due to mass or speed or combination of both
- Kinetic energy, $$KE = \frac{1}{2}mv^2$$

Freight train

- 40,000 tonnes = $4*10^7$ kg
- 60 km/h = 16.67 m/s

$$KE_{freight} = \frac{1}{2} * (4 * 10^7) * 16.67^2 = 5.55 * 10^9 J\ (5.6GJ)$$

High speed passenger train

- 400 tonnes = $4*10^5$ kg
- 320 km/h = 88.9 m/s

$$KE_{passenger} = \frac{1}{2} * (4 * 10^5) * 88.9^2 = 1.58 * 10^9 J\ (1.58GJ)$$

Introduction

- Stopping distances for trains
- Relationship between velocity, acceleration and distance

$$v^2 = u^2 + 2as$$

$$s = \frac{(v^2 - u^2)}{2a}$$

Freight train

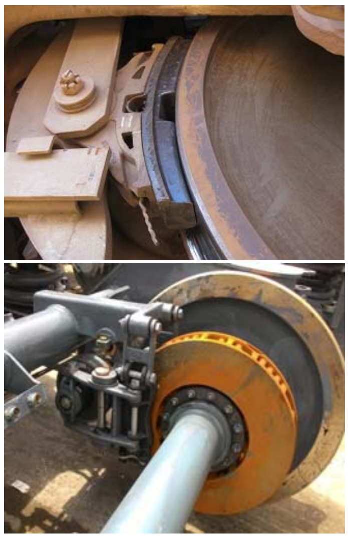
- Initial speed, u = 80 km/h = 22.22 m/s
- Final speed, v = 0 m/s
- Deceleration rate = -0.3 m/s^2

$$s = \frac{(0^2 - 22.22^2)}{2 * -0.3} = 823\text{m}$$

(this is on level track, much higher on downhill grade)

Historical and Social Influences

- To slow or stop a train, friction blocks are pressed against the steel wheels, or pads against discs attached to axles
- Most train brake systems use compressed air to force blocks onto wheels or pads onto discs - known as “air brakes” or "pneumatic brakes”
- Air brakes are based on a design patented by George Westinghouse around 1873



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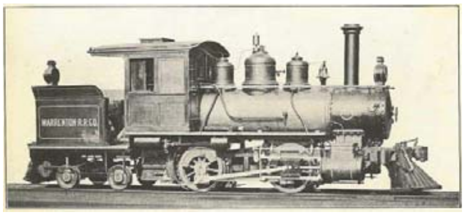
Historical and Social Influences



1880s

1970s

Air brake fundamentals haven't changed in 140 years but there have been significant technology changes and improvements

1930s

2000s

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Historical and Social Influences

- Air (pneumatic) is used in lieu of hydraulic or pure mechanical
- Key advantage of compressed air is that it can be "created" on the train in the large volumes required, using onboard compressors
- Air connections are also easy to control when connecting and separating vehicles
- Today's systems use electronic-based control systems, replace "brake pipe" with electrical signals but still use air to apply the force
- Most trains utilise electric traction systems, there is significant use of electro-dynamic (electric) braking in both dissipative and regenerative forms, as well as use of blended pneumatic and electric brakes

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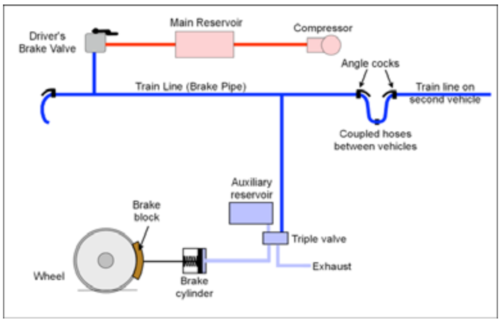
Engineering Mechanics and Hydraulics

- Compressed air is transmitted along the train through a "brake pipe" and stored in reservoirs to provide brake application forces
- Reducing or increasing air pressure in the pipe causes a change in state of the brake on each vehicle
- Can apply, release or hold "on" after a partial application
- The brake cylinder may act directly on the block or through a mechanical linkage
- System is designed so it "fails safe"



Source: The Railway Technical Website (http://www.railway-technical.com)

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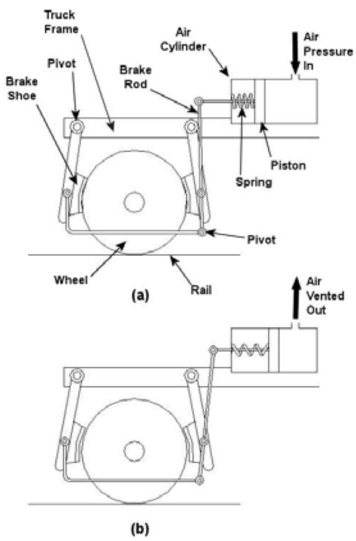
Engineering Mechanics and Hydraulics

- Block brake pressed on a wheel is like an inside-out drum brake – takes advantage of steel wheel so no separate "drum" is required
- Freight trains don't have slide control, so reliance is on limiting forces to avoid skids
- However, there are many axles in the train so braking forces can be distributed along the train



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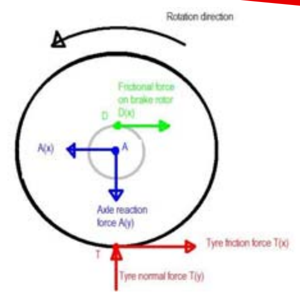
Engineering Mechanics and Hydraulics

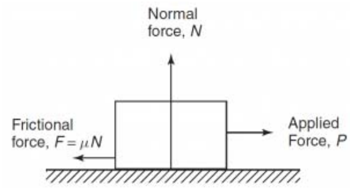
- The frictional braking force that can be applied to a wheel (or disc) is limited by the friction between the wheel and the rail, otherwise wheel slide occurs and causes damage to wheel and rail

$$\mu = \frac{\text{frictional force } (F)}{\text{normal force } (N)}$$

- Typical values for coefficient of friction when sliding is occurring, i.e. dynamic coefficient of friction, are:
  - For polished oiled metal surfaces < 0.1
  - For steel wheel on steel rail
    - Dry – 0.4 to 0.6
    - Lubricated – 0.15
  - For rubber on dry road, approaching 1.0



Source: Wikipedia, Adhesion Railway



Source: www.me-mechanicalengineering.com

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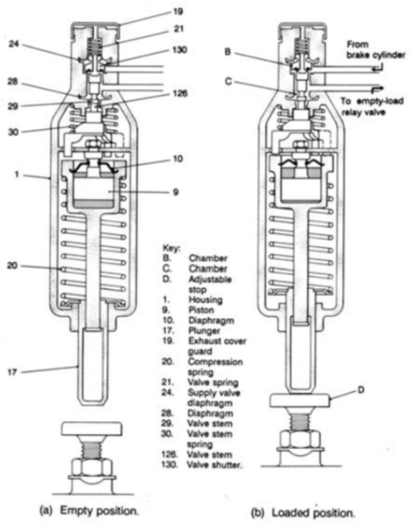
Load control

- Need to account for difference in loaded and empty mass of wagons, ratios can be as high as 7:1
- If design for 20% braking in tare to avoid skids then loaded will be less than 3%!!??
- Answer: include a load changeover valve that increases brake pressure when the wagons are loaded
- Mounted across suspension so displacement under load operates valve
- Passenger trains measure air suspension pressure to calculate passenger load



Engineering Mechanics and Hydraulics

- Brake disc designs are similar to automotive – may use discs bolted to the wheel or multiple discs
- For high speed trains, there are fewer axles so need more braking effort applied to each axle
- Engineering response is use of multiple discs per axle and…
- …incorporate brake slide control systems (equivalent of automotive ABS)

Engineering Materials

- Forces, stresses and heat are significant
- Steel wheels have high hardness to carry the heavy loads but also need to provide thermal resistance due to the heat generated
- Wheel materials are constantly evolving, new alloys and heat treatments being introduced
- Brake discs may be Cast Iron, Steel or Aluminium
- Brake blocks used to be cast iron or include asbestos, but today's designs may be sintered metals or organic compounds

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Electric Braking (Dynamic Braking)

- Modern electric trains use dynamic braking systems. There are two main types of dynamic braking:
    - Rheostatic dynamic braking where the kinetic energy is converted into electric energy and then dissipated into the atmosphere as heat (suitable for diesel electric and older electric trains)
    - Regenerative dynamic braking were the kinetic energy is converted into electric energy and then fed back into the supply system (used on all modern electric trains)
- Dynamic braking is used on trains with DC or AC traction motors

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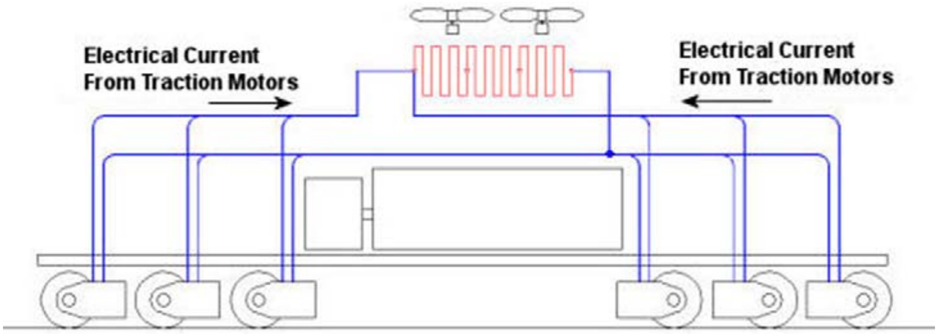
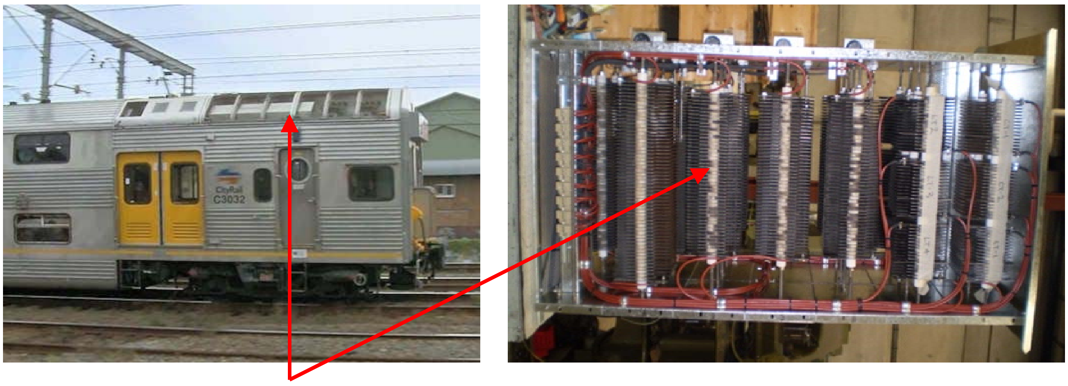
Rheostatic Braking

- The traction motors are disconnected from the supply and reconnected to a set of resistors
- The traction motors continue to rotate (driven by the inertia of the train) and generate electric current
- The current through the resistors causes a power (and energy) loss as heat (remember $P = I^2R$)
- The reverse torque (back EMF) on the motors causes the train to slow down

Rheostatic Braking



Rheostatic Braking



Dynamic Braking Resistors

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Regenerative Braking

- Modern electric trains whether running on a DC or AC overhead wiring systems use electronic inverters to convert the overhead supply to variable voltage variable frequency (VVVF) supply for motor speed and torque control
- When braking, the motors act as generators and the generated power is fed by the inverters back into the overhead wiring
- The reverse torque on the motors causes the train to slow down
- This is much more efficient as the power being fed back into the overhead wiring can be used by other trains on the network

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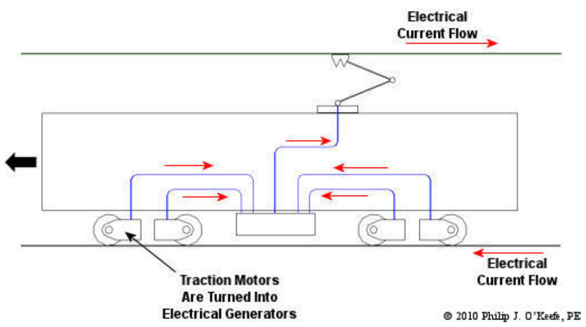
Regenerative Braking



Brakes and the Safety imperative

Allows the driver to:
- Control speed of train on downhill grades
- Slow the train to required safe speed for curves
- Bring the train to a stop at signals, stations and yards
- Bring the train to a stop in an emergency situation
- Hold the train stationary on level and grades

Allows the control and protection systems to:
- Slow or stop the train to avoid exceeding a safe limit
- Stop the vehicles if there is a breakage within the train
- Stop the train if monitoring systems indicate an unsafe condition

When it goes wrong!

By Sûreté du Québec

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Montparnasse derailment

- October 22, 1895
- Granville–Paris Express overran the buffer stop at its Gare Montparnasse terminus
- With the train several minutes late and the driver trying to make up for lost time, it entered the station too fast and the train air brake failed
- Ran through buffer stop, crossed the station concourse and crashed through the station wall; locomotive fell onto the Place de Rennes below, where it stood on its nose
- A woman in street below was killed by falling masonry
- The engineer was fined 50 francs and one of the guards 25 francs.

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Lac-Mégantic rail disaster

By Sûreté du Québec

- July 6, 2013
- Town of Lac-Mégantic in Canadian province of Quebec
- Unattended 74-car freight train carrying crude oil parked at top of a 1.2% (1 in 80) grade
- Park brakes not correctly applied and air “leaked” off the train releasing the air brakes
- Train rolled down the hill and derailed in town centre
- Resulting fire and explosion of multiple tank cars
- Forty-seven people died
- More than 30 buildings in town's centre were destroyed and all but three of the 39 remaining downtown buildings had to be demolished due to petroleum contamination

QR Cleveland Station

- 31 January 2013
- Queensland Rail passenger train failed to stop at Cleveland station platform and collided with buffer stop, platform and station building at about 31 km/h
- There were 19 people on board the train (including driver and guard); three people were on the platform and five were in the station building
- A number of people were treated for minor injuries
- ATSB investigation found that local environmental conditions had resulted in formation of a contaminant substance on rail running surface, causing poor adhesion and reducing braking effectiveness

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