



ENGINEERS
AUSTRALIA

Engineering Studies Teacher Development Session – Breaking Systems - Trains

Bringing Schools and the Engineering
Industry together

Neil Saville
BE(Mech) FIEAust CPEng NER
RPEQ





ENGINEERS
AUSTRALIA

Train Braking Systems

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



ENGINEERS
AUSTRALIA

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





ENGINEERS
AUSTRALIA

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

$$KE_{passenger}$$

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



ENGINEERS
AUSTRALIA

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, $u = 80 \text{ km/h} = 22.22 \text{ m/s}$
- Final speed, $v = 0 \text{ m/s}$
- 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)



ENGINEERS
AUSTRALIA

Historical and Social Influences

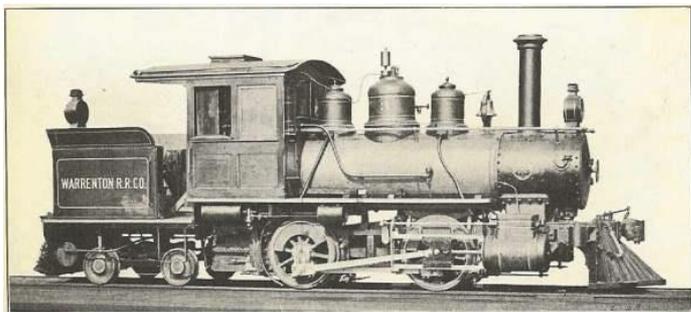
- To slow or stop a train, friction blocks are pressed against the steel wheels, or pads against discs attached to axles
- Most train brake systems use compressed air to force blocks onto wheels or pads onto discs - known as “air brakes” or “pneumatic brakes”
- Air brakes are based on a design patented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





ENGINEERS
AUSTRALIA

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





ENGINEERS
AUSTRALIA

Historical and Social Influences

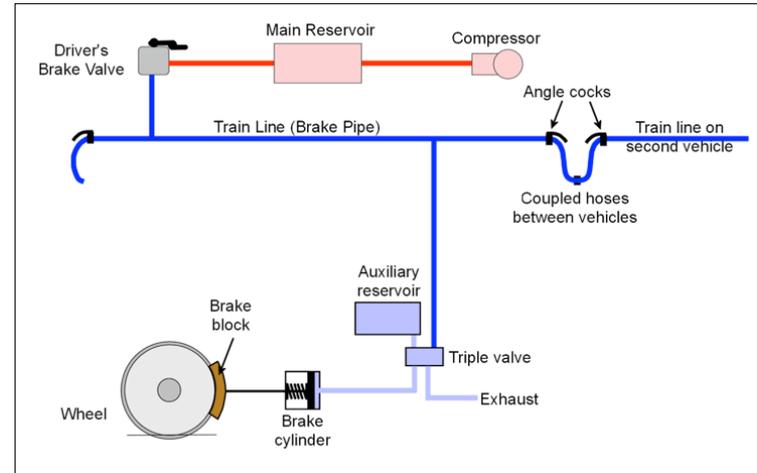
- Air (pneumatic) is used in lieu of hydraulic or pure mechanical
- Key advantage of compressed air is that it can be “created” on the train in the large volumes required, using onboard compressors
- Air connections are also easy to control when connecting and separating vehicles
- Today’s systems use 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



ENGINEERS
AUSTRALIA

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>)



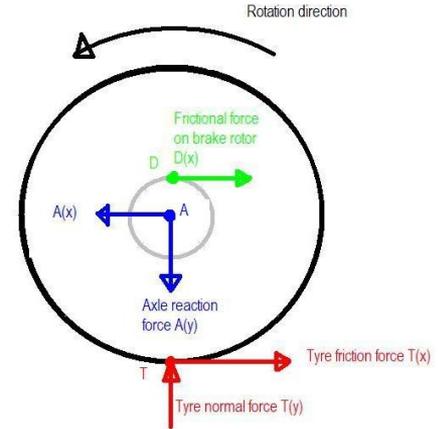
ENGINEERS
AUSTRALIA

Engineering Mechanics and Hydraulics

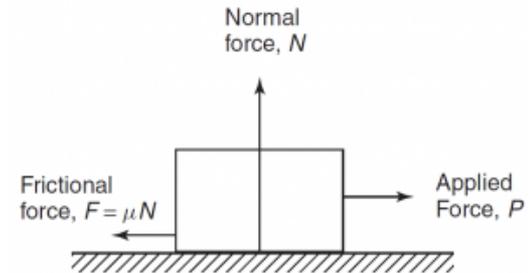
- The frictional braking force that can be applied to a wheel (or disc) is limited by the friction between the wheel and the rail, otherwise wheel slide occurs and causes damage to wheel and rail

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

- 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



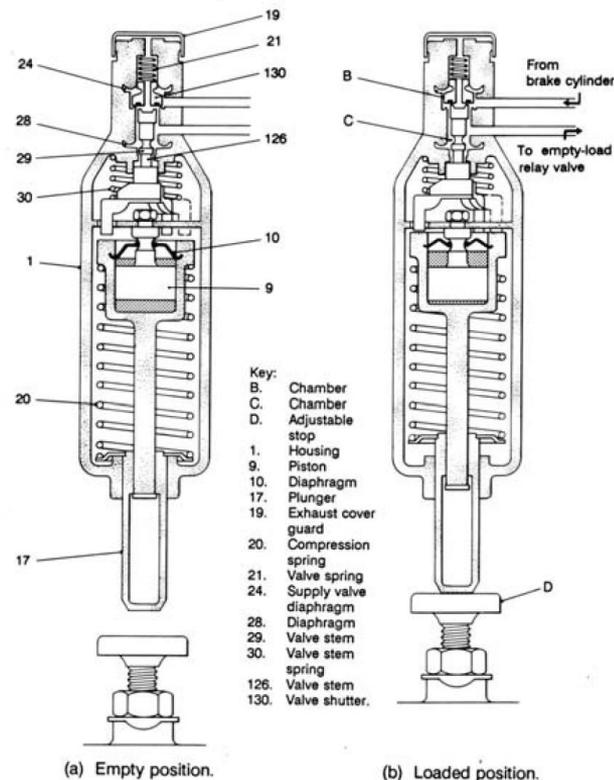
Source: www.me-mechanicalengineering.com



ENGINEERS
AUSTRALIA

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





ENGINEERS
AUSTRALIA

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)





ENGINEERS
AUSTRALIA

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





ENGINEERS
AUSTRALIA

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 where 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



ENGINEERS
AUSTRALIA

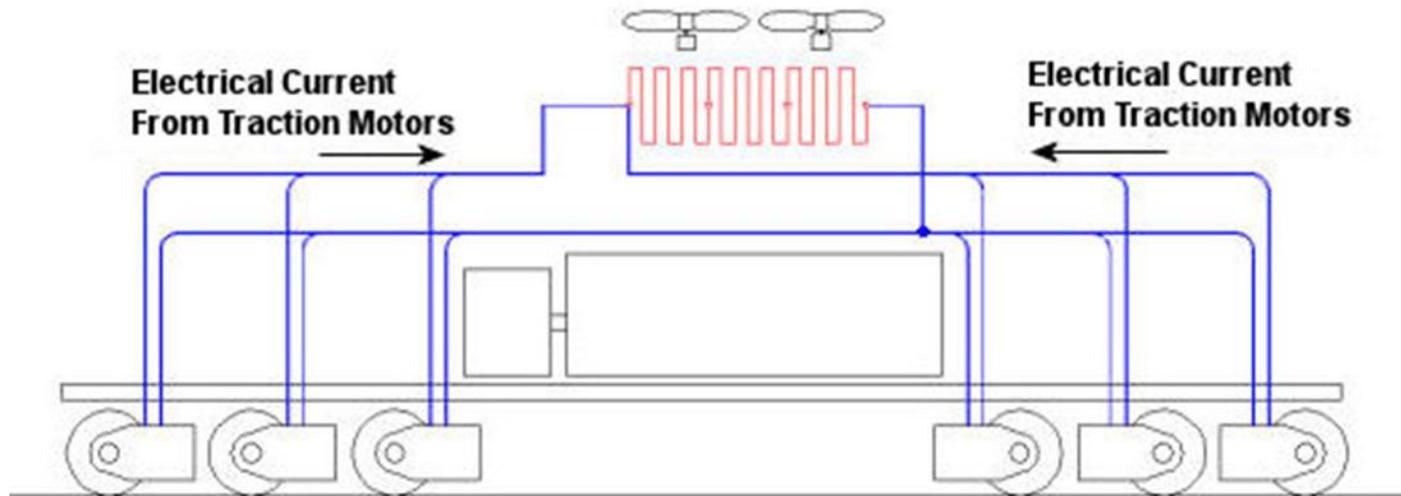
Rheostatic Braking

- 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



ENGINEERS
AUSTRALIA

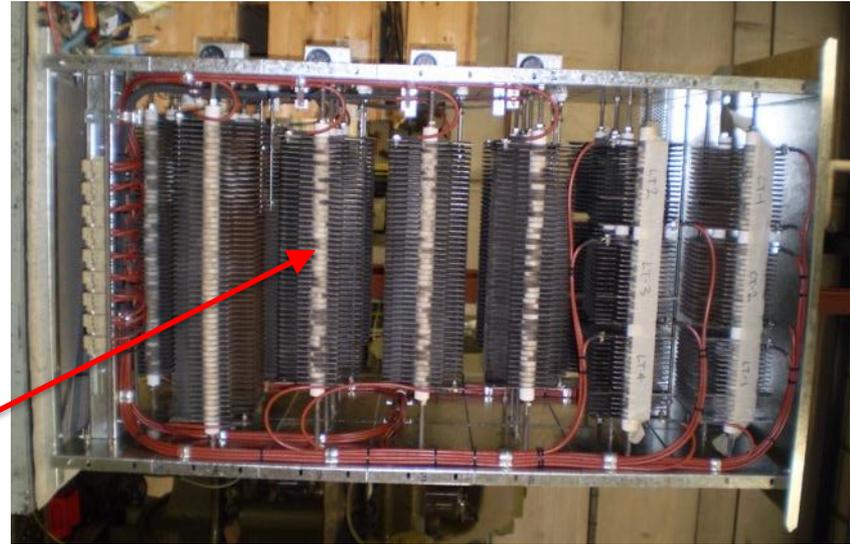
Rheostatic Braking





ENGINEERS
AUSTRALIA

Rheostatic Braking



Dynamic Braking Resistors



ENGINEERS
AUSTRALIA

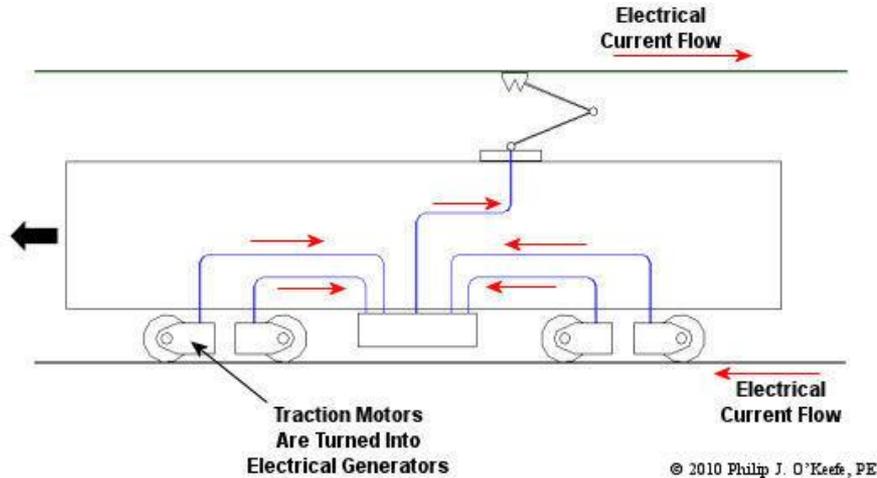
Regenerative Braking

- 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



ENGINEERS
AUSTRALIA

Regenerative Braking





ENGINEERS
AUSTRALIA

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



ENGINEERS
AUSTRALIA

When it goes wrong!

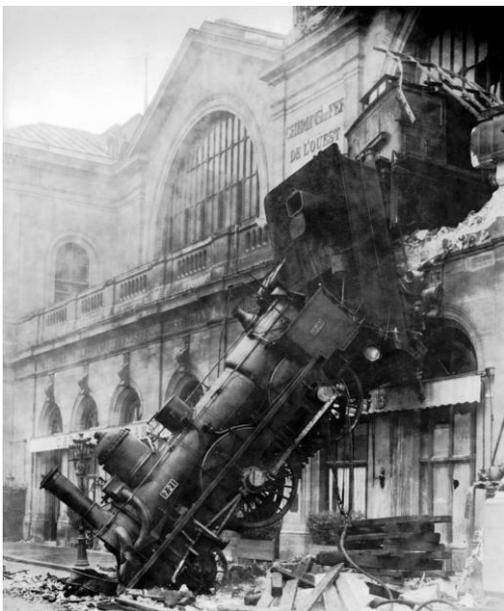


By Sûreté du Québec



ENGINEERS
AUSTRALIA

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.



ENGINEERS
AUSTRALIA

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



ENGINEERS
AUSTRALIA

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



Engineers Australia is the trusted voice of the profession. We are the global home for engineering professionals renowned as leaders in shaping a sustainable world.

engineersaustralia.org.au