How an army of engineers battles contamination and sleep deprivation to take Large Hadron Collider to new heights

October 18 2016, by Graeme Burt And Robert Appleby

LHC. Credit: CERN

The Large Hadron Collider at CERN is the world's largest particle accelerator, and experiments like this have reached a scale where physicists are no longer able to build them alone. Instead, qualified engineers now lead the construction of these behemoths. And we are part of a team of engineers and physicists working on upgrading the LHC and eventually constructing a successor.

On the surface CERN is a 1960s glass and concrete building. It's often described as what people 50 years ago thought the future might look like. The cafeteria looks like any other, except you probably don't get as many Nobel Prize winners in most canteens. But the real work goes on underneath the surface. The tunnel that houses the LHC is 27km in circumference, which is the same as the Circle Line in London's underground system. But while the deepest London tube line is only 60 meters down, the LHC is 175 metres below ground. In the tunnel is also 50,000 tonnes of equipment weighing the same as six Eiffel Towers.

The LHC works by colliding two beams of particles at very high energy, travelling in a circle close to the speed of light before they are crashed into each other. The particles used are protons – positively charged particles that make up the atomic nucleus, along with neutrons – that are attracted to negatively charged plates. Metallic chambers called "radiofrequency cavities" contain strong electromagnetic fields that are used to accelerate the protons.

The LHC has the world's highest accelerator magnet and the world's largest superconducting system at 10,000 superconducting magnets. These have wires with zero electrical resistance at low temperatures, meaning they can create intense magnetic fields. LCH also has the highest current controlled to very high precision and the highest proton-beam energy (13 TeV). So to build an accelerator like the LHC we need electrical engineers, electronic engineers, mechanical engineers and civil engineers with a huge range of specialisations including radio frequency acceleration systems, cryogenics, control, tunnel drilling and mechanical stability.

The energy stored in each beam is the same as an airbus jet travelling at take-off speed and can melt 12 tonnes of copper. So the materials used must be able to take this hit, and this requires a lot of engineers testing them and controlling systems that avoid the beam depositing all its energy in one spot. Energy management is also a big task – the LHC requires 120MW, which is 10% of the entire energy budget of Geneva – and 50% of the largest power station in the northwest of England.

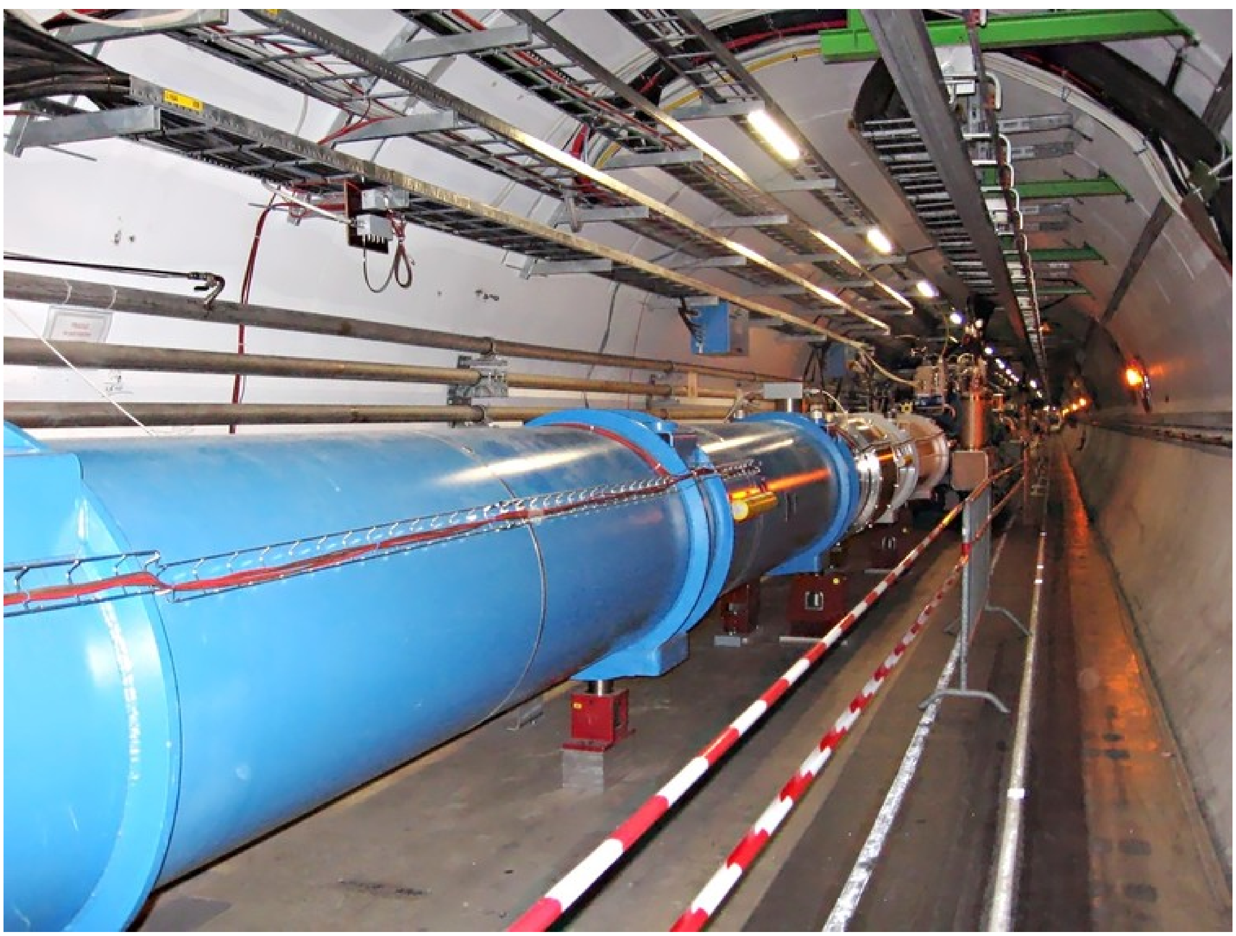
Risky business

When running, the machine is too radioactive to go into. This radiation is produced when protons interact with the nuclei of surrounding material or gas. But every few years it undergoes a long shutdown to allow engineers to install new components. On the surface the collider entrance looks much like a building site, and hard hats must be worn. There are many risks – including high radiation levels from stray protons hitting the walls and generating showers of particles, high voltages, cold cryogenic gasses in confined spaces (which have exploded in the past), as well as the usual heavy items falling and of being in a tunnel deep beneath the surface.

There is a long wait as the lift takes you down into the depths. The detectors are pretty big to begin with but when you get close and see on a small scale the amount of electronics packed into every space of a three-storey tall detector you realise the scale of the engineering involved. The same goes for the tunnels themselves.

A lot of the engineering work conducted at CERN isn't in the tunnels, however, but in the many testing laboratories or assembly areas. Lancaster University is involved in testing the LHC's acceleration cavities. Huge radio-frequency amplifiers (like big mobile phones) blast the cavities with enormous powers to test if they can withstand the massive electric fields generated in the particle accelerators. Because of radiation, everything is controlled from a little room filled with racks of computers and electronics. The cavities are sensitive to dirt and dust, which can cause them to fail. They are therefore cleaned with water so pure it can eat through metal pipes. To remove the surface layer we also use acid mixtures containing the extremely potent hydrofluoric acid.

Often these tests run continuously so one of us – Graeme – often spends 24 hours in a concrete room with no windows staring at a screen. But once you know what's on the screen, and what every blip means, it's definitely more exciting.



LHC tunnel. Credit: Julian Herzog/wikipedia, CC BY-SA

CERN makes a lot of the specialist components themselves so there are also large workshops with massive cutting and welding machines, staffed by some of the world's top technicians.

Bigger and better

We are now working with the physicists to design the LHC's successor, which will be 100km in circumference. Before that the LHC will be upgraded to operate with ten times the number of collisions to allow the physicists to discover new particles faster.

The UK is involved in this through the High Luminosity-LHC-UK project, led by the Universities of Manchester and Lancaster, in which engineers work with physicists to create the new technology. This will involve building new superconducting radio-frequency systems that create 3m-volt electric fields to align the bunches of protons to within nanometer precision. A superconducting material, which has zero electrical resistance at low temperatures, allows these devices to store energy with very low energy loss.

Engineers are also looking at special "collimators" which remove stray particles in the beam and hence must be able to take huge energy being deposited on them. This involves creating superconducting cables that can transport the huge currents required to power the magnets from the surface to the tunnel without loss. Physicists and CERN engineers will also develop new ways of measuring the proton beams.

CERN is leading to ground-breaking scientific research that is advancing our knowledge of the world around us. And it is through the collaborative work of the world's finest engineers, alongside the best scientific minds, that are making these discoveries possible.

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