Peter Campbell

Going electric

Taking the train to the Games

A 'Javelin' high-speed train

Sustainability has been a high priority for the London organising committee for the 2012 Olympic and Paralympic Games. The declared aim is 'for 100 per cent of spectators to get to the Olympic Park by public transport, or by walking or cycling.' Railway lines with a combined capacity of 240 000 passengers per hour will serve the Olympic Park, most of them using Stratford station.

Long before preparations for the 2012 Game began, rail services through Stratford had been electrified. Electrified trains have many advantages over the diesel-powered trains which they replaced:

- zero emissions at the point of use, so no adverse impact on local air quality
- electric motors are lighter, so train weight does less damage to the track
- 20–35% less carbon emissions per passenger mile

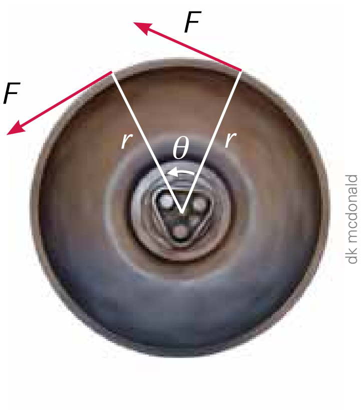
Stratford station, with the Olympic Park under construction beyond it.

All of these railway lines through Stratford station are electrified.

- North London overground line, powered by a 750 V DC third rail system from Richmond to Acton Central, 25kV 50 Hz AC overhead lines from Acton Central to Stratford
- Docklands light railway, powered by a 750 V DC third rail system
- Jubilee and Central underground lines, powered by a four-rail system. A third rail at +420 V DC is beside the track, and a fourth rail at -210 V DC is centrally between the running rails, giving a traction voltage of 630 V DC
- Great Eastern mainline and suburban overground lines serving east London and Essex, powered by a 750 V DC third rail
- 'Javelin' high-speed rail service to serve Stratford International from St Pancras and Ebbsfleet International stations, during the Games only. Powered by 25 kV 50 Hz AC overhead lines.

Torque and work done

Railway engineers commonly use the concept of 'torque' or turning effect, because the motive force on the track depends on wheel size. Just as with simple machines like levers and pulleys, the turning effect depends on the size of the force and how far from the pivot or axle it is applied.



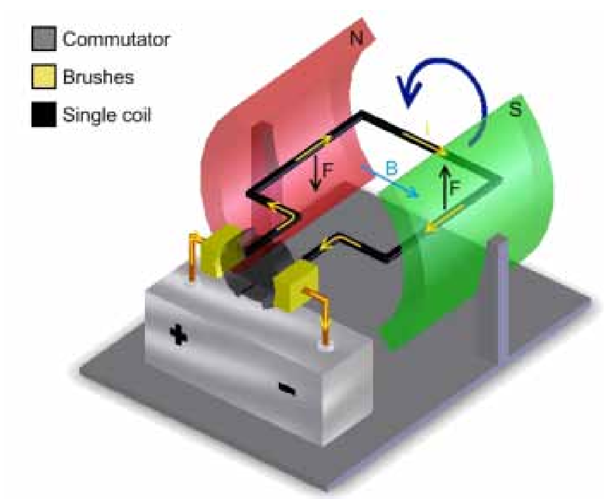
Torque is the product Fr. The work done by a drive wheel is given by $W = Fr\theta$, where r is the wheel radius and θ is the angle (expressed in radians) through which it turns.

Most noticeably, work is done when a train accelerates on leaving a station platform or when it climbs a gradient. But work is also done against resistive forces when a train is travelling at constant speed.

Speed control of electrified trains

Electrified trains generally have several motors. For example, all 7-car Jubilee Line underground trains have two units called 'Driving Motor cars'.

What makes any electric motor turn is the interaction between two independent magnetic fields. One magnetic field is stationary and the other rotates with a current-carrying coil of wire.

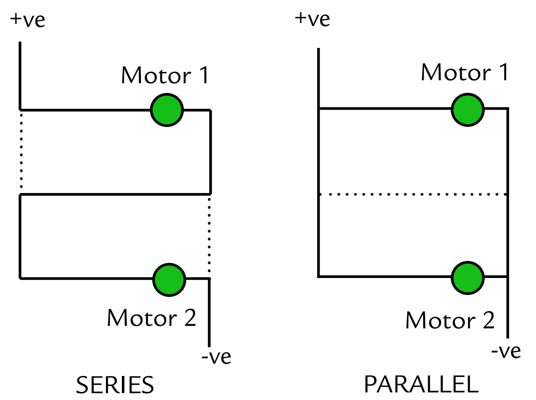


A DC electric motor. The current (yellow arrows) in the coil produces a magnetic field which interacts with the field produced by the stationary magnets (N and S), causing the coil to turn.

But any coil of wire rotating in a stationary magnetic field produces a dynamo effect. A voltage (also called a 'back EMF') is therefore induced in the motor coil which opposes the rotation. The faster the coil rotates, the greater the reverse voltage induced.

A simple motor produces maximum torque when it is just starting to turn, because there is no back EMF. As it spins faster, the torque that it can produce falls. This is because the net voltage across the coil falls and so there is less current through it.

To get larger torques as an electrified train speeds up, its motors are arranged so that they can be switched between working in series and parallel. The circuits also include large, switchable resistances that can be used in different ways.



These circuits control motors as the train speeds up. Not shown: in each configuration, every branch also contains resistors.

As the train starts moving, part of what happens is that its electric motors are connected in series (diagram a), so the motor voltage is smaller than the railway supply voltage. As the train approaches its maximum speed, circuits are switched so that they are in parallel (diagram b). This means each motor receives the full supply voltage, compensating for the back EMF induced at higher speed.

Regenerative braking

The dynamo effect within electric motors means that electrified rail systems can re-use the energy that would otherwise be lost when a train is braking. If there is another train drawing power from the system on a nearby section of track, circuits in a braking train can be switched to feed electricity back into the overhead wires, or power rails. The braking train slows down as its kinetic energy changes to electrical energy.

If there is no other train nearby the braking train, then yet another switching arrangement feeds the electricity generated by the braking train through massive on-board resistors, so wasting the energy as heat. This wasteful electrical heating effect can be compared with frictional heating in the brakes of cars and trucks.

Peter Campbell taught physics in London schools and colleges for over 20 years.