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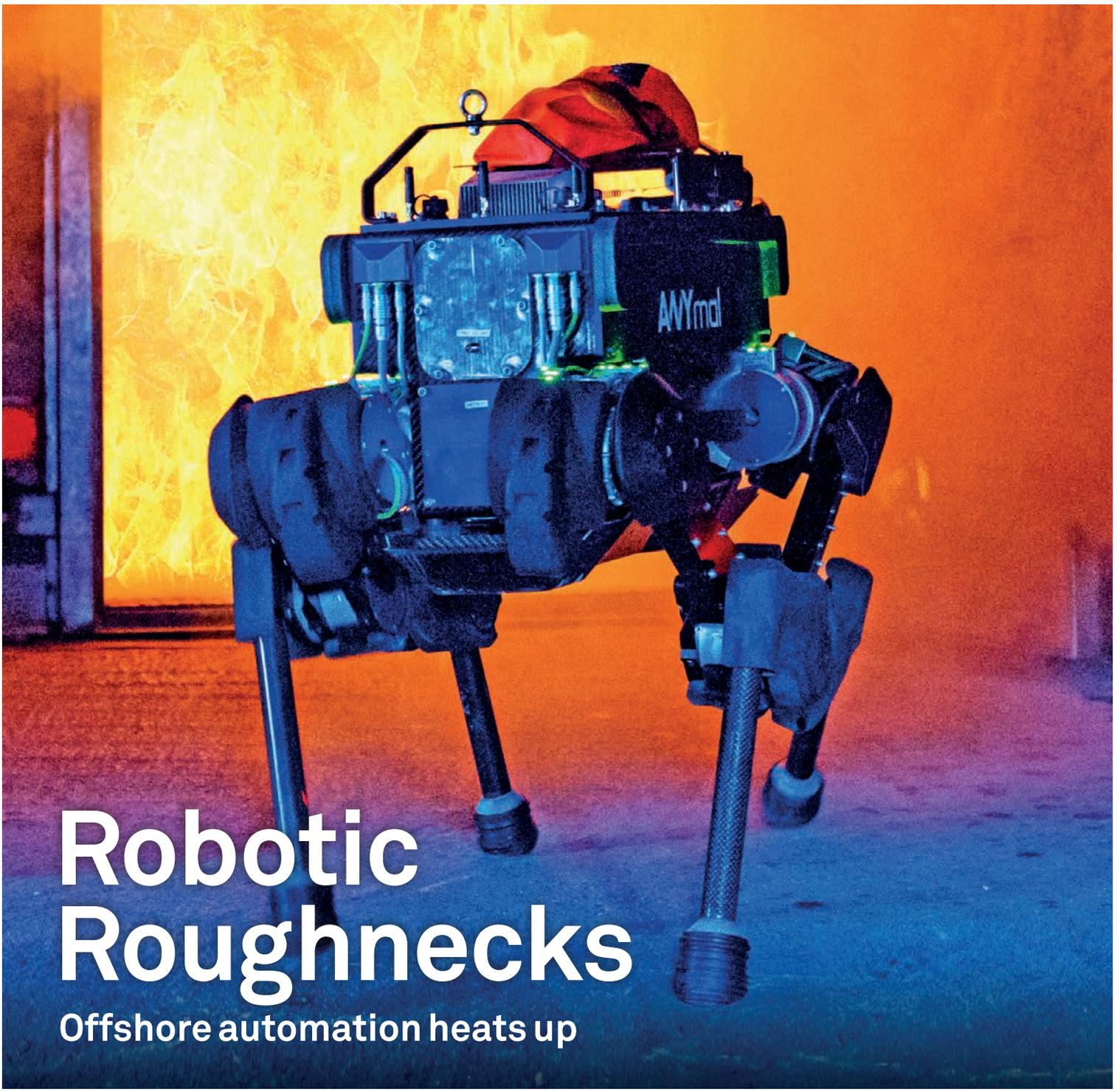

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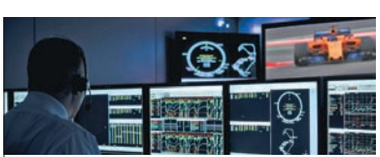

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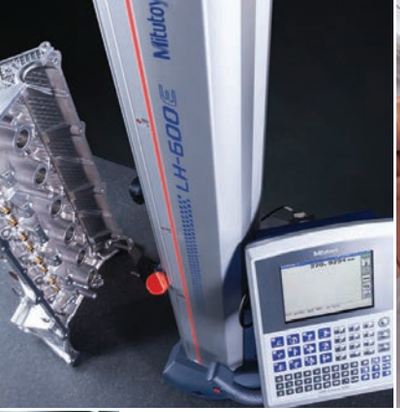

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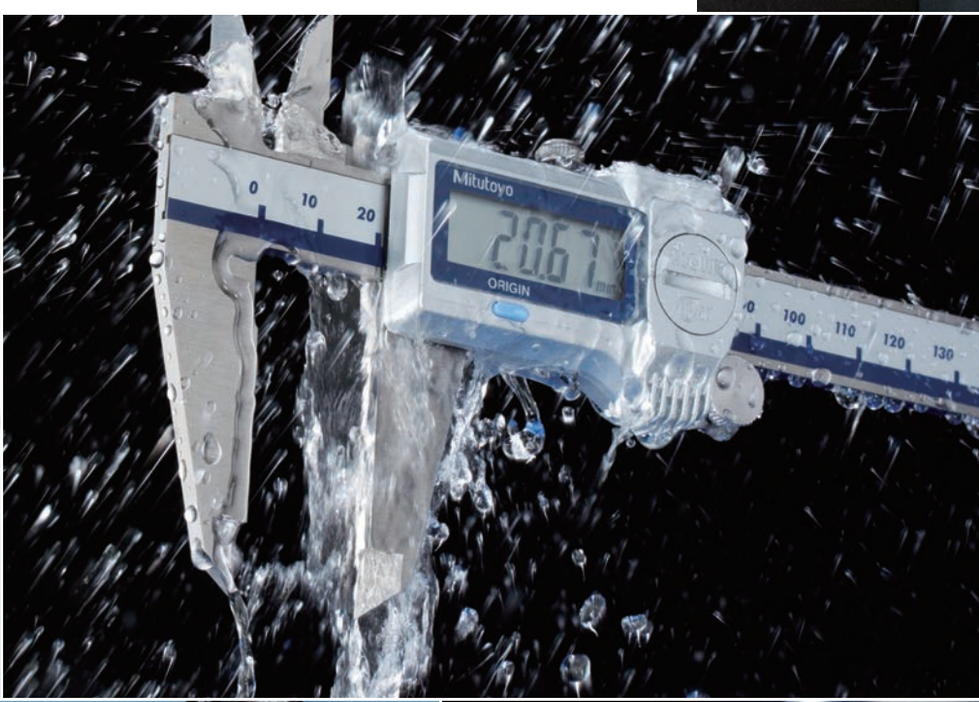

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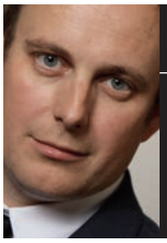

our**opinion**

Offshore rewards

Of all the harsh environments in which engineers can be found, the offshore oil and gas platform is perhaps one of the least forgiving.

With long shifts; weeks and sometimes months away from friends and family; often cramped living conditions; and limited recreational options, it can be a physically and mentally challenging place to work.

But as we report in this issue's cover story (p22) this could all be about to change, thanks to the emergence of a new generation of robot workers that promise to automate many of the tasks currently performed by humans.

As previously reported by *The Engineer,* the sector is no stranger to robotics: remotely operated and autonomous underwater robots have been used for some time to carry out the dangerous inspection tasks once performed by divers. But the next generation of offshore droids will take this one step further, and use tools and manipulators to actively carry out maintenance procedures both on platforms and beneath the waves.

> "Some believe oil and gas will be transformed within 10 years"

With serious commercial interest in the technology, and a number of trials either ongoing or due to start, some believe that the sector will be utterly transformed within the next 10 years, and that one of engineering's loneliest and most isolated manned-outposts will soon be a thing of the past.

With the majority of the sector's engineers now working onshore, the rise of the rig robot is – we're told – unlikely to put people out of work, which will be a relief to the oil and gas sector respondents to our 2018 salary survey (page 44) who remain amongst the highest-paid engineers in the UK.

Although, as always, it's an interesting read, perhaps the biggest "take-home" finding from this year's survey is how little has changed since 2017. While average salaries are still high compared to other industries, they have remained roughly the same year on year and have even declined in some sectors. Meanwhile, the alarming pay gap between men and women shows no sign of narrowing. The metrics that have changed – a marked reduction in the number for engineers considering a change of job and a growing concern over the potential impact of Brexit – all add to a picture of a sector that is hunkering down and bracing itself for a period of uncertainty. It'll be interesting to see what's changed when we publish next year's first post-Brexit survey. We'll be publishing an even-more detailed analysis of this year's results on our website on 18 June, along with a salary calculator that you'll be able to use to see how your salary stacks up against that of your peers.

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CENTAUR MEDIA

BIOTECHNOLOGY

£20m to look into how life works

Magnetic resonance equipment will probe molecular structures

HELEN KNIGHT REPORTS

A £20m investment in new nuclear magnetic resonance equipment is expected to give scientists in Britain a greater understanding of materials and molecular structures.

Global efforts to map the genes of humans and other creatures may have revealed the basic building blocks of living organisms, but without better knowledge of the way the millions of macromolecules within cells assemble and interact, scientists are still some way from fully understanding how life works.

In an effort to improve the understanding of how these individual components come together to create the molecular machines that carry out basic biological functions, researchers at Oxford University are undertaking a project to upgrade the institution's ultra-high field 950MHz NMR spectroscopy system.

The upgrade is part of a wider £20m investment in very high and ultra-high field NMR spectroscopy by EPSRC, alongside the Biotechnology and Biological Sciences Research Council, the Medical Research Council and Natural Environment Research Council.

NMR spectroscopy is used to determine the molecular structure of a wide range of materials. The technique can provide detailed information on the topology, dynamics and three-dimensional structure of these materials, including biological components in solution. It is the only technique that can offer a detailed view of biological components under conditions similar to those that occur in living organisms, or even in the living cell itself.

The technology consists of large, powerful magnets, alongside electronics used to transmit and detect signals.

The upgrade to the Oxford system will include the purchase of a "cryoprobe", high-sensitivity electronics designed to boost the system's signal detection capabilities, according to project leader Prof Christina Redfield, of the Department of Biochemistry at Oxford University.

In a cryoprobe, the electronics are cooled in a stream of helium gas at a temperature of around 20K (253C). This increases the sensitivity of the probe, and reduces the level of thermal noise generated by the electronic circuits and components within the signal receiver itself.

"In NMR the signal-to-noise ratio is a crucial factor, and this cryoprobe improves that ratio by up to a factor of three, meaning we can collect the data more quickly, or we can study more difficult samples," said Redfield.

In particular, the concentration of the solution in which the samples are held is an important factor in determining the signal-to noise ratio, she said. This means there is a limit to how dilute samples can be made.

"By having a probe which improves the signal-to-noise ratio, it means you can look at more dilute protein samples," she said. "Many proteins are unhappy in solutions at high concentrations, so being able to work at lower concentrations means that there are more proteins available for us to study."

The upgrade will also include a sophisticated sample changer, which will allow for more automated data collection, and for samples to be held at a pre-set temperature.

The upgrade will cost around £500,000, compared to £5m for a new NMR system with similar capabilities.

Alongside Oxford University, seven other universities are also receiving funding as part of the UK investment in NMR infrastructure.

Birmingham University will install a 1GHz system for use in medical research, such as real-time measurements of cancer cell metabolism, and in drug discovery, for example.

Warwick University will also be installing a 1GHz system, for use predominantly in materials science research. The system offers the potential for improved pharmaceutical formulations and drug delivery, and better quality materials for energy and catalysis, the university said. ■

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AUTOMOTIVE

Breakthrough in motor design

Better recycling, lower costs

HELEN KNIGHT REPORTS

A new motor design that eliminates the need for expensive rare earth magnets, allowing it to be much more easily recycled, has been developed in the UK.

Advanced Electric Machines (AEM), a spin-out from Newcastle University, has developed the High-Density Switched Reluctance Machine (HDSRM), which it claims is the most sustainable motor in the world.

The motor technology, which the company presented at the JSAE Spring Congress in Japan with support from the UK's Advanced Propulsion Centre, is designed for use in hybrid, range-extended and electric commercial vehicles.

Conventional traction motors used in the automotive industry are based on the use of rare earth magnets, according to Dr James Widmer, CEO of AEM. But these are expensive and need to be removed before the motor can be recycled, in order to recover some of their cost, while there are also concerns about the availability of supply, said Widmer.

"If you are starting to consider electric vehicles being manufactured in larger and larger volumes, it makes a great deal of sense to try to eliminate these materials altogether," he said. There are also technical drawbacks to the use of rare earth magnets in motors. When their temperature reaches 150°C, for example, they can de-magnetise, said Widmer.

"So in a hybrid vehicle, when you want to cool the motor with the same coolant that is being used for the internal combustion engine, and the temperature of that coolant is over 100°C, it gets very difficult to make the magnet work robustly and reliably," he said.

By eliminating rare earth magnets, the new motor can be very closely integrated with the internal combustion engine, including sharing coolant, simplifying the powertrain.

The technology is based on a switched reluctance motor, a type of motor in which power is delivered to the stator in the windings rather than the rotor, but unlike existing designs, the new device has a different drive configuration.

As opposed to a conventional switch reluctance motor, which needs specialist electronic equipment to allow it to operate, the new design uses an off-the-shelf inverter, making it cheaper to produce.

The company has also developed a more advanced motor that incorporates technology to allow the copper in the windings to be replaced with aluminium with no loss in performance, according to Mike Woodcock, strategy director at AEM.

This reduces the weight and cost of the motor, and also means it can be recycled more easily. ■

INDUSTRY

May sets out four goals

Technology a catalyst for growth

JASON FORD REPORTS

Britain will use data and AI to transform the prevention, early diagnosis and treatment of diseases like cancer, diabetes, heart disease and dementia by 2030.

This ambition is one of four addressed in a speech delivered at Jodrell Bank, Cheshire on May 21 in which prime minister Theresa May outlined new missions as part of the government's Industrial Strategy.

These include the production of zero emission cars and vans by 2040, more than halving energy use in new buildings by 2030, and the development of "well-designed products and services" to help people age healthily.

"As a government, we have set the goal of research and development investment reaching 2.4 per cent of GDP by 2027," said May. "That could translate to an additional £80bn investment in the ideas of the future over the next decade."

May outlined how government intends to incubate "a whole new industry around AI-in-healthcare", and work with industry to help "set global standards for managing technological change to maximise the benefits" of zero emission vehicles. The mission to halve energy use in new commercial and residential buildings is similarly expected to provide the catalyst for new technologies and more productive methods of construction.

"In each one of these four missions, scientific and technological innovations have the potential to create jobs, drive economic growth across the country and deliver tangible improvements for everyone in our country," said May.

The PM also used her speech to acknowledge the value of EU programme collaborations, and the Government's ambition to achieve a deep research and innovation partnership with the EU. ■

Newsinbrief

Brexit concerns

An EEF report has found 47 per cent of UK manufacturers concerned about accessing the skills they require after the UK leaves the EU. *Navigating Brexit: The Migration Minefield* urges more clarity from the UK government in relation to the post-Brexit landscape. According to the report, 68 per cent of manufacturers want guidance on what the changes after March 2019 will mean.

Costly skills shortage

A study by STEM Learning, the UK's largest organisation providing STEM education and career support, shows that current skills shortages are costing businesses in the sector a total of £1.5bn per year in temporary staffing, recruitment, training costs and inflated salaries. Some 89 per cent of businesses have struggled to recruit staff over the past year.

Carillion bosses blamed

Bosses at Carillion were "too busy stuffing their mouths with gold" to show any concern for the welfare of their workforce or pensioners. The final government report on Carillion's downfall also describes bosses as "delusional" and "shysters".

Oil confidence returns

The 28th Oil and Gas survey shows business confidence returning to the UK Continental Shelf. Overall, 64 per cent of contractors indicated they are more confident about doing business than they were a year ago compared with eight per cent being less so.

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ENERGY

Rapid charging network project

£1.6bn programme will enable the mass adoption of electric vehicles HELEN KNIGHT REPORTS

The world's first two gigawatt network of grid-scale batteries and rapid electric vehicle charging stations is to be built across the UK.

Pivot Power has unveiled plans for a £1.6bn programme to build the infrastructure needed to support the mass adoption of electric vehicles.

The battery network will also help the National Grid to manage supply and demand, particularly with the greater use of intermittent renewable energy and mass charging of electric cars.

The company, which has secured funding from UK investment manager Downing LLP, is planning to develop 45 sites across the country, with the first likely to begin operating at a location near Southampton in 2019, according to chief technical officer Michael Clark.

A further nine sites are due to begin operating within the next 18 months, he said. "Then the ambition is that over a five-year period, we'll have all 45 sites up and running."

Pivot Power will install 50MWh batteries at electricity sub-stations, which will be connected directly to the extra-high-voltage transmission system. This will allow the network access to far greater capacity than would be possible if it were linked to the lower voltage regional distribution system, said Clark.

"It means that we can operate at a scale that we couldn't dream about if we were going in at the 11,000 volt network on the distribution side," he said. "It also means that we can avoid some of the costs that we would have to incur if we were a lot further down the distribution system."

The battery network will be capable of storing enough electricity to supply 235,000 homes for a day, and releasing or absorbing two-thirds of the power of the planned Hinkley Point C nuclear power plant.

The vehicle charging stations will be able to support up to 100 rapid 150kW chargers. Once available in the UK, they will also be able to support rapid 350kW chargers.

Each charging station will have a 20MW power connection, enough to supply a town of 10,000 homes.

Combining batteries with electric vehicle charging will maximise the value from each grid connection, while gaining economies of scale. ■

Power surge: Many new charging stations will be needed in the UK

MEDICAL

Green tea to fight lung cancer

Quantum dots of leaf extract could be powerful weapon in treating disease

Researchers from Swansea University have found that quantum dots made from green tea could be a powerful weapon in the fight against lung cancer.

Quantum dots are nanoparticles used in everything from computers and solar cells to tumour imaging. They are usually made using synthetic chemicals, but the process can be expensive and sometimes results in toxic side effects.

In the search for a plant-based alternative, the Swansea team mixed green tea leaf extract with cadmium sulphate ($CdSO_4$) and sodium sulphide (Na_2S). The solution was allowed to incubate, causing quantum dots to form. Working alongside two Indian universities, the UK-based researchers were initially able to back up previous work conducted on quantum dots made using tea leaves.

"Our research confirmed previous evidence that tea leaf extract can be a non-toxic alternative to making quantum dots using chemicals," said lead researcher Dr Sudhagar Pitchaimuthu. "The CdS quantum dots derived from tea leaf extract showed exceptional fluorescence emission in cancer cell bioimaging compared to conventional CdS nanoparticles." AW

AEROSPACE

Drone could stay in the air for a year

Solar-powered UAV developed as an alternative to satellites

JASON FORD REPORTS

UK engineers have signed an agreement to further develop a solar-powered unmanned aerial vehicle (UAV) that can stay airborne for a year to deliver services that include surveillance and communications.

Engineers from Prismatic and BAE Systems will collaborate on the development of PHASA-35, a High Altitude, Long Endurance (HALE) UAV that can also be used for remote sensing or environmental science tasks at altitudes of between 55,000 and 70,000ft. Work is under way to prepare for a flight test in 2019.

According to BAE Systems, Solar HALE vehicles offer a significantly cheaper alternative to conventional satellite technology, with PHASA-35 (Persistent High Altitude Solar Aircraft) being a concept solar electric UAV that uses Li-ion battery technology and ultra-lightweight GaAs (Gallium Arsenide) solar cells to potentially maintain flight for up to 12 months.

The PHASA-35 concept has a 35m wingspan and weighs 150kg. A quarter-scale model completed a maiden flight in 2017, with Prismatic and BAE Systems now looking to take the technology a step further.

Michael Christie, strategy director within BAE Systems' Air sector, said: "Prismatic is a fast-paced and forward-thinking company and PHASA-35 is a great example of what the team can achieve in a short space of time."

BAE Systems will invest in the development and flight testing of the PHASA-35 system as part of its drive to develop new technologies to support future aircraft, working with SMEs and academia. ■

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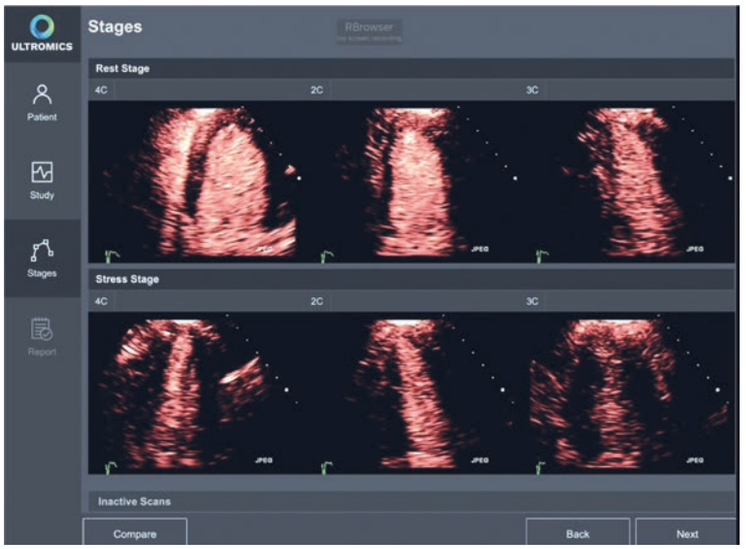
MEDICAL

AI to help heart disease diagnosis

New technology now being trialled aims to reduce errors by 75 per cent

HELEN KNIGHT REPORTS



The use of artificial intelligence to significantly improve the accuracy of coronary heart disease diagnosis has been given a boost, after its UK developer received a £10m investment.

Ultromics, a spin-out from Oxford University, is developing AI technology that analyses echocardiograms to detect signs of coronary heart disease, and is aiming to reduce diagnostic errors by up to 75 per cent.

The technology, known as Topological Analysis, is already being trialled in six NHS hospitals, with 14 more due to join the trial later this year, according to Ross Upton, CEO and co-founder of Ultromics, alongside Paul Leeson, professor of cardiovascular medicine at Oxford University.

Heart disease affects almost half of people over the age of 40, making it the world's biggest killer.

To diagnose the disease, cardiologists typically assess images created by echocardiograms, but even the best centres are only correct around 80 per cent of the time. This means many patients are sent for unnecessary surgery, while others with potentially fatal coronary heart disease go undiagnosed.

The AI technology has been trained on a huge database of patient records held at Oxford, in order to spot signs of the disease, and detect where clinical mistakes were made, said Upton.

The system looks at changes in the heart's geometry under stress conditions, he said. "We use thousands of measurements, and combine them with machine learning, to be able to predict patient outcomes."

Prime minister Theresa May has pledged millions in government funding to support the development of AI for early disease diagnosis.

"Our work ties directly in to that mission statement; it is using AI to help diagnose patients and create better patient outcomes," said Upton.

> "The system looks at changes in the heart's geometry"
> Ross Upton

"Just by using [the technology] we can stop patients being referred for surgery unnecessarily, and we can stop patients being sent home with coronary heart disease," he said.

The company recently announced that it has raised £10m in Series-A investment, which it will use to market the technology in the US, and make it available in the UK in early 2019. ■

DEFENCE

Autonomous minesweeper

Royal Navy takes delivery of system that can detect even the most advanced sea mines

A new unmanned minesweeper capable of clearing digital mines has been handed over to the Royal Navy.

The demonstrator was designed and manufactured by Atlas Elektronik UK in Dorset under a £13m contract. It comprises an 11m long, 10-tonne unmanned surface vessel (USV) that tows three coil auxiliary boats behind it. The auxiliary boats emit magnet, electric and acoustic signals that can detonate numerous mines, including digital mines that detect and target passing ships.

"This autonomous system will restore the Royal Navy's sweep capability, enabling it to tackle modern digital mines that may not otherwise be discovered in challenging minehunting conditions," said Brigadier Jim Morris of the Royal Marines.

The vessel features a "sense and avoid" capability and is designed to operate alongside other autonomous systems. Operated either from a ship or a portable control cabin, the minesweeper has been undergoing trials for the past four months, carried out by Atlas Elektronik and the Navy's Maritime Autonomous Systems Trials Team. AW

RAIL

Hydrogen-powered train tested

Move is response to government call to eliminate diesel

JASON FORD REPORTS

Alstom is working with Eversholt Rail on plans to convert Class 321 electric trains to hydrogen operation through the installation of hydrogen tanks and fuel cells.

The move is said to represent the rail industry's first substantive response to calls from government to phase out diesel rolling stock by 2040.

"The potential for hydrogen trains is enormous," said Nick Crossfield, managing director, Alstom UK and Ireland. "Not only are hydrogen trains zero carbon, they are near-silent and emit no particulates, which means they offer substantial air quality and noise pollution benefits."

Crossfield added that under 50 per cent of the UK rail network is electrified, a situation exacerbated in 2017 when transport secretary Chris Grayling cancelled three rail electrification projects.

Alstom is currently investigating alternatives to diesel rolling stock with the Coradia iLint, a passenger train that runs on electricity generated by a hydrogen fuel cell.

Hydrogen can be produced using sustainable electricity and electrolysis or through industrial processes. The fuel cell on the train produces electricity through hydrogen and oxygen to create water. The electrical energy is intermediately stored in batteries and the train is powered by an electrical traction drive. The only exhaust is steam and condensed water.

During tests in Germany, iLint achieved a speed of 80km/h. ■

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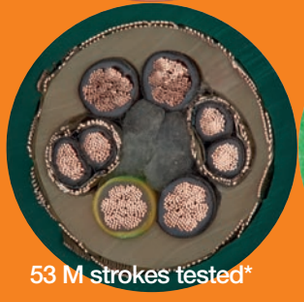
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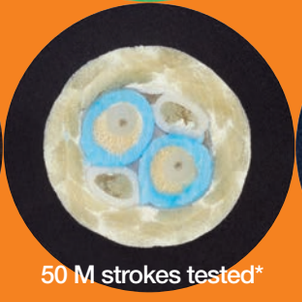
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CIVIL

Protecting road and rail slopes

Newcastle-led project will attempt to prevent need for costly repairs HELEN KNIGHT REPORTS

Vital infrastructure such as road and railway slopes could be better monitored and maintained, thanks to a project by researchers in the UK.

In Britain alone, there are 748,000 properties with at least a 1-in-100 annual chance of flooding, while train derailment caused by slope failure is the greatest infrastructure-related risk faced by the railways.

The cost of infrastructure failures is also high, with emergency repairs costing Network Rail ten times as much as planned works, which in turn cost ten times as much as maintenance.

A £4.8m EPSRC-funded project, led by researchers at Newcastle University, is aiming to gain a better understanding of the way linear infrastructure deteriorates under increasing environmental pressures, such as more extreme weather, according to project leader Dr Stephanie Glendinning, of Newcastle's School of Civil Engineering and Geosciences.

The research programme, Assessment, Costing and enHancement of long life, Long Linear Assets (ACHILLES), also involves researchers from Southampton, Durham, Loughborough, Leeds and Bath Universities, plus the British Geological Survey, infrastructure owners and consultants.

"We don't actually know which slopes are going to fail and when, so we're trying to identify at-risk places on the network, so that they can be preemptively monitored and perhaps repaired," said Glendinning.

As part of the project, the researchers are investigating how soil responds to cycles of wetting and drying, to understand how slopes and bedding are affected by more periods of heavy rain, for example.

The researchers have carried out preliminary work that has shown these wet and dry cycles do reduce the strength of the soil, but hope to include surface chemistry and minerology studies to investigate further, said Glendinning.

"There could be things going on in these soils that we haven't been looking at before, which could give us a pre-cursor to failure, so that we can then go out onto the network and look for these signs," she said.

They also hope to use information gathered by network operators, such as data from those slopes that are already equipped with instrumentation to measure water content and pressure, and soil movement, for example.

Imaging vegetation could also reveal important clues. ■

Vulnerable: stretches of line like that at Dawlish need monitoring

AEROSPACE

£24m Goonhilly investment

Financial services company founder puts money into famous earth station facility

UK businessman Peter Hargreaves has joined the private space race with a £24m investment in the Goonhilly Earth Station based on Cornwall's Lizard peninsula.

The funding – the largest single investment in the facility – will see Hargreaves, who is the founder of financial services company Hargreaves Lansdown, take a controlling share in the site.

Once the largest satellite earth station in the world, Goonhilly is famous for its role in the first transatlantic TV transmission which was made using Telstar, the world's first telecommunications satellite. It also beamed the lunar landings in 1969.

Current owner Goonhilly Earth Station Ltd acquired the facility from BT in 2014 and has since invested £5m in rejuvenating the site, which provides spacecraft tracking and monitoring services to satellite operators.

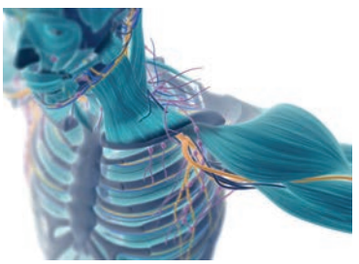
The latest investment follows the announcement of an £8.4m contract with the European Space Agency which will see its 32m diameter GHY-6 antenna upgraded for missions to the moon and Mars. JE

MEDICAL

New implants could target young people

Aim would be to fix problems early in life to avoid issues in old age

HELEN KNIGHT REPORTS



Implants that can fix early problems in bones and joints before they become too serious could be developed in a new UK research and development centre.

The Medical Device Prototype and Manufacture Unit at Imperial College London will use additive manufacturing and advanced imaging techniques to print parts with nanoscale features and then study how they interact with the body.

Bone and joint disorders are now one of the biggest expenditures in the NHS, according to project leader Dr Jonathan Jeffers. "The current generation of orthopaedic implants are brilliant, but they tend to treat the end-stage disease, and are very invasive, because they involve chopping out the entire joint," he said. "What surgeons need is something that can treat younger patients, to try to prevent the disease progressing."

The researchers plan to produce early intervention implants using material that is tailored to make the surrounding bone stronger, by controlling the strain experienced.

They also hope to make smart instruments and implants that can measure biomarkers in synovial fluid to measure joint health, and new biomaterials such as nanoneedles that can bypass the membrane of bacteria cells and act as an anti-infection coating for the devices.

Finally, they hope to manufacture ligament, tendon and capsule repair patches a Velcro-like surface to adhere to soft tissue. ■

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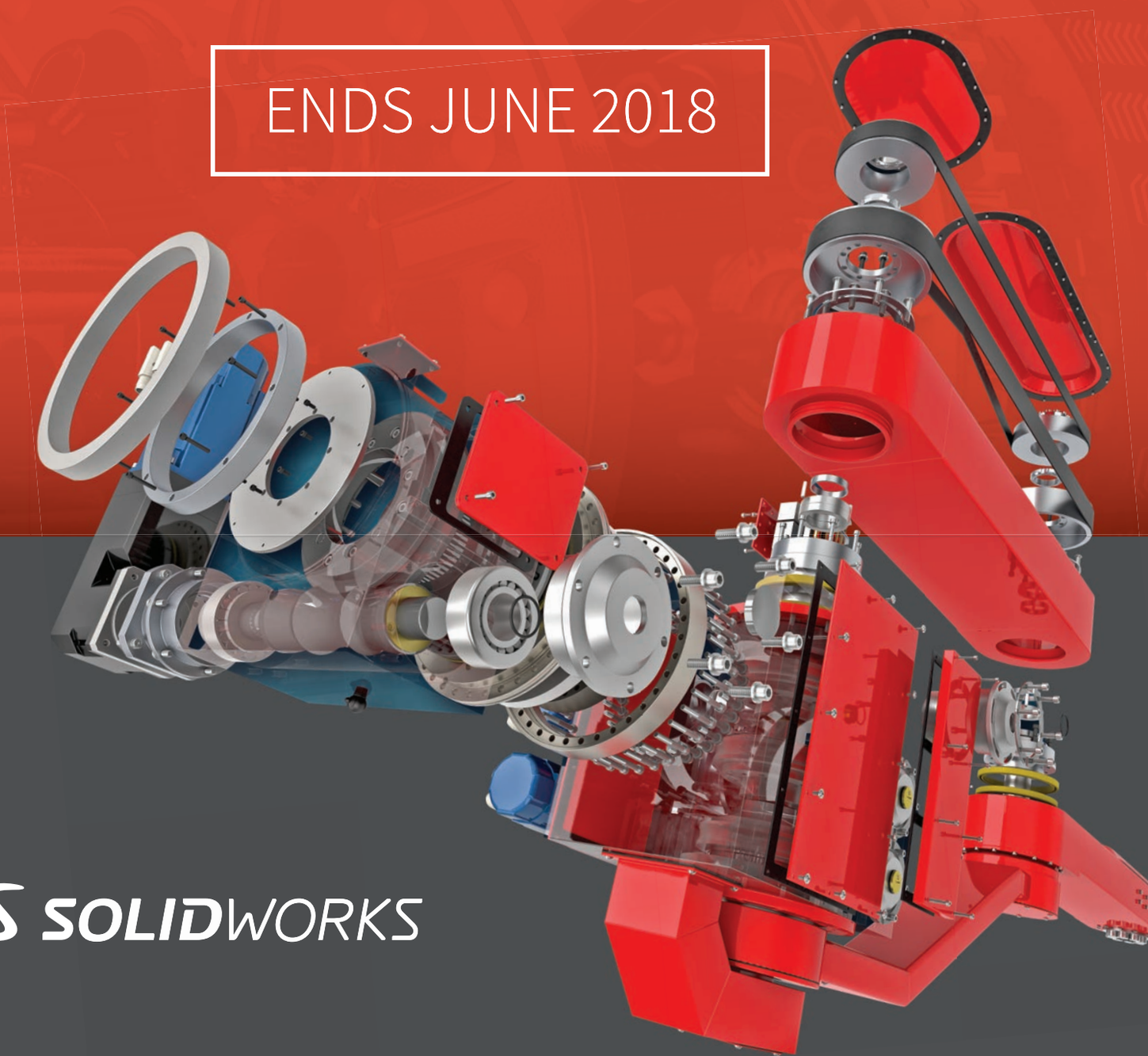

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AUTOMOTIVE

Diesel cars may have a future

Bosch experiments with a system that dramatically reduces NO_x

JASON FORD REPORTS

Bosch believes there is a future for diesel cars following the development of an air and temperature management system that dramatically cuts NO_x emissions.

The technology – combining a new air management system, and intelligent temperature management – has been undergoing real driving emissions (RDE) tests in Stuttgart.

"We are convinced that in the future, no one will be able to impose a blanket ban on diesel in cities," said Bosch CEO Volkmar Denner. "The Euro 6 standard allowed 80mg of NO/km in the test bay, and is currently 168mg on the road, set to decrease to 120mg as of 2020. Using our new exhaust technology, automakers will be able to come in well below these limits."

Temperature and driving style are two factors that have limited the performance of diesel cars in relation to NO_x emissions.

Most diesel cars are fitted with Selective catalytic reduction (SCR) components that are supplemented by doses of AdBlue in the exhaust system, which catalyses nitrogen oxides into nitrogen and water vapour.

Dr Michael Krüger, Bosch's head of diesel technology development, explained that SCR systems are active at temperatures from 200°C up to 550°C.

"This temperature range must be maintained, which isn't such an issue at high-speed but temperatures of 200°C are not always achievable in urban motoring for a couple of reasons: low average velocity, stop and go, traffic jams," he said. "To rectify this, you need to actively control the exhaust gas temperature."

In order for the SCR to reach optimum performance, the engine's exhaust gas recirculation (EGR) system has been adapted to optimise the amount of hot exhaust gases directed at the SCR and diesel particulate filter (DPF) units, while AdBlue dosing is also enhanced. The engine's DPF and SCR system have also been positioned closer to the engine to mitigate against heat loss.

Bosch's platform demonstrator has been adapted with a 1.7l diesel engine and conventional turbocharger with reduced mass inertia to speed up faster and accommodate dynamic driving styles without incurring a spike in emissions.

"That's important because for RDE a fast air system is essential," said Krüger. "Besides exhaust gas treatment and thermal management, [it's] one of the key success parameters." ■

> "Temperatures of 200°C are not always possible in urban motoring"
> Dr Michael Krüger of Bosch

Cleaner drive: Bosch's test vehicle in Stuttgart

AEROSPACE

Stronger, cheaper plane material

Consortium hopes to upscale production of material produced in laboratory

Bath University is spearheading a project to develop a new type of thermoplastic composite for aerospace that is lighter, stronger and cheaper than current materials.

The New Hybrid Thermoplastic Composite Aerostructures (NHYTE) manufactured by Out of Autoclave Continuous Automated Technologies project is being funded with €5.2m from Horizon 2020.

Its aim is to produce a material based on a commercial PEEK (poly ether ether ketone)-Carbon Fibre Prepreg with the addition of amorphous polyetherimide films.

So far, these types of materials have been limited to the laboratory. However, the NHYTE consortium is aiming to identify and implement a suitable manufacturing process which can be upscaled to industrial levels. Parts will be produced by a robotic machine using new processes such as automated fibre placement and continuous forming, and will be assembled by induction welding.

"This innovative material... is an example of multifunctional composite, since it returns both functions of toughness improvement and process simplification," said Prof Michele Meo, from Bath's Department of Mechanical Engineering. AW

SENSORS

Spectrometer can fit inside a drone or plane

Infrared device uses the optical properties of silicon

STUART NATHAN REPORTS

Brazilian researchers have devised a method for making an infrared spectrometer that could fit into a drone or smart phone.

Researchers from the University of Campinas' device research laboratory in Brazil, collaborating with colleagues at the University of California San Diego, have developed the Fourier-transform Infrared (FTIR) spectrometer based on silicon photonics. The technique uses the optical properties of silicon, whose components can be made using the same processes used to mass-manufacture electronic components.

Resulting from the PhD project of Mario César Mendez Machado de Souza, the device uses silicon waveguides, a basic type of component in silicon photonics. The main problem that Souza had to overcome was that the refractive index of silicon, which determines how fast different wavelengths of light travel in it, is a thermo-optical effect; that is, it is temperature-dependent. To achieve high resolution, the temperature needs to be high, and this induces non-linear changes in refractive index, making it hard to control.

"In practice, what happens when a thermo-optical effect is applied to a silicon-based infrared spectrometer with integrated photonics is that the Fourier transform mathematical operations used to convert the radiation spectrum data collected produce completely wrong results," Souza explained.

To overcome this, Sousa and his colleagues developed a laser calibration method to quantify and correct the distortions. ■

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LEONARDO

Patent filings: the truth behind the data

New figures suggest innovation in the UK has increased, but we are lagging behind other parts of Europe and Brexit could yet turn the clock back

The latest batch of patent filing data released by the European Patent Office (EPO) reveals that innovation activity in the UK has increased, which is always a good sign. However, dig a bit deeper and the true picture becomes clear– UK innovators are still not doing enough to protect their inventions, unlike those in many other parts of the world.

The total number of patent filings made to the EPO by UK businesses grew by 2.4 per cent to 5,313 in 2017, a sign that investment in innovation remains buoyant. Drilling down into the UK data for industry sectors, the number of patent applications for innovations related to civil engineering rose considerably – increasing by 20.2 per cent. Similarly, the number of pharmaceutical and biotech patent applications rose by 15.7 per cent and 25.3 per cent respectively. Patent applications for medical technology overtook transport as the UK's most active technology field, with 364 patent applications made in 2017.

While these statistics suggest that innovation in the UK is increasing, it is significant that the UK's share of the overall number of patent applications made to the EPO in 2017 remains low by comparison with some other countries. Ranked 17th in the table of countries that made applications to the EPO in 2017, innovators in the UK filed just 82 applications per million of population. Puerto Rico, Norway and Ireland ranked higher. Topping the table, innovators in Switzerland filed over ten times as many applications per head of population, which makes them the most innovative country in the world.

The outlook for UK innovation is improving strongly in some areas, however. The rise in patent applications related to pharmaceutical and biotech innovations is particularly positive and shows that UK-based businesses are active players in the development of new cancer drugs and other much-needed medicines. The high volume of filings in this sector could also be due to greater awareness and understanding of the value of patent protection. The sharp rise in the number of patent applications related to construction in 2017 may well be linked to current investment in several large-scale infrastructure projects, including Crossrail and HS2.

However, despite the chinks of light in the data, cultural issues still need to be addressed in order to ensure that UK businesses don't lose ground to competitors. While the Government has indicated a willingness to support UK innovation, the economic uncertainty expected over the next few years, as Britain exits the EU, makes it even more important that the conditions are right to enable the UK to realise its innovation potential.

The Government's Industrial Strategy has set out plans to boost the productivity and earning power of people throughout the UK, and in February the Government announced a new £90m fund designed to align the UK's agriculture supply-chain businesses with AI, robotics and data science. While this is helpful, the Government has a more important role to play and this should be its main focus.

In particular, diversity and international collaboration should be recognised and supported to ensure that Brexit doesn't negatively impact the UK's ability to attract skilled research scientists and to facilitate research projects at university level.

Furthermore, it is vital that innovators are able to achieve a good return on investment after Brexit. To assist with this, the Government must ensure that British companies have access to key markets, with as few trade barriers as possible.

Reaching for solutions: robotics and AI present huge opportunities for the UK

However, the problem of Britain's underwhelming performance when it comes to commercialising its innovations is not simply due to a lack of government intervention. There is also an onus on businesses to ensure that they are nurturing and supporting innovation.

Taking lessons from nations where innovation is considered an integral part of growing a successful business, British companies should consider establishing 'skunk' works or labs to sponsor research activity within their own corporate structures. They should also make innovation part of their business strategy and set goals for achievement in the same way as they might set targets for financial performance.

UK companies may also need to reconsider what it means to be innovative. Instead of concentrating on the springboard effect that comes from being first to market, they should be taking a more long-term view of commercialising their innovations.

In today's intensely competitive and fast-paced markets, the real value of innovation often comes from licensing deals or industry collaborations, where patented technologies are shared to accelerate change. Of course, a deep understanding of the value of intellectual property rights is critical to this way of working.

In short, if Britain wants to increase its share of EPO patent applications in the future, it must start by self-learning a new approach to doing business that fosters innovation in every way and at every level. ■

Karl Barnfather is chairman of intellectual property firm Withers & Rogers

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Mailbox

Thehottopic

Brexit and skills

Our coverage of the EEF's report on employers' fears of a gap when we leave the EU sparked a lively debate

It is a mystery to me why large corporations can't find the 'talent' they need from within the UK. Are British people intrinsically less talented than people from other countries? I accept that there might be exceptional cases but these are rare. How about industries investing in training instead of poaching talent trained by foreign industry?
Michael Morley

I work in an international company, and I have worked in British companies. From my experience, reasons firms look elsewhere are:
1) The UK has been a service-oriented economy for some three decades, so that is where STEM graduates have gone in the past.
2) More supply gives lower costs. So why not cast your net wide? Firms are money-making machines, they are not interested in the welfare of the public.
Mohammed Abdullah

Is this 47 per cent more, or less, than the proportion worried about a skills shortage before Brexit? As far as I can remember, about half of employers have always moaned about the difficulties of recruiting skilled workers; i.e. those already trained by someone else. It's about time they actually did some training themselves.

It is difficult to have any sympathy with the likes of the EEF and their ilk who are directly responsible for causing the situation by neglecting the youth of this country for the sake of short-term profits. It is this philosophy which greatly affected the Brexit vote where the working population of this country and particularly the young were treated to zero-hours contracts, a job in McDonald's or long hours in a supermarket.

Not a very inspiring prospect for the future, as was highlighted by the recent Willets' report which advocated giving 25-year-olds £10,000 to be able to afford to buy a house. What is really needed are proper, meaningful and interesting jobs paying the correct money for young people to be able to buy their own homes and achieve job satisfaction. If it takes Brexit to achieve this then so be it – it would be a big improvement on the status quo.
Quiet Observer

There are job positions that UK workers do not want to take or even train for (not just in engineering). Why shouldn't positions be made available for both skilled and unskilled workers from outside of the UK if they are willing to work? What about all of the British workers such as me who have been given opportunities to work outside of the UK? I know plenty of British people here in Germany either studying (often mechanical engineering) or working in manufacturing. The transfer of knowledge and skills across borders is healthy. 'British Jobs for British People' is completely the opposite.
Alec Thorne

I have been working in industry since 1963, starting as an apprentice toolmaker. I am still working, and over the years have witnessed an ever-increasing decline in skills training.

The majority of people appear to blame our industries for the lack of training. I do not feel this is the whole story. It is more a cultural misconception of getting your hands dirty.

It starts from the home through the education system and ultimately leads to a degree, that in the end has no, or little, reference to the ultimate career/job that the young person will follow. The attitude is that a degree in anything is better than no degree, so worry about the job later.

A conversation with a university lecturer several years ago led me to despair when I asked what career her 17-year-old son was about to embark upon, and received the reply that he (the son) wanted to read engineering at Warwick, but they (the parents, both lecturers) felt it was too narrow a subject.
John Smith

Inyouropinion

Readers were intrigued by our May issue's feature on Oxford firm First Light Fusion

Sounds very positive, almost unbelievable for something that's generally regarded as the holy grail when producing power. Good luck is what I say.
Tony Ruttle

It reminds me of a lecture I went to in 1975, where they were firing a pulse of laser light at a bead of frozen deuterium. The idea was that the shockwave would create sufficient pressure in the centre that the nuclei would fuse to helium. Creating a power station would be a challenge, but the speaker said there would be a conveyor belt of beads (sitting on needles). As soon as one was blasted, the next one would slot into place and be blasted.

So it would be a continuous process, like a nuclear internal combustion engine.
Ian Downie

I'm assuming that all these nuclear techniques are still focusing on generating heat, which they will use to vaporise water to drive steam turbines to create electricity? Can we not think about cutting out all these extra processes (heat, steam, rotating magnets) and consider ways to generate a current directly? Stimulating the flow of electrons in a conductor? That would give a fresh meaning to the term 'Direct Current'.
Graham Field

That makes at least two companies in the UK hoping to do for millions what the world has spent billions trying to achieve.

First there was Tokamak Energy, which hopes to do a poor man's ITER. Now First Light Fusion is trying to do what the National Ignition Facility (NIF) in the USA is up to.

The NIF uses 'inertial confinement fusion', the approach that Ian Downie refers to [above]. Now all we need is someone to revive cold fusion.
Michael Kenward

Join the debate theengineer.co.uk

Thesecretengineer

You can laugh all you like about 'health and safety gone mad', but there is a serious side to all this, argues our secret engineer

It's a funny thing, perspective. You believe you've got the hang of something, formed your opinions and are happy with them; and then along comes something else to change that perspective and you start questioning what you know. Such a shift came about recently during a conversation with a few colleagues.

We were talking about the use of ladders and how these days you have to go on a course to use one. Although not totally disparaging of the need for such a thing, there was a slight note of derision hanging in the air; especially when the practice of regularly inspecting stepladders and passing them as fit for service was brought in. We all understood the need for caution but there seemed to be a general response of "really?" The consensus was that if 'nanny state' was ever writ large, then it was in this case.

The need for training with regard to lifting heavy objects met with more sympathy, especially as one member of our little group had recently been suffering quite badly with a bad back. A bad back that he felt could be traced to trying to move a particularly cumbersome crate in the factory. He was aware that he could have asked for help and that lifting equipment was available.

However, filled with hubris and possibly a reluctance to recognise that he is no longer 21, he gave it a go on his own and the next day he could barely get out of bed. If he'd been on a course he would have been equipped to make the decision and to gauge the risks before diving in.

However, a day learning to lift boxes was still generally agreed upon as possibly a bit "health and safety gone mad". Yet another way of removing any personal application of common sense along with the active neutering of personal responsibility.

Having said this, we are all experienced in the field of industry. None of us was actually anti-safety as such, and in fact some had their awareness of the importance of these matters heightened by close brushes with catastrophe on a personal level.

I clearly recall an incident at Whizzbang Aviation where a group of us were rounded up to help lay down a free-standing steel frame with various bits of pipe and random vacuum-related gubbins attached to it.

All went well until it got to about 30 degrees from the vertical. The true weight suddenly became apparent and everyone ran away abandoning it to its fate – except for me. I was thrown flat on the floor with one of the pieces of cast pipe crashing down across my ankle. Fairly miraculously I fell on a stack of plasterboard that crushed nicely, and the flanges on the ends of the pipe stood the main section off the floor just sufficiently to not cause me any damage. I could feel it pressing firmly against the bone though and the frame had to be lifted before I could get my foot out – it was that close.

The shift in how 'health and safety' is to be viewed came through an example recalled by one colleague about a previous place of work. Apparently a senior member of staff had climbed on to a low, flat roof to undertake some task but hadn't 'tethered on'. The low altitude was emphasised, as was the marginal risk of falling off the expanse of roof; leading to the inescapable conclusion that the health and safety bod was a petty busybody.

The moral clearly apparent to all at the telling of this sorry tale was that the seemingly simplistic courses were undertaken just so that the company wouldn't be sued if anything went wrong – which is when the penny dropped. They force you to be responsible by equipping you to safely carry out tasks.

In short, if anything goes wrong you will legally only have yourself to blame. Rather than legislation removing the need for personal responsibility or "common sense", it forces you into using them and that, surely, is far from mad? ■

Engineering, science and the politics of EU research programmes

Encouraging signals in prime minister's keynote speech

On 21 May I found myself on a train to Macclesfield with a bevy of other stakeholders from the world of science and research, including the science minister and business secretary, all heading off to hear the prime minister give a speech on science and the Industrial Strategy at Jodrell Bank.

A prime ministerial speech focused entirely on science is a sufficiently rare event to render the very fact that it is happening as significant as the words spoken. Happily, there was much to applaud. Firstly, I was delighted to hear the PM refer explicitly to engineers and innovation, alongside scientists and research. Secondly, the speech positioned science and engineering firmly at the heart of the Industrial Strategy, acknowledging the role of entrepreneurs and business in delivering the benefits associated with research. Thirdly, she set out a vision that was both ambitious and inclusive, stating: "Our challenge as a nation, and my determination as prime minister, is not just to lead the world in the fourth industrial revolution – but to ensure that every part of our country powers that success."

Perhaps most notable of all was the impassioned finale of the speech in which she stated for the first time that the UK would seek full association with the excellence-based European science and innovation programmes – including the successor to Horizon 2020 and the Euratom Research and Training Programme, the primary vehicle through which the EU funds civil nuclear research. A few days later, the Government added further colour to this high-level aspiration by releasing the slides that they had presented to European Commission negotiators, setting out the key elements of their proposed future partnership for research and innovation, including the possibility of an ambitious, and unprecedented, Science and Innovation Pact.

Interestingly, the presentation hints at a willingness to make concessions. For example, it states that in the context of these programmes, the UK "will respect the remit of the CJEU [European Court of Justice], where relevant" and acknowledges that any Science and Innovation Pact would have to be "underpinned by wider agreements and arrangements on cross-cutting issues such as data sharing and protection, researcher mobility and intellectual property". The presentation ends by throwing down the gauntlet to the Commission to come to an early agreement on this.

Over the past few months, the Academy has been exploring the significance of EU research and innovation funding programmes to UK businesses. This topic has received far less attention than the significance of these programmes to UK academia, and we organised a round table in March for science minister Sam Gyimah to hear directly from businesses and entrepreneurs about European collaboration. The discussion highlighted the fact that many UK businesses, large and small, have both extracted important benefits from accessing EU programmes and played influential roles in shaping European research and innovation agendas across a range of sectors and disciplines.

> "I was delighted to hear the PM refer explicitly to engineers and innovation"

This is reflected in the data, which show that UK business is consistently highly engaged across all industrially relevant areas of the EU research and innovation framework programmes. The UK currently ranks fourth of all 28 EU member states for the number of business participations in Horizon 2020, with support for SMEs of particular importance. SMEs receive the majority of funding awarded to UK businesses and the UK is continually one of the top-performing countries in SME-specific schemes.

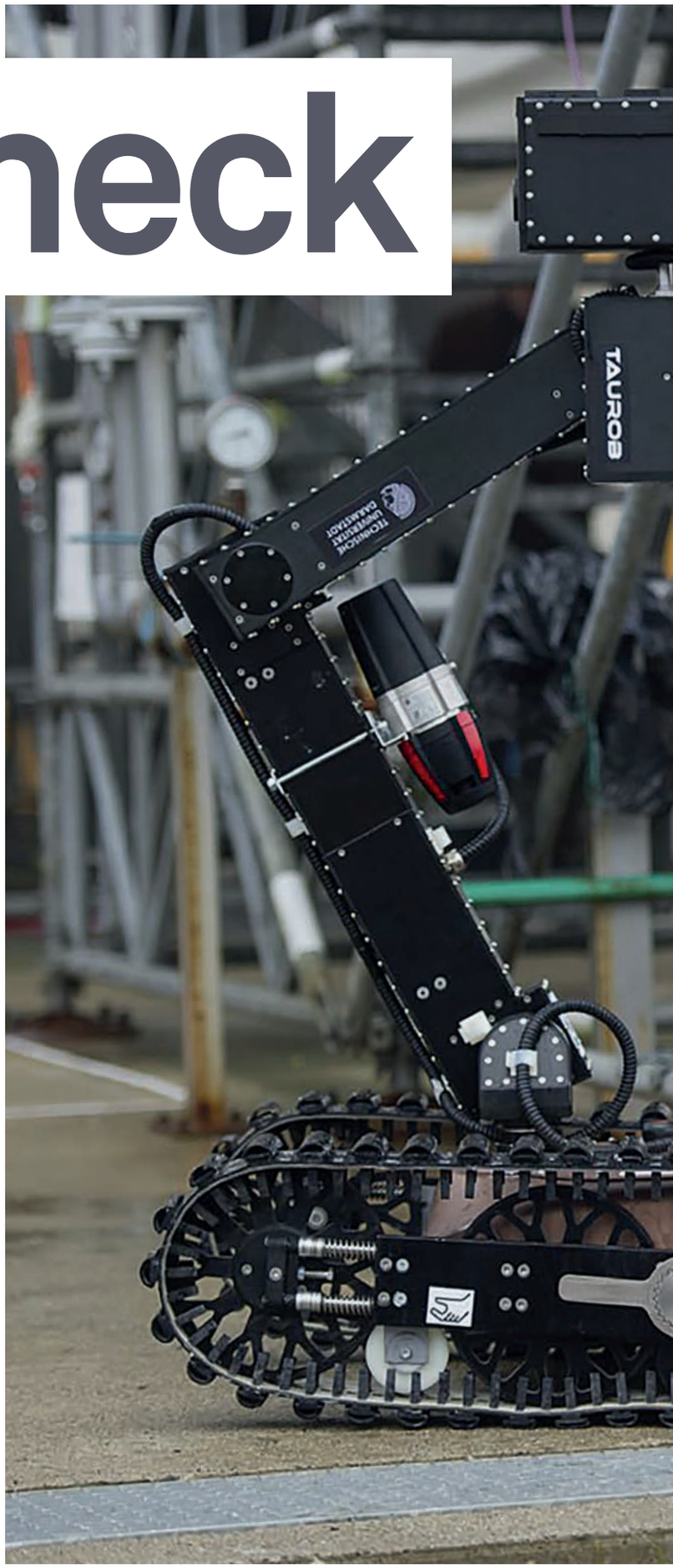
Businesses say the benefits of participation go far beyond access to funding, providing important opportunities to build trusted relationships with international partners, whether through formal collaborations, participation in networks or across supply chains. Other distinctive features of EU research and innovation support from the perspective of business include the scale of support on offer, in terms of both budget and number of partners; the availability of support across the full spectrum of research and innovation; the breadth of sectors that are supported; and the long-term nature of the support, which is regarded as being less subject to short-term changes than the UK's national provision.

However, UK business performance in Horizon 2020 has recently fallen, with the UK slipping from second position in September 2016 to its current fifth position in terms of funding received by business. While UK businesses that are already established partners in EU programmes continue to be involved, they are receiving fewer new approaches to join collaborations, and businesses without prior experience of EU programmes are finding it more difficult to engage.

The response of the Commission's negotiating team to the UK's proposals was said to be encouraging, and science and innovation collaboration is widely regarded as one of the least controversial elements of our future partnership with the EU. Time will tell whether these positive signals will translate into early agreement on a Science and Innovation Pact, or whether the goodwill on both sides will be insufficient to outweigh the politics and complexity of the wider negotiations. ■

Dr Hayaatun Sillem is chief executive of the Royal Academy of Engineering

Roughneck robots



The offshore industry faces a future where completely unmanned platforms are operated, inspected and maintained by teams of autonomous robots. Andrew Wade reports.

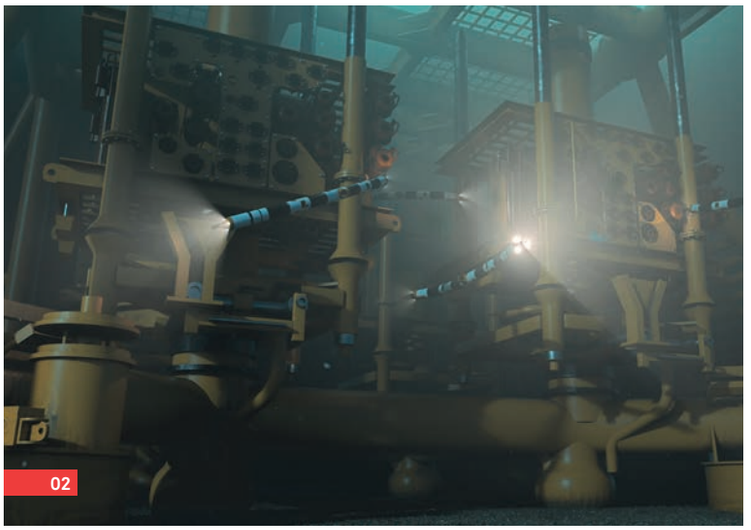
In many ways, the offshore industry is a perfect candidate for automation. Inherent dangers and remote locations make for tough working conditions, with long stints at sea taking their toll on both body and mind. Recruitment has become difficult, and the oil price collapse of 2014 helped further erode an already ageing workforce. While prices have recently recovered, the lean years in between prompted investment in robotics, as big oil was forced to pursue efficiencies and prepare for a more uncertain future. With automation technology becoming more prolific, the industry now stands on the verge of fully unmanned platforms.

"For millennials – although it's hard to generalise – going to work offshore in return for lots of money isn't necessarily what they want to spend their life doing," Prof David Lane, from Heriot-Watt University, told *The Engineer*.

"Oil companies do have a long-term view that they would like to have fewer people offshore. Basically, if they could get to all-robotic inspection, repair and maintenance, they'd love it. If you could make it reliable for people back on 'the beach', as they call it, back on dry land, that reduces cost, it reduces risk and it also helps them with recruitment."

As well as heading up the Edinburgh Centre for Robotics, Lane is also the director of ORCA (Offshore Robotics for Certification of Assets), a nascent research consortium exploring robotics and AI for the offshore sector. Backed by EPSRC, the group brings together five universities (Heriot-Watt, Edinburgh, Imperial College London, Oxford and Liverpool) alongside more than 30 industrial partners. Its goal is to build certified assets that can further de-risk the offshore environment, licensing out the technology it develops or bringing it to market through in-house start-ups. "The overall objective actually isn't about robotics, it's about asset integrity management," said Lane. "It's about being able to do more opportunistic inspection."

Robots for subsea inspection and survey have been prominent in the oil and gas sector for several decades. Autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs) dominate these missions. Exciting advances continue to be made here, with more agile and intelligent robots taking on increasingly complex waterborne roles. However, it's out of the water where the biggest changes are happening. In the long term, these 'robotic roughnecks' will not only be able to measure and inspect, they will also be able to interact with



the platform environment. "The maturity is around systems that can inspect," said Lane, who believes interaction is the next key phase of automation. "So not just looking at things, but then starting to fix them. Being able to turn valves, for example, turn things on and off and do simple intervention tasks."

One of the robots ORCA is working with is ANYmal, an autonomous quadruped designed for extreme environments. ANYmal weighs 30kg and can operate a 10kg sensor payload for about three hours. Its flexible joints allow it to get flat to the ground and inspect areas that other robots may find difficult to reach, as well as crawl up stairs with an incline of up to 45 degrees. A ruggedised design and IP-67 certification protect the robot from water and dust ingress. Parent company ANYbotics – spun out of ETH Zurich – is targeting the oil and gas sector in particular, where it believes quadruped robots are uniquely equipped to deal with the intricate layouts of offshore rigs.

"An offshore platform consists of complex installations of machinery which includes steps, pipes and other obstacles as well as steep stairs connecting multiple floors," explained ANYbotics co-founder and software engineer Péter Fankhauser. "These environments are designed with humans in mind but pose a challenge for traditional robots to navigate. With a legged platform such as ANYmal, obstacles, stairs, and narrow paths can be more easily navigated."

As with most of the new breed of offshore robots, ANYmal can operate with a high degree of autonomy, using lasers and cameras to navigate. If it gets stuck or encounters an "anomalous situation", a human operator back onshore can step in and take control. Using a docking station, multiple robots can operate in shifts, providing round-the-clock visual, thermal, and acoustic inspection as well as gas detection. For now, intervention is limited to using its limbs to push buttons, but more advanced manipulation capabilities are planned.

"We are currently running several pilot projects both onshore and offshore and we are targeting long-term deployment of ANYmal for 2019," said Fankhauser. "Currently, ANYmal can solve simple manipulation tasks by using its feet to, for example, push a button. However, adding additional manipulation skills is definitely on our roadmap."

01 ARGONAUT, which will be deployed by Total on its Shetland gas plant

02 Eelume's underwater robots can be deployed in teams

ANYmal emerged from the ARGOS (Autonomous Robot for Gas and Oil Sites) Challenge, an event set up by French energy giant Total in 2013. It challenged teams to design and build robots for routine on-platform inspection as well as emergency situations. Five international teams went head-to-head in a series of increasingly difficult tasks. Team ARGONAUTS, comprising members from Austrian robotics firm Taurob and Germany's TU Darmstadt, was eventually named the winner in May 2017. "They were the best in class in robustness, reliability, and also being able to transfer between the autonomous functionality and tele-operated use," Total's Kris Kydd told *The Engineer*.

Having graduated with a Masters in Electronic and Electrical Engineering

from the University of Dundee, Kydd spent the best part of a decade working at Total's UK subsidiary in Aberdeen. In 2013, he transferred to the company's R&D headquarters in Pau, south west France, where he became head of robotics. He was later tasked with setting the parameters for the ARGOS Challenge. Now he's spearheading the North Sea pilot scheme.

The next 18 months will see two new versions of the ARGONAUT robot deployed on Total's Shetland gas plant, with a plan to eventually have them stationed on the company's Alwyn North platform, 440km north-east of Aberdeen. Operating as a team, the twin bots will work in shifts, autonomously returning to a docking station when running low on power. Unlike ANYmal, ARGONAUT is tracked rather than legged, resembling a slimmed-down version of iRobot's PackBot. Born from the same competition, it shares many of the same inspection capabilities, such as leak detection, and thermal and visual assessment.

"The sensor payload today for the routine inspection has a series of cameras on the robot body and robot head," Kydd explained. "We have an ultrasonic microphone, an infrared gas detector, night vision capabilities, video capabilities. We're also looking at what NDT (Non-Destructive Testing) type of sensors we can include on the robot as we move through the pilot."

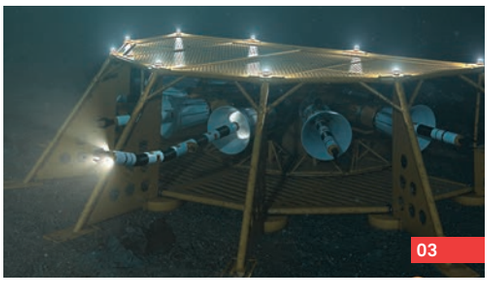
By Total's own admission, operating in the cut and thrust of a functioning plant is a very different challenge from the staged environments of the ARGOS Challenge. For logistics purposes, the robots will cut their teeth in the relatively accessible surrounds of Shetland before being pushed to the limits in the heart of the North Sea. Robust communications are absolutely fundamental, according to Kydd. "For any wireless robotics system, if the communications infrastructure isn't established correctly, you can forget about everything else," he said.

Although the robots will operate autonomously, they will also have Wi-Fi and 4G LTE capability, providing flexibility for updates as well as communications redundancy. "With ARGOS, we had all of the autonomous processing done onboard the robot," said Kydd. "What we're looking to do is offload as much of the non-critical processing to the cloud, so the robot can run for longer."

This also provides Total with the ability to introduce new algorithms and software updates over the air, with no need to physically interact with the robots. During the pilot, the machines will share the Alwyn North platform with more than 100 workers and – like ANYmal – their role for now is limited to inspection. Intervention capabilities will eventually come, however.

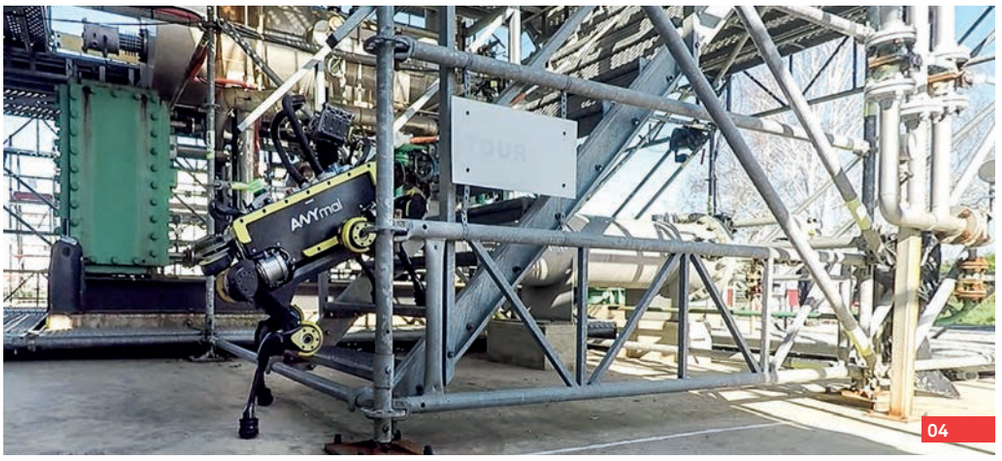
"Once we've proved the inspection capabilities, we want to be able to add manipulation," said Kydd. "Taurob actually has a commercial robot, the Taurob Tracker, and that can come with a customised arm. Manipulation is something we're going to be looking at towards the end of the 18-month period, as we move into developing future versions of the robot."

As AI and autonomy advances, it's inevitable that the offshore workforce will be impacted. Unsurprisingly, the industry claims jobs will simply migrate back to the safety of the shore rather than be lost altogether.



03 Eelume's underwater docking station for its inspection robots

04 ANYmal can climb stairs, which is useful on traditional platforms



As well as developing robotics, part of Prof Lane's remit at ORCA is to build systems where offshore AI isn't operating in a vacuum, providing human operators back on the beach with visibility over what's happening on increasingly automated platforms. It's part of a subdomain known as 'explainable AI'. Neural networks tend to be black boxes that deliver outputs without describing the process. While this may be fine for the lab, real-life applications and certification demand visibility and understanding of why something is happening.

"In some circumstances the robots are working quite autonomously, they're making their decisions, doing relatively simple tasks," said Lane. "But if they get into situations where tasks are a bit more complex, or they're not quite sure about the next step, then the operator gets involved. The aim is for the human operator to understand what the robots are doing. Most of the time, for practical reasons, the human won't be directly controlling the robot one-to-one. So we have what we call a shared autonomy interface [that shows] what plan the vehicle is executing, what stage the plan is at, what's gone wrong, what could go wrong."

Water-based robots are reaching a higher level of maturity. Based in Trondheim, Norway, Eelume is a start-up that evolved from the nearby Norwegian University of Science and Technology (NTNU). Its modular snakoid robot promises to revolutionise how subsea inspection, maintenance and repair (IMR) is carried out. Designed to live permanently underwater, Eelume connects to a docking station on the seabed that can potentially house teams of robots. A flexible body allows it to adopt a torpedo-like shape for travelling over distance, hitting speeds of 4-6 knots. But when operating in and around subsea infrastructure, it can twist and curve into a variety of shapes, illuminating and inspecting, as well as using a range of tools for manipulation. Arne Kjørsvik, Eelume's CEO, says inspiration for the robot came from an unlikely source.

"The whole idea started after several fires in the city of Trondheim in the late 1990s and early 2000s, where the concept of a controllable fire hose came up," he told *The Engineer*. "So at the Department of Engineering Cybernetics at NTNU, they started to research snake robotics."

Eelume was spun out of NTNU in 2015, and the following year it formed a strategic partnership with Statoil and Kongsberg, bringing a wealth of offshore and robotics knowledge. The robot's different modules can provide multiple combinations of forward and lateral thrust, as well as camera and sensor suites and payload capabilities such as grabbers, torque tools, cleaning heads and sonar.

"By nature the robot is built by flexible joints and rigid sections," said Kjørsvik. "The vehicle distinguishes from other underwater vehicles since it can change its shape, it is very slender and can access constrained areas."

The robot could enter service in early 2019, delivering a level of offshore automation not previously seen. On-platform robots have some way to catch up, but the technology is developing rapidly.

"There are already unmanned platforms in the North Sea," ORCA's David Lane explained. "The thing that's not automated is the inspection, repair and maintenance. I'd like to think that in, say 10 years, we'd be doing a lot more of the intervention autonomously. That's possible." ■

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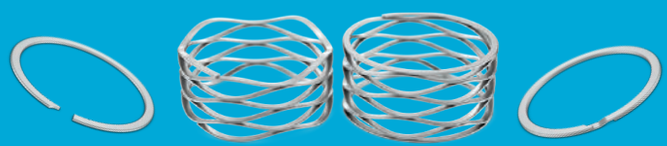

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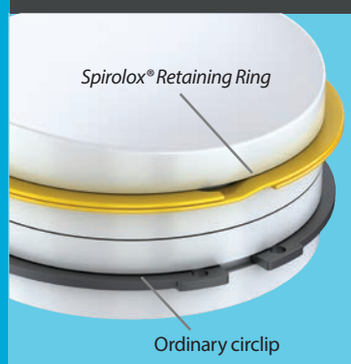

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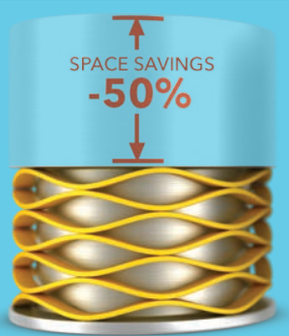

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Staying in charge

Stuart Nathan **continues his exploration of the technologies which are set to improve the storage of electricity in an era of EVs**

In our April cover feature, "Charging into the future", we looked at developments in battery technology aimed at storing large amounts of charge for long periods; the main application for this is in storing intermittent renewable energy when it is available, so that it can be sent to the grid when the sun is not shining, the wind is not blowing or at periods of slack tide.

However, batteries are not the only game in town even when it comes to electrochemical storage. Capacitors, originally a method for storing electrical charge and, in fact, the forerunners of batteries, have now developed to the point where they can be used alongside – or some developers believe, instead of – batteries. Often called super-capacitors or ultra-capacitors, these devices are capable of storing a great deal of charge, and as materials chemist Prof Claire Gray of Cambridge University explains, they tend to store at high power but with lower energy density than batteries. "We are now looking at systems which are a hybrid between super-capacitors and batteries. They have electrodes which are able to handle very high rates of power and design principles of both a battery and a super-capacitor. The chemistry is almost a mixture between the two," she said.

In the design of batteries and capacitors, power and energy always trade off against each other. Batteries tend to have low power but high energy density, while capacitors are the opposite. Gray explained that the traditional role for capacitors is an application such as AC to DC rectification, where they store charge as the AC waveform peaks and discharge it as it troughs, changing the electricity supply from a sine wave into a flat line.

But the new generation of super- and ultra-capacitors do not fit into this paradigm. For example, UK start-up ZapGo is positioning itself as an ultrafast charging energy storage solution, but to basic principles it looks far more like a capacitor than a battery.

Founder and chief executive Stephen Voller explained to *The Engineer* how the company and its technology came to be. "We started about four years ago," he said.

"Originally our materials were developed in the material science department at the University of Oxford and we licensed the technology to commercialise it. Specifically, it's a new form of carbon which we're looking at to replace lithium in batteries, and the idea is to create something which performs much more like a super-capacitor than a battery so it charges very, very quickly, but at the same time we retain the energy inside the cell like a battery does. It has a much higher energy density than you normally get with super-capacitors."

01

To illustrate the difference between a battery and a capacitor, Voller explained that if you put a standard capacitor into a mobile phone, it would reach full charge in about a minute, but in use it would be completely exhausted after three minutes. "You can hit them with a lot of current but they're not designed to retain the charge for a long period of time," he said.

The ZapGo technology is different. The primary way that it combines fast charging with a long discharge duration is the design of materials inside the unit. "We are, in essence, a materials science company," Voller said.

Like batteries, the essential components of a capacitor are a cathode, an anode and an electrolyte between them. Classically, that electrolyte is an insulator known as a dielectric, which can maintain an electric field with the cathode holding a higher negative charge – that is, more electrons – than the anode. In the case of ZapGo, the cathode and anode are identical but are separated by an ionic electrolyte. "We have the combination of a very high capacity carbon material, together with the higher voltage electrolyte, and the key formula – that engineers love – is that the energy you store is proportional to half of the capacitance multiplied by the voltage squared.

"If you increase the voltage, you get a dramatic improvement in energy stored because it depends on the square of the voltage. That's why we use ionic electrolytes, because they can operate at much higher voltages. A standard super-capacitor uses an organic electrolyte which maxes out at about 2.7 V."

Voller believes that the most likely application for this type of cell is for it to be used effectively like a battery charger. "Where we are really interested currently is in very high rate DC charging of battery electric vehicles where we buffer the grid and we do this behind the meter," he explained.

"The idea is that if you're a petrol station operator, then you want to offer very-high-speed charging. Most petrol stations aren't in locations where it is easy for the National Grid to upgrade the network. So if you want to avoid digging up streets, you can buffer the grid by putting electricity storage in to the filling station site that is filled at standard electricity rates, such as at night when you have off-peak rates. When vehicles turn up for charging, they can charge very quickly because our cells discharge rapidly."

Currently, Voller said, the automotive industry would like a network of 350kW chargers which would take about five minutes to provide enough charge to a car for it to cover 100 miles. That's similar to filling up with enough petrol to cover the same distance.

"Today, there aren't any vehicles on the road that can charge at 350kW. They all use what we call generation one lithium batteries, which have a maximum charge rate of about 120kW. If you try to charge them any quicker, they'd catch fire. To get 30kW of energy onto a vehicle in five minutes, you need batteries that can charge much more quickly and that's what our cells can do.

"In the first instance you'd have a hybrid approach where the vehicle would have our cells and lithium battery. You would charge up the ZapGo cell at the filling station, and then when you drive away the cell would charge the on-board lithium at its maximum safe rate." ZapGo is currently in talks with automotive suppliers to supply such systems, Voller said, but could not reveal which suppliers.

ZapGo's current high-profile application is at Heathrow airport, where banks of its cells sit beneath the seats of the transport pods that shuttle passengers between terminals. "That works with the hybrid system I just described, so it has a lithium battery as well," Voller said. "Now, instead of the vehicle taking four hours to recharge, we can recharge a vehicle in 35 seconds."

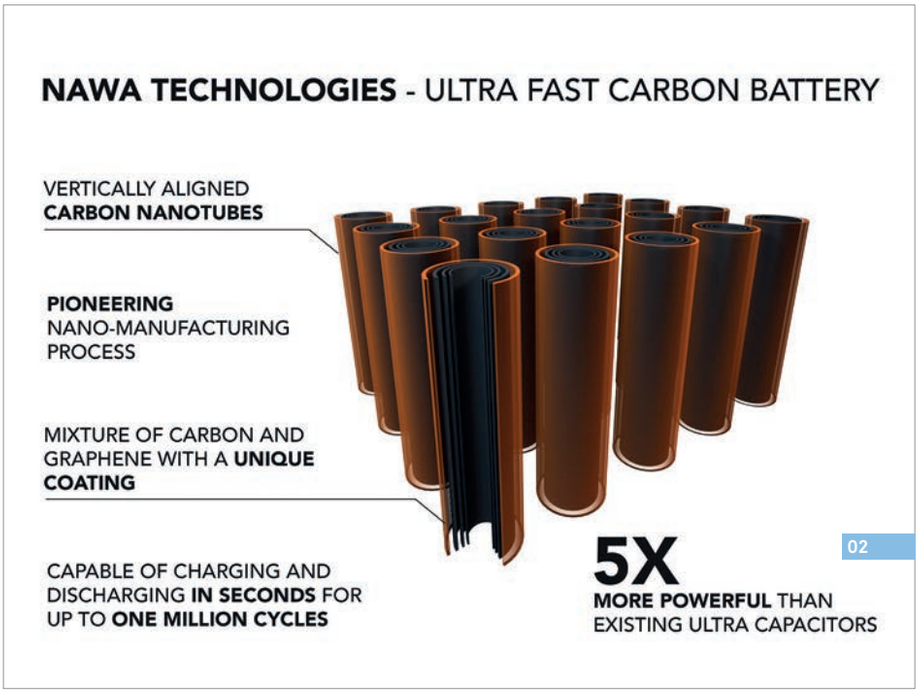
Another innovation has come from a French start-up called NAWA Technologies, which was started by Pascal Boulanger, a veteran of the French Alternative Energies and Atomic Energy Commission. Like ZapGo, NAWA bills itself as an ultrafast carbon battery supplier, but its technology is different. Rather than the electrolyte, the properties of its products result from the electrodes. "The core technology that we are bringing into the energy storage industry is a new way of storing electrical charges; it's a carbon material made of vertically aligned carbon nanotubes," Boulanger told *The Engineer*.

Most carbon electrodes are made from powders, according to Boulanger. There might be a small proportion of carbon nanotubes, but these will be dispersed and pointing in random directions. "You have lots of problems with expansion, you have lots of problems with ion circulation, electrical conductivity and so on," he explained.

NAWA's more ordered electrodes resemble a toothbrush, with the bristles made from nanotubes. "We can have 10 billion nanotubes in parallel per square centimetre. That gives us a higher conductivity and a high specific surface area."

The key to the cell behaviour is that the nanotubes can be coated with materials to give them specific properties. "If we do carbon only, it behaves like an ultra-capacitor," Boulanger said. "But other coatings will make it behave like a battery. The fact that we can coat means we can bring a new function to the nanotubes, and this coating can give us a battery effect or a pure capacitor effect. If we coat with sulphur it will do one thing, if we coat with lithium metal it will do something else."

Initially, NAWA is targeting three applications. The first is short-term energy storage for microelectronics and power tools. The second is to address perturbations in renewable energy storage facilities, such as a cloud that might affect a photovoltaic plant for 10 to 15 minutes. The third application is in automotive, which because of qualification periods is likely to take five years to come to fruition, according to Boulanger's business partner, Ulrike Grape. In this case, the company claims that adding one per cent of the storage capacity of a lithium battery to a system in the form of one of its carbon cells will increase the battery lifetime and storage capacity by 10 per cent. ■



01 A Heathrow pod, which charges up its lithium ion batteries via on-board ZapGo cells

02 A NAWA graphic explaining its ultrafast carbon battery

03 A cell using ZapGo's nanostructured carbon electrodes and ionic electrolyte

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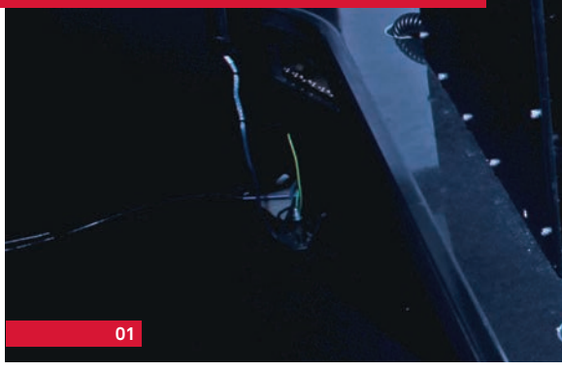
Putting Britain in pole position

Dr Caroline Hargrove, CTO of McLaren Applied Technologies, talks to Jon Excell about how motor racing is helping other sectors modernise



01

While top-flight motorsport has sometimes struggled to stress its wider technological significance, it's fair to say that in recent years its reputation as a hothouse for a nimble approach to innovation and technology development has been somewhat reinvigorated.

And there are few more striking illustrations of this dynamic at work than the turbo-charged growth of McLaren Applied Technologies, the spin-out arm of the celebrated Woking-based racing and automotive group. Formed in 2004 when McLaren merged its composites and electronics operations, McLaren Applied Technologies now employs around 520 people and last year grew by 36 per cent, cementing its position as the wider group's main engine for growth.

It's a growth that the firm's chief technology officer Dr Caroline Hargrove puts down to the fact that the expertise honed on the track – particularly with regards to data – is suddenly much more relevant to the wider world. In today's highly connected, data-rich world, sectors ranging from healthcare, to manufacturing to public transport are increasingly aware of the transformative benefits of an intelligent approach to data, and McLaren's expertise – built up over almost three decades – is, she said, directly applicable to the challenges many other sectors now face.

"We have operated in a data-rich environment for a long time," she told *The Engineer*, "and a lot of people are only experiencing data in the last 10 years or less. A lot of the stuff, like the so-called digital twin, we've been doing for 20 years – we did a digital model of the race car in great detail, which is what a digital twin is, but we just didn't use that terminology."

The division's recent growth has also coincided, she said, with a decision to drop a somewhat scattergun approach to projects and concentrate instead on a few key markets where it feels it can have maximum impact.

Unsurprisingly, the biggest of these areas is the motorsport sector, which accounts for just over half of the business. The firm's electronic systems and software tools feature in most of the world's big motor racing series, and it's the sole supplier of the engine control units used in Formula 1, NASCAR and IndyCar Championships. It also recently won the contract to supply the batteries for the Formula E championship, a move Hargrove says puts the company in a good position to capitalise on the worldwide push for electrification. "It's an exciting time. This is where the industrial strategy is pushing, and luckily motorsport isn't lagging behind," she said. "Our new Formula E battery, which will be used in the new Gen2 cars is a step in the right direction for both the series and the potential application of the battery technology in road vehicles."

Beyond motorsport, the wider automotive market is clearly an obvious destination for the firm's expertise. And one of the biggest success stories here, said Hargrove, is the development of road car simulation technology based on McLaren's Formula 1 simulator – a system that Hargrove played a major role in developing.

Hailed as a step-change in vehicle simulation, the McLaren system dispenses with the somewhat clunky traditional hexapod-based motion simulators, and instead uses an innovative combination of air springs and linear motors to more accurately replicate the twists and turns of a real-life driving experience. The system plays a key role in helping Mclaren's race engineers work with the drivers to optimise their technology, but now, working with US firm MTS Corp, the company is bringing its benefits to the wider automotive market. Hargrove said that as well as being used by McLaren's own automotive division, the technology is already helping a number of OEMs accelerate their own development programmes.

> "A lot of the stuff, like the so-called digital twin, we've been doing for 20 years"

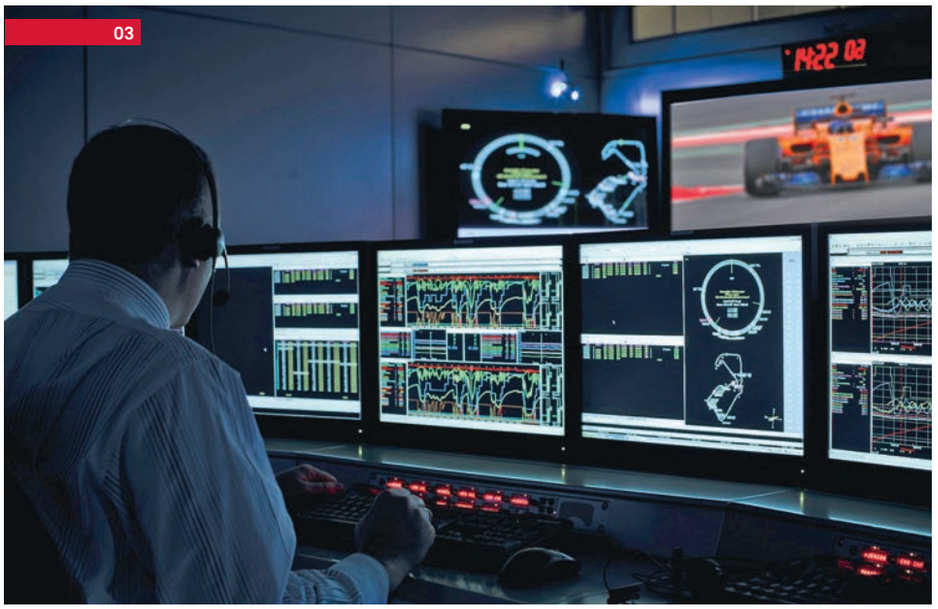
02

The firm is also looking at the wider world of public transport. Here in the UK, it has been working with train operator C2C on a system that gives vastly improved Wi-Fi connectivity to commuters travelling on the firm's Southend to London route. The technology takes all of the different communications signals (3G, 4G, Wi-Fi etc) and seamlessly switches between them, depending on which has the most bandwidth.

Further afield, it recently announced a project to develop a condition monitoring system for Singapore's Mass Rapid Transit network that will see sensors and data loggers more commonly used in Formula 1 deployed on the network's trains.

This project, claimed to be a first for race to rail technology transfer is, said Hargrove, part of a broader push to apply the lessons learned in motor racing to the railway track. "There are many things we are doing to improve the performance of trains," she said. "We're also looking at whether we can do disruption management – when something goes wrong, your crew are at the wrong place, your trains are at the wrong place, and there's a lot of factors. How do you solve that one? At the moment humans are solving this one and we think we can do a better job by supporting the humans by doing loads of computation in the background."

A less mature area for the company, but one where Hargrove believes there could be huge



potential, is in healthcare. "It's in our sweet spot of lots of data being streamed, processed locally and in the cloud – and we keep thinking there's something there for us."

She's certainly not alone in this ambition. Indeed, in a major speech in May, prime minister Theresa May argued that smart use of data and AI could help save hundreds of thousands of lives a year by enabling earlier diagnosis.

But although McLaren has been involved in a number of projects in the field – including a notable collaboration with the University of Oxford on the development of decision support tools for surgeons – Hargrove is frustrated by a somewhat cluttered innovation pathway for potentially game-changing medical technologies. "The route to market is difficult," she said. "There's lots of innovation, but fragmentation of sector, and the way technology is procured holds the UK sector back."

01 Mclaren's Formula 1 simulator

02 McLaren Applied Technologies is investigating healthcare applications of its data knowhow

03 Data is king in the fast-moving world of top-flight motorsport

Another key market for the firm, the Industry 4.0 obsessed world of manufacturing, is somewhat further along in its thinking. Here, McLaren is collaborating with Deloitte on the development of a smart decision support system to help manufacturers deal with the ever more complex demands they face.

Hargrove is passionate about the impact such tools could have on broader industrial productivity in the UK, particularly on the UK's long-tail of manufacturing SMEs. "The people we've worked with so far are often the people who already do a decent job – we need to find a way of cracking the people who if they don't do this, their productivity is really going to go down. How can we reach those companies who are not really thinking that's an issue to show that it's often not that difficult to raise your bar a little bit?"

It's hard to think of a more stimulating and exciting engineering environment than the one described by Hargrove and yet, in common with many other less-well known and less glamorous firms, she said that McLaren does struggle to find the right skills. In an effort to address this, the company recently opened a data science office in Waterloo, to tap into the skills of London's buzzing tech start-up community. But while this is proving to be an effective short-term move, Hargrove believes much more needs to be done to shore up the future pipeline of skilled engineers and is puzzled that a profession capable of generating so much excitement doesn't have the right "glow" for the next generation.

"Kids buzz when you give them something exciting to do, but I don't think the school system or teachers have got the bandwidth or experience to give them that – I'm not sure how to fix it, other than everyone trying to do a little bit." ■

Disrupters prepare banking for 4th industrial revolution

From APIs to blockchain, a host of financial technology (or fintech) platforms are helping manufacturers secure the funding they need to drive growth. Will Stirling explains

As the Government seeks to boost industry with a shiny new Industrial Strategy, it is worth remembering the basics. Among the building blocks for the engineering sector is access to finance, especially for smaller firms. During and immediately after the financial crisis of 2007-9 was a dire time for small and medium enterprises (SMEs) as liquidity dried up, and when it returned, most credit was less risky residential mortgages, not business loans.

An improving economy and market innovation has helped recapitalise British industry and, 10 years on, the situation is much healthier. The body UK Finance finds that eight out of 10 business loan applications by SMEs are successful and its latest SME Finance Monitor, a survey of around 4,500 SMEs, found an increase in demand for finance in the final quarter of 2017. Liquidity is back and today access to finance is characterised by innovation and choice.

In addition to the big high street banks and challengers such as Aldermore and Metro Bank, SMEs can now also turn to a clutch of sources known as "alternative finance" to raise money. This includes financial technology, or "fintech", platforms that use digital technologies including blockchain and application programming interfaces (APIs) to source capital in a peer-to-peer model. And while other peer-to-peer structures such as crowdfunding are also increasingly used to pay for growth, fintech has made arguably the biggest dent on the bank loan market.

London-based fintech company MarketInvoice published a survey in September 2017 that found 65 per cent of 3,482 UK businesses have adopted at least one fintech solution, with 19 per cent making use of four services. Such fintech products are helping firms to save on average over £5,500 a year. MarketInvoice extrapolated the findings to 1.3m UK businesses, to produce a total net saving of £4.6bn. Meanwhile, the firm's own loan book to manufacturing companies is growing; in 2015 it was £4.3m, and is £12.1m in 2017.

MarketInvoice makes use of various APIs to analyse customers' creditworthiness. These include a wide range of metrics for the borrower, including data from the electoral roll, Companies House and other information sources, to produce an arguably more "holistic" credit profile. Banks tend to focus on credit history and profits declared to assess a borrower.

Speed is a factor for fintech platforms such as MarketInvoice. "For our API model, about 65 per cent of the result is underwritten through the API algorithm that takes about 15 seconds to run," says Craig Flyger, senior partnerships manager at MarketInvoice. "The rest is run by our underwriting team, by looking at the individual's credit history and industry trends." A borrower typically does not need such a long credit history to secure an API-based lending decision.

Assessing the sector the customer operates in is also relevant. "Our real-time data analysis means we are more nimble at approvals, but we can also respond better with industry trend analysis," Flyger adds. "If an industry sector is having a downturn or experiencing rapid growth we can adjust the rating or decision accordingly."

> "Our real-time data analysis means we can be more nimble"
>
> Craig Flyger, MarketInvoice

Blockchain is coming

Blockchain is the most famous example of distributed ledger technology, the same technology that Bitcoin is based on. A blockchain is a list of records, typically managed across a peer-to-peer network that collectively adheres to a protocol for "inter-node communication" and for validating new records, known as "blocks". This allows multiple participants in a network to see and verify the authenticity of each block or record, which improves security and reduces fraud. Blockchain allows individuals to exchange money and other assets with one another without requiring an intermediary to do so.

With so much capital equipment to finance in manufacturing, the sector has attracted the attention of innovative financiers who are actively exploring blockchain advantages, for both borrower and funder.

"The technology protects the funder from fraud by offering a robust, incorruptible ownership and financing ledger, that can be inspected before granting finance. A blockchain serving the entire asset finance industry would benefit all participants" says Eamonn McMahon, managing director of EquipmentConnect, an asset finance start-up that is developing a blockchain solution.

The start-up company is at the vanguard of bringing blockchain into asset financing. It has secured Innovate UK funding to complete a feasibilty study on applying blockchain to sectors that the Industrial Strategy focuses on: manufacturing, construction and logistics. While banks are doing their job and approving more loans to SMEs, fintech disruption is ensuring a focus on speed and low-cost delivery while also introducing fresh sources of funding to the manufacturing sector.

Security against centralised failure and continuation of the service is a big part of a blockchain solution, advocates claim. "A key feature of the credit process is the importance of back-up servicing," McMahon says. "That is, in the event the original funder is no longer a going concern, there is infrastructure in place to continue the administration of the loan or lease. The role of back-up servicing is a lot easier if an immutable database, synchronised across the different infrastructure partners, is already in place. A blockchain helps achieve this."

Blockchain is about facilitating an exchange of value with minimum friction; it is intended to enable individuals to exchange currency and other assets with one another without relying on a third party to manage the transactions. This has appeal to a new generation of wealth creators less dependent on the business, and indeed social, institutions of old.

01 Blockchain is coming

02 The team at EquipmentConnect is at the vanguard of bringing blockchain into asset financing

How are the banks and traditional lenders responding to this disruption?

Santander has become the first international bank to launch a cross-border payments system based on blockchain, using the new technology with a view to taking on specialist fintechs. Lloyds is spending £3bn on a digital transformation programme, but blockchain is not currently part of this. RBS is pushing ESME, its independent digital lending platform, with a bold new marketing campaign.

Like other asset finance providers, Close Brothers Asset Finance's approach has been predicated on a face-to-face sales model, where it forms strong and long-lasting relationships with customers.

"Technological advance has brought with it new funding models; for example crowdfunding, which works for some but not for others," says Ian Barker, managing director, engineering and manufacturing division, of Close Brothers Asset Finance. "The types of deals we get involved in tend to be at the more complex end of the scale, and are therefore – in many cases – bespoke. By its nature, this involves a consultative approach to better understand a business's requirements, which can change over the course of a discussion, and it's here that the human element comes into its own."

But he adds, "We see no reason why various funding models can't be complementary rather than competitive – there is a balance that can be struck."

Fintech companies and banks need to get their collective act together in preparation for a potential investment drive. Industry 4.0 is coming and while low-cost digitalisation is possible, this will inevitably mean more capex investment. Auditors PwC, in a 2016 report, said total worldwide industrial investment in Industry 4.0 technology is expected to be $907bn a year until 2020.

Any finance solution that improves speed of approval, lowers funding costs, and offers fraud prevention and security is likely to have a captive market in the new, digitally-native manufacturing sector.

The Range Rover goes electric

The new plug-in hybrid model boasts 404PS and a usable electric-only range. So how does it compare? Chris Pickering finds out

Nobody could have predicted just how influential the Range Rover would go on to become when the original three-door model was launched in June 1970. It brought off-roaders out of the farmyard and onto the high street – paving the way for the hordes of SUVs and crossovers that now dominate the global car market.

Like many iconic cars, its shape was in fact penned by an engineer rather than a stylist. But that didn't stop Spen King's original concept being exhibited in the Louvre, alongside the *Mona Lisa* and the *Venus de Milo*. The fact the silhouette has changed so little in the intervening half a century is testament to its inherent rightness.

Under the skin, things have changed rather more radically. The current generation Range Rover was the first SUV in the world to feature an all-aluminium monocoque construction when it debuted in 2012. It was the most extensive finite element analysis project that Jaguar Land Rover had ever undertaken at the time – subject to a staggering 1,000 CPU years of processor time. The end result was a structure 39 per cent lighter than the steel equivalent, contributing to an overall weight saving of up to 420kg (depending on the market and specification).

One of the other major changes brings us on to the car you see here, the Range Rover P400e plug-in hybrid. Strictly speaking, this is not the first hybrid powertrain to appear in a Range Rover – that honour goes to the previous diesel-electric Range Rover Hybrid launched back in 2013. But it is the only one you can buy now, not to mention the first to feature a plug-in capability and a meaningful electric-only range.

Flip up the iconic clamshell bonnet and you'll find the smallest engine ever fitted to a Range Rover – the 2-litre four-cylinder Ingenium petrol unit now found in everything from the Jaguar F-Type to the Land Rover Discovery. It features high-pressure direct injection, a variable lift system on the intake valves that allows the throttle to be left open most of the time, and a twin-scroll turbocharger, which uses ball bearings to improve efficiency and transient response. The end result is 300PS (296bhp) from just 1,997cc. But that's just half the story. Mounted on the ZF 8-speed gearbox there's an 85kW (116PS) electric motor, capable of powering all four wheels. Due to the different characteristics of the two powerplants, you can't quite add up their individual outputs, but the combined total is still an impressive 404PS (398bhp) and 640Nm (472lbft) of torque. More to point, it means the P400e officially returns 101mpg and emits just 64 g/km of CO_2 on the NEDC cycle.

01

"The electric motor adds vast reserves of easily modulated torque right from zero rpm"

Of course, as with any hybrid, these laboratory figures bear scant resemblance to the real world. We saw a rather less eco-friendly 21mpg on our drive through the Cotswolds. Admittedly, it was driven with considerable gusto.

Does that defeat the object of a hybrid powertrain, then? Not at all. For a start, Land Rover claims an all-electric range of 31 miles on the NEDC cycle. We didn't have a chance to put that to the test, but we're told well over 20 miles is achievable in the real world, which means the average British commute could potentially be done on little or no petrol – particularly if there are recharging stations at both ends. For fleet operators, company car drivers and city dwellers

01 When fully charged the Range Rover 400e gives a range of up to 31 miles

02 The in-car infotainment system is one of the best you'll encounter

03 As with any Range Rover, you can confidently take it off-road

there are also numerous financial benefits associated with its on-paper figures. These include significant tax incentives and exemption from the London Congestion Charge.

There are other benefits, too. With both powerplants working in unison, the 2.5-tonne Range Rover feels every bit as rapid as its 6.4 second 0-to-60mph time would imply. In fact, it's second only to the supercharged 5.5-litre V8 in the line-up. What's more, the electric motor adds vast reserves of easily modulated torque right from zero rpm, which makes this particular Range Rover even more formidable off-road.

Truth be told, however, it's not the Range Rover's performance or its off-road ability that has given the model such enduring appeal; it's the fact it's also a world-class limousine. Here, too, the electric motor helps. At least up to a point.

The good bits first: Electric-only mode brings a level of serenity to the cabin that even the very best combustion engines would struggle to match. And despite the electric motor's modest power output there's enough torque to make effortless progress. It's an ideal fit with the Range Rover's luxury remit.

The downside is that the petrol engine is quite keen to cut in once you switch to hybrid mode. By four-cylinder standards it's a fine effort, but it simply doesn't sound as cultured as the larger V6s and V8s in the range. Somewhat curiously, the addition of the hybrid system also seems to have added a slightly crashy edge to the ride (it's not entirely clear why this has happened, because although it's some 250kg heavier than the petrol V6, the P400e is only a few kilos heavier than the V8, which glides along beautifully). In the grand scheme of things these are both relatively minor niggles, but at this price point – £105,865 as tested – you'd be forgiven for being picky.

Inside, there's the same brilliantly executed cabin as you'll find in the rest of the range – now featuring a vastly improved infotainment system first seen in the Range Rover Velar. The twin 10-inch touchscreens are intuitive to use and great to look at, plus there's an excellent voice control function co-developed with Nuance. There's also one of the best head-up display units we've tested, a plethora of connectivity options and all the latest driver assistance functions.

Land Rover likens the infotainment system to a 'digital butler', waiting on your every need. And some of its most interesting work takes place behind the scenes. In hybrid mode, for instance, the navigation system can analyse the roads and the GPS altitude data for your chosen route and plan the most effective energy management strategy. It can also learn your preferred routes to work and check real-time traffic information to deduce the best option for that particular morning. Likewise, if you're running late for a meeting it can send ETA updates to your fellow attendees and if you're on the way to the airport it can alert you if your flight has been delayed.

Whether or not you choose to pay a premium for the plug-in hybrid will depend very much on your requirements. For business owners and company car drivers the P400e may well be the default choice within the range. Likewise, for those who can carry out a reasonable number of journeys in electric-only mode it offers a compelling proposition. Ultimately, though, the conventional models remain that little bit more polished – at least for the time being. ■

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A practical approach to smart manufacturing

Rockwell Automation's Richard Sturt **offers advice on how manufacturers can understand and exploit the benefits of digital technology**

From the Industrial Internet of Things to The Connected Enterprise, we're not short of buzzwords and phrases in industry at the moment. But what do they really mean? A quick internet search will produce a huge amount of information, but it can be difficult to see the real business benefits. However, with the right approach and a focus on business requirements rather than technology, real progress can be made.

Smart manufacturing technologies

A long list of technologies are driving change – including big data and analytics, low-cost and high-performance wireless communication, GPS positioning, artificial intelligence, virtual reality, additive manufacturing, and so on – and these technologies can make a big difference in many areas of a business. Whether it is the product that is being produced, consumer behaviour or plant efficiency, they are all impacted to a lesser or greater extent by these technical advances.

Is there an impact for your products?

The first question for any manufacturer should be: Do any of these technologies have an impact for my product? This needs to be "product" in the widest sense; not just the physical product but the delivery time, minimum order quantity, etc. Will I go from mass production to a custom product? Will the demand profile change? Will smaller batch sizes and faster changeovers be expected? Do I need faster time to market? Will my customers expect tailored logistics? In some cases the impact will be minimal, but in others it will totally change the demand put on the manufacturer.

At the other end of the scale are products that could benefit from mass customisation, such as individually tailored medicines, and somewhere in between the extremes are products where the demand could be affected by social media; a single Tweet from a celebrity could increase sales of a product significantly or change a product mix, with a knock-on effect through the production process and supply chain.

New technologies have the capability to completely change business models, so it's important to keep an open mind about what could happen in the future. Will changes to your products and consumer behaviour put pressure on your process plant or manufacturing facility to change?

01

Are you flexible enough? Could you be more efficient?

Manufacturing and process plants

After considering any new demands put on the manufacturing facility, the second question to ask is: Can the process plants themselves take advantage of new technologies? Technology improvements can impact almost every aspect of a plant, whether it's a smart field device able to diagnose potential faults before they fail, or the analysis of data in the cloud to understand production efficiency and quality improvements. With advances in technology, it is more cost-effective than ever to deploy smart sensors and communication technologies. Also, maintenance staff themselves typically cover a large area.

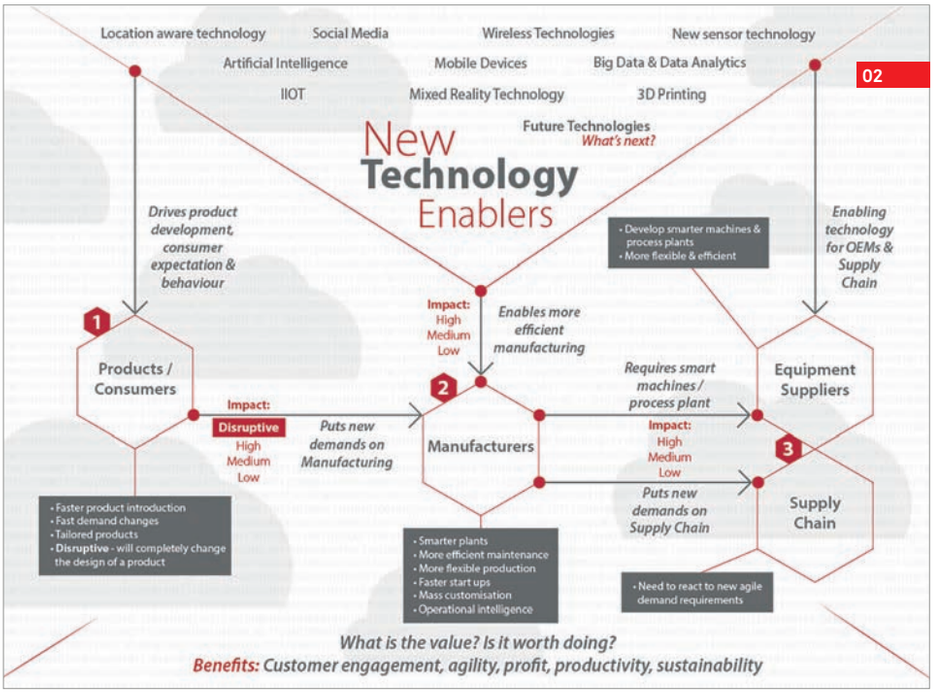
"New technologies have the potential to change business models"

There are gains from being able to access control systems remotely, reducing the time it takes to troubleshoot problems and ensure supply.

But what if the technology changes have a wider impact? Changes to the product or demand curves, for example. If you are producing a product that is impacted then this will place additional demands on manufacturing. This could result in smaller batches, faster product changeovers and simultaneous global roll-outs of a new product.

These demands will require greater production agility to cope effectively. The right questions here are: How quickly can we introduce a new product and ramp up demand if required? And: Is the production plant flexible enough to deal with the likely changes? With these demands, the link between information technology (IT) and operational technology (OT) becomes critical. You need to automate as many of the processes as possible to make the plant agile.

Mass customisation will put the biggest demands on the manufacturer. If every order is tailored to an individual customer, this has huge repercussions for the production process. Everything from order entry through the whole supply chain to production and on to distribution has to be automated and streamlined to be efficient.



Equipment suppliers and supply chain

It's likely that you will need to work with equipment suppliers who are able to take advantage of new technologies to achieve your smart manufacturing vision. You will probably need machines or process plants that are much more flexible and ready to be connected to the rest of your enterprise. There could also be a knock-on effect on your supply chain. Are they ready to react?

Business case

I have sympathy for those making business cases for smart manufacturing. It is far easier to do the calculations for a single mass-produced product on a dedicated production line than it is for a more flexible approach. Some key business drivers are:

- Customer Engagement
  Do I need to change my product to meet my customers' expectations? Will they expect a more customised product in future?
- Agility
  Is my business agile enough to cope with new demands?
- Profit
  Can any of the new technologies be applied to directly increase profit?
- Productivity
  Increasing output and value add is critical to stay competitive. Do you need to employ some of these new technologies to increase productivity? Will analysis of production data allow you to squeeze extra productivity from an existing line?
- Sustainability
  Can new technology be employed to save energy, reduce waste and improve sustainability?

Analysis of these key areas will help you focus on the business benefits.

Implementation – incremental approach or big bang?

For some applications it will be possible to have a steady, incremental approach. A trial project can prove the introduction of smart technologies and give you confidence. However, it may be that you need to fundamentally change the capital equipment, plant layout or manufacturing operations software to achieve the desired business outcomes. The business risk is obviously much larger because of the high capital outlay. Fortunately, modern simulation tools can help to reduce the risk and in many cases you can simulate the plant performance before it is built. You may want to develop a "digital twin" to help model plant performance. You may be able to break down a large smart manufacturing project into several more manageable projects, tackling those that give greatest benefits or are low risk first.

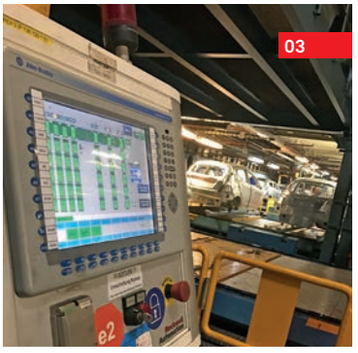
What comes first, the technology or the business case?

If you don't know what technology is available then how can you know how if it will benefit your business? It's best to keep abreast of a wide range of new technologies to see how they can help. Then you can evaluate each technology and look to see if there is a real benefit to your business.

Automation suppliers and resources

Once you have identified your key business drivers for smart manufacturing, you will want to work with suppliers who can deliver your vision; specifically, suppliers who have a good understanding of all the new technologies and have experience in applying them. It's unlikely one supplier will have all the solutions, but you need to make sure that your main supplier understands smart manufacturing and supports systems to integrate with other suppliers.

Richard Sturt is business development manager with Rockwell Automation



01 Smart technology can put your employees firmly in control, even if working remotely

02 New technology enablers and the impact of change

03 Choose a supplier whose systems integrate with other suppliers

Superior inspection tools help jet boards hit the water

Accuracy of components is vital for sports equipment

Supplier: Bowers Group

M-CNC Precision Engineering is using Bowers inspection tools to ensure accuracy on components used in a range of adrenaline sports, including jet boarding.

Based in Somerset, the company manufactures parts for Riders Racing of Riders Motorcycles, centre plates for advanced rotary engines for unmanned aerial vehicles (UAVs), and engine components for Mako Boardsports' jet-powered surf boards. Mako's flagship board is propelled by the XT100 engine, a 100cc unit that can propel riders at speeds up to 55km/h. But delivering components for an engine that can slot into a surf board requires extreme precision, and quality measurement equipment is essential.

M-CNC estimates that it carries out more than 5,000 bore measurements per week. Regular measurement of components containing lots of bores means that M-CNC required high-quality measuring equipment to ensure that the measurements are accurate first time, from a measurement range of 10.000mm to 250.000mm.

"We find Bowers Group's products very reliable as well as accurate," said Leigh Howarth, business development manager at M-CNC. "The internal bore mics are easy to use, accurate, and the adjustable fit is very useful. The guys on the shop floor love them; they are so precise and straightforward. Our aim is to achieve zero defects by engaging the workforce in the complete manufacturing cycle. We are already very close to that target and our mantra is to 'be the best we can be at all times'. Our quality and inspection is, therefore, a large part of our ability to deliver excellence to our customers."

In addition to a large number of bore gauges from the Bowers Group's range, M-CNC also uses a Sylvac Hi-Cal 450 Height Gauge for a variety of measuring tasks, including step heights, internal/external diameters and centre-line distances. ■

Reducing fire risk of waste

Thermal imaging equipment gives alerts on hotspots

Supplier: Termisk Systemteknik – FLIR thermal imaging

For companies involved in waste management, spontaneous fires are a fact of life and the critical issue is to detect an outbreak and prevent it spreading.

One such company is Sweden's Jönköping Energi, which turns up to 160,000 tonnes of waste per year – or 20 tonnes an hour – into heat and electricity.

"We have trucks bringing in waste... which is dumped in a waste bunker, mixed by automatic cranes and stored awaiting transportation to the boiler," said plant manager, Magnus Olsson. "These waste piles can be a dangerous mix. Spontaneous combustion from biological products or other heat sources is a continual threat that needs to be monitored 24/7."

Historically, the plant relied on aspiration-based smoke detection, but for the system to generate an alarm, smoke had to make contact with the sensor which was installed on the ceiling of the waste bunker.

Jönköping Energi switched to a system from Termisk Systemteknik, based on FLIR thermal imaging. For fire detection, infrared senses the surface temperature of material. In effect, it 'sees' the source of the fire in its infancy.

The chosen system comprises two FLIR A615 thermal imaging cameras mounted on pan and tilt systems, one at each end of the bunker. They are controlled via Termisk's TST Fire software, so that when a hot spot is detected by one camera, the other camera is also trained on it.

The software calculates the co-ordinates of the hotspot based on the combined thermal images and an alarm is generated. Operators can then direct the water canon to the hotspot.

Compliance with GigEVision and GenICam standards allows the FLIR A615 to be integrated with a variety of similarly compliant equipment and is supported by third party software including TST Fire. Trigger and synchronisation capabilities enable it to control, or be controlled, by a host of other types of equipment. ■

Helping to cut inspection times for turbine blade manufacturer

New measurement machines increase efficiency

Supplier: Renishaw

Italian Rolls-Royce subsidiary Europea Microfusioni Aerospaziali has halved the inspection times for aerospace and energy-generating gas turbine blades with the help of equipment from metrology specialist Renishaw. Based near Avellino, EMA produces stator and rotor blades in specialist alloys for the high, intermediate and low pressure stages of gas turbines used in airliners and military aircraft, ships and submarines, and industrial turbines.

Turbine blades are among the most exacting industrial components, and every single one from the production line must be checked for dimensional compliance. "We had to find a solution that would allow us to improve the efficiency of the dimensional verification process in terms of quantity of parts measured in a unit of time," said Vittorio Caggiano, quality control manager. Of the two available options – invest in new measurement technology or reduce measurement cycle time – EMA chose the former.

The company used coordinate measurement machines (CMMs) equipped with 3-axis indexing heads for this task. But owing to the complexity of the parts, each measurement cycle required the indexing heads' stylus to be changed several times.

"We worked closely with Renishaw technicians to find a better solution," Caggiano explained. "We also sent our parts to the Renishaw facility in Turin for measurement tests. After these tests, we concluded that the best solution was to invest in new, more flexible and efficient PH20 5-axis probe heads, as well as MODUS metrology software. Renishaw retrofitted the new probes to our existing CMM machines and created 50 measurement programs, written by Renishaw SpA staff on site during our training."

This change has meant fewer stylus changes during the control cycle. It has also reduced measurement times, said CMM programmer Maurizio Rullo. The cycle time for measuring a single blade was cut by 30-50 per cent and in some cases more, Rullo added. An additional investment, in a Renishaw equator flexible gauge, allowed EMA to perform checks that previously required multiple instruments to be pooled. ■

Climbing non-destructive testing robot passes field trials

Major benefits in the pipeline for oil and gas industry

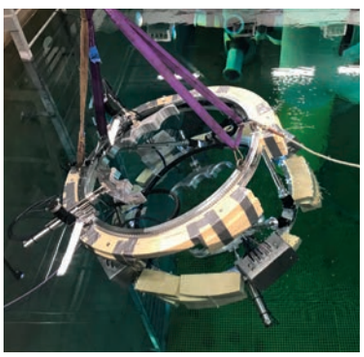
Supplier: TWI

A robot designed to hook on to, and scale up and down, large mooring chains, both at sub-sea level and in the air – with a non-destructive testing (NDT), ultrasonic imaging system on board that scans for critical defects – has recently undergone successful field trials.

The climbing robot, named RIMCAW (Robotic Inspection of Mooring Chains in Air and Water), is the result of a year-long Innovate UK funded-project that's being delivered by collaborative partners Computerised Information Technology Ltd, Innovative Technology and Science Ltd, London South Bank University and TWI Ltd.

The inspection of large mooring chains, of the type most commonly used in the oil and gas industry, presents challenges due to the dynamic service conditions of both the underwater and atmospheric environments. RIMCAW, with its ability to autonomously move up and down a mooring chain, and handle the catenary curve, as directed from a top-side control system, is designed to uniquely address these and will start scanning for flaws as soon as it is deployed. It will identify issues such as fatigue cracking as it progresses, and record the scanned data for subsequent downloading and analysis once it has completed its inspection.

The field trials took place in the



diving facility at TWI, Middlesbrough. The robot was tested for being neutrally buoyant, watertight and functional as anticipated, while simultaneously putting its sophisticated hardware through its paces. These successful simulated trials have proved that RIMCAW is fit-for-purpose, as well as commercially viable, paving the way for trials in real-world conditions.

Channa Nageswaran, RIMCAW project leader and NDT team manager at TWI, explained: "Failure of mooring chain systems in offshore oil and gas structures represents a critical threat to the assets themselves, human life and to the environment. The RIMCAW robot will enable chains to be inspected in service for the first time and can be rapidly deployed on demand. In combination with its ability to scan each mooring chain link separately for critical defects, using the on-board NDT technology, it will offer significant benefits to industry. These include: provision of data on the emergence of critical fatigue cracking to inform traceability of mooring chain lifetime monitoring; diminished risk to the environment; improved health and safety for personnel; and potential cost savings as a result of the enhanced inspection procedure," he said. ■

Brexit doubts persist as average falls

***The Engineer*'s 2018 survey shows a small decrease in earnings overall, oil and gas once again topping the league and a growing gender disparity**

The past 12 months have been a period of considerable uncertainty in the UK. Despite relief over the Government finally agreeing the terms of a post-Brexit transition period with the EU, concerns over the extent of the UK's future trading relationship with member states after this period have continued to dominate the headlines.

And while the pound's weakness in the first half of this period helped to make UK exports more attractive to overseas buyers, there remain concerns about the impact Brexit will have on future investment into the UK.

Even the weather has added to the uncertainty, with the so-called Beast from the East cold snap followed by spells of unseasonably warm weather affecting both productivity and consumer spending. But how has all this uncertainty affected the UK's engineering sector? Have salaries and job security been impacted by doubts about the UK's future, and have some sectors of the industry been weathering the storm better than others?

There remain concerns about the impact of Brexit on investment into the UK

Each year, *The Engineer* surveys professionals from across the industry, to find out how much they earn, where in the UK they work and in which sector, and how they feel about their jobs. With 2,864 engineers taking part this year, from 11 different sectors, we have analysed the results to find out which industries and regions have the highest salaries, how large the gender imbalance within the profession is, and how satisfied respondents feel by their chosen career. By comparing this year's results with those of previous surveys, we can also reveal how things have changed for engineers over the last year or so.

The average salary for all engineers in 2018 is £47,896 a slight decrease on last year's average of £48,197. This compares reasonably well with other professions in the UK, sitting below those in strategy and consultancy on £57,554, qualified accountants on £53,887, and those in banking on £52,666, but above those in financial services on £47,250.

Of those surveyed, 61.2 per cent of engineers are concerned about the potential impact of Brexit on the

£44.5k-£53.9k

Average salary by sector

Oil & Gas	**£53,913.00**
Energy/Renewables/Nuclear	**£52,653.00**
Chemicals & Pharma/Medical	**£50,890.00**
Automotive	**£48,967.00**
Food & Drink/Consumer Goods	**£48,155.00**
Defence & Security/Marine	**£47,968.00**
Aerospace	**£47,752.00**
Materials	**£47,130.00**
Rail/Civil & Structural	**£45,871.00**
Academia	**£44,774.00**
None of these	**£44,563.00**
Telecomms & Utilities/Electronics	**£44,504.36**

JohnDocherty FIRP – client development director, CBSbutler

We are delighted to be once again associated with this important national salary survey for the engineering industry.

It's worth reminding ourselves just how important the UK's engineering sector is to the economy: 19 per cent of the total UK workforce is in the sector, generating 23 per cent, or £1.23 trillion, for UK PLC. In a sector that demands 124,000 new hires a year while managing a skills gap of 59,000, employers are seeking our experience at CBSbutler to help them meet their growth ambitions and retain their existing workforce. Their employees, on the other hand, are naturally keen to ensure their rare skills are being rewarded and recognised appropriately. This survey should help educate all of these important stakeholders.

With oil and gas yet to recover to historical levels, we are not surprised to see a slight drop in overall average salaries. However, engineering still offers graduate starting salaries 18 per cent higher than elsewhere. As more millennials become an embedded influence in the workplace, it is interesting to see how happiness and diversity have become key factors in the survey – subjects off most people's radar until quite recently.

A contented workforce is a productive workforce, right? With the happiest workers appearing to be in the academic sector, there is a clear indicator for employers to foster even closer relationships with universities and colleges to better understand why these working environments provide for a happy workforce.

Diversity is an increasing area of importance for employers – many of CBSbutler's clients are now aiming for one in four hires in the next five years to be female and from the BAME community. Some 7.2 per cent of our survey respondents were female, which is less than the 12 per cent which make up the female engineering workforce. In our view, a large part of the skills shortfall can be addressed by attracting more women to engineering. This is in stark contrast to many European and International countries where a far greater proportion of technical staff are not men – we have a long road ahead in the UK to attract women into the profession.

For me, key findings were the high level of concern on Brexit – the UK has long been dependent on highly skilled migrant workers. An already large skills gap could be exacerbated by the ending of a key staffing route. We should be further alarmed by the worrying drop in apprenticeships since the introduction of the Apprenticeship Levy.

At CBSbutler we like to promote and champion opportunities, particularly in the untapped talents pools; women in STEM vocations and young people who still harbour stereotypical impressions of the sector.

With decades of experience in recruiting within engineering across a wide range of sectors, CBSbutler has specialist insight into both the challenges and opportunities afforded to job seekers. Well-qualified, highly trained and experienced engineers really do have a wealth of options at their disposal – both domestically and globally. Those individuals who prefer flexibility in their work will find strong demand, lucrative earnings and continuity of employment.

The Government's Year of the Engineer has been a positive campaign tackling the engineering skills gap and aiming to widen the pool of young people who join the profession. We finally see a national outreach programme that is working with hundreds of business partners who are trying to encourage young people and their parents to take a closer look at engineering. We hope that this will encourage industries to inspire the next generation of engineers. With the introduction of the UK's Big Bang Fair and the Royal Academy of Engineering programme we can finally see some really engaging initiatives that will squash all preconceptions.

Overall, the engineering sector is clearly in rude health and offers interesting and well-rewarded careers. To maintain this buoyancy, however, we cannot afford to take our focus off attracting the best people from all parts of our society.

Lastly, I must say thank you to our respondents, all 2,864 of them! Without their input this report wouldn't hold its value.

industry, a slight increase on last year. However, like 2017, only 37.1 per cent are worried about the impact of Brexit on their own job security.

Among the different sectors, once again engineers in the oil and gas industry command the highest salaries, with an average of £53,913. This is a slight decrease on last year's average salary in the sector, of £54,461.

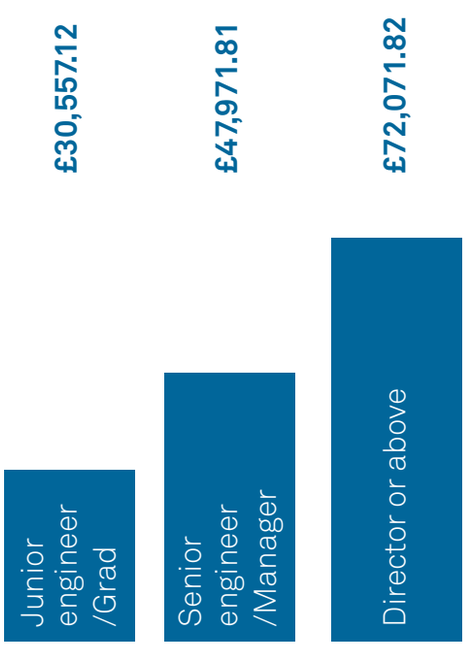
Engineers in the energy, renewables and nuclear sector continue to earn the second highest salaries in the profession, with an average of £52,653, up from £51,953 last year.

Just under a quarter of those engineers surveyed are employed directly in the automotive and aerospace industries, a slight drop on last year's figure, while as in previous years, three-quarters describe themselves as senior engineers or managers.

The manufacturing heartland of the West Midlands and East Anglia again employs the largest number of engineers, with a quarter of respondents based in the region. This is once again followed by London and the South East, where 21.8 per cent of respondents are based.

As in previous years, over 90 per cent of respondents are male, and just under 90 per cent are white, while over 80 per cent expect to remain in the profession for at least the next five years. Over the following pages we have analysed in greater detail what the findings of this year's survey tell us about the state of engineering in 2018.

Average salary by seniority



£47.8k

average salary for engineers in all sectors

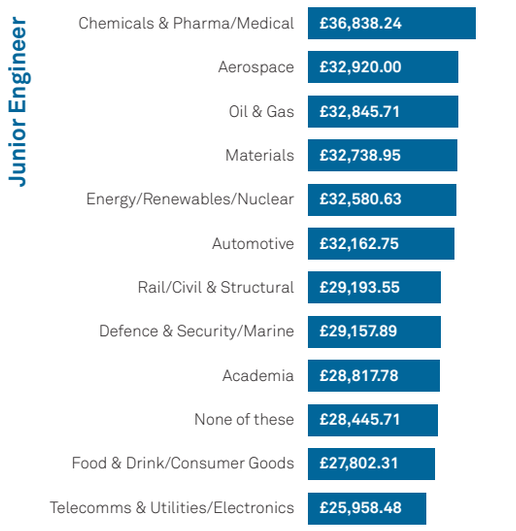
£53.9k

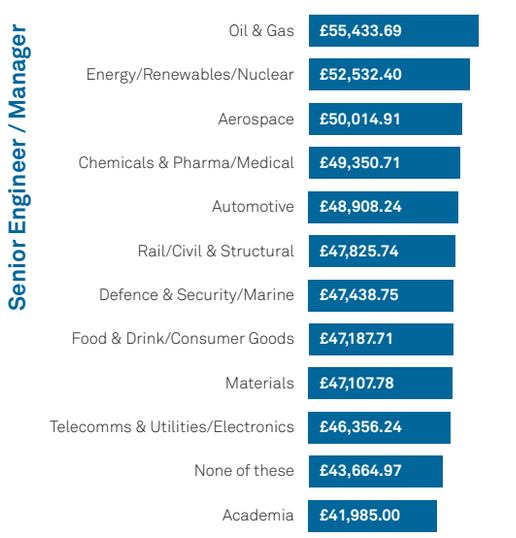
average salary in the oil and gas sector – the highest-paid

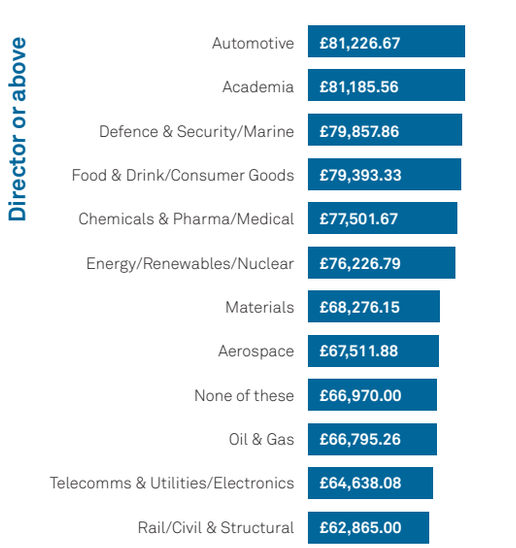
average salary by industry

The highest average salaries are found at director level in the Automotive sector

£81.2k







1. seniority

This year, 85.1 per cent of respondents to our survey describe themselves as senior engineers or above. This is a slight increase on last year, but continues to reflect the seniority levels of the overall audience of *The Engineer*.

Of those surveyed, senior engineers continue to make up the largest group, at 44.7 per cent, which is strikingly similar to the 2017 figure. Managers make up the second largest group, at 30.2 per cent, followed by junior engineers at 12 per cent, directors at 7 per cent, chief executives at 3.2 per cent and graduate trainees and apprentices at 3 per cent.

For the majority of engineers responding to our survey, average salaries have remained fairly static year on year, with relatively minor fluctuations both up and down. Senior engineers and managers saw their pay decrease from £48,102 in 2017 to £47,971 in 2018. Junior engineers and graduate trainees have seen a small increase in average pay, from £29,020 in 2017 to £30,557 in 2018.

However, those describing themselves as a director or above have somewhat surprisingly seen a slight drop in their average salaries over the past twelve months, declining from £75,825 in 2017 to £72,071 in 2018.

This drop is even more striking in the oil and gas industry, which is typically the sector offering the most generous pay packages, where those describing themselves as a director or above have seen their average salary decrease from £81,805 in 2017, to £66,795 this year.

For the majority, average salaries have remained fairly static this year

By contrast, in academia, which is often at the bottom end of the table for directors' pay levels, average salaries have increased from £58,500 in 2017 to £81,815 in 2018. This puts those in the sector just behind the top paid directors in our survey, those in the automotive industry.

While the unexpected results for directors are possibly skewed by the relatively small size of the sample group, respondents describing themselves as senior engineers and managers account for a far more robust sample group and here the picture is more in line with previous years, with those in the oil and gas industry earning the highest average salaries of £55,433 in 2018. This is over £10,000 more than their equivalent senior engineers and managers in academia, who earned £41,985 on average.

As in 2017, junior engineers in the chemicals, pharmaceuticals and medical industry had the highest average salaries in 2018, at £36,838. This is once again over £10,000 more than the average salary for junior engineers in the telecoms, electronics and utilities industry, who took home £25,958 in 2018.

The average age is 45.8, almost exactly the same as in 2017. Once again almost half are 50 or above. The percentage of female directors, managers and senior engineers is broadly the same as the overall picture for the profession, at around 5 per cent.

2. regions

As our survey demonstrates, British engineers can be found working throughout the UK and beyond.

The largest group of engineers can once again be found in the traditional manufacturing heartlands of the Midlands and East Anglia. However, this percentage has seen a gradual decline over the last few years, dropping from 29.8 per cent in 2016, to 27.9 per cent in 2017, and down to 24.8 per cent in 2018.

In contrast, the percentage of engineers working in London and the South East has increased slightly, up from 20.4 per cent in 2017 to 21.8 per cent in 2018. This is closely followed by the North of England, where 17.1 per cent of engineers say they are based, the South West, on 12.7 per cent, outside the UK, on 14 per cent, and Scotland, Wales and Northern Ireland on 9.7 per cent.

Once again, the highest earners are engineers working in London and the South East, with an average salary of £50,880, although this is a slight decrease on their average salary for 2017 of £51,743.

Where are the UK's engineers?	
Midlands or East Anglia	24.8 %
London or South East	21.8%
North	17.1%
Outside UK	14%
South West	12.7
Scotland, Wales or NI	9.7

Of all the engineers working in London and the South East, those in oil and gas earn the highest average salaries, at £66,636. This is followed by engineers in the materials industry, with an average of £59,857. Engineers in the South East's telecoms and utilities industry earn the lowest in the region, on average, at £44,896.

Professionals working overseas earned the second highest regional salaries last year, with an average of £50,505. Perhaps unsurprisingly, those working in the overseas oil and gas industry received the highest average earnings, at £62,002, closely followed by those in the overseas aerospace industry, on £61,461.

At the other end of the spectrum, engineers working in Scotland, Wales and Northern Ireland have dropped below their colleagues in the South West of England to earn the lowest average salaries, at £44,404.

Despite being the highest earners, engineers in London and the South East are amongst the least likely to be happy with their pay, at 29.5 per cent, down from 37.6 per cent in 2017. This may be explained by the slight drop in average earnings of engineers in this region.

Engineers in the Midlands and East Anglia are the most likely to be happy with their pay, at 35.7 per cent. Indeed, engineers in the manufacturing heartland appear most satisfied overall, as they were also the most likely to say they are happy in their job, at 53.7 per cent.

Midlands or East Anglia

Energy/Renewables/Nuclear	£52,196.08
Automotive	£51,614.75
Chemicals & Pharma/Medical	£51,586.21
Food & Drink/Consumer Goods	£49,620.00
Academia	£48,000.00
Telecomms & Utilities/Electronics	£47,307.69
Rail/Civil & Structural	£47,222.22
Defence & Security/Marine	£46,941.18
Aerospace	£45,954.55
Materials	£44,846.77
Oil & Gas	£43,615.38
None of these	£41,825.24

North (England)

Energy/Renewables/Nuclear	£61,138.89
Oil & Gas	£50,300.00
Defence & Security/Marine	£48,588.24
Chemicals & Pharma/Medical	£47,026.32
Academia	£46,769.23
Aerospace	£46,750.00
Food & Drink/Consumer Goods	£46,717.39
Automotive	£46,528.30
Materials	£44,478.26
Rail/Civil & Structural	£42,766.67
None of these	£39,626.87
Telecomms & Utilities/Electronics	£37,541.67

Outside UK

Oil & Gas	£62,008.33
Aerospace	£61,461.43
None of these	£60,212.79
Chemicals & Pharma/Medical	£54,740.37
Materials	£54,430.83
Telecomms & Utilities/Electronics	£49,301.46
Rail/Civil & Structural	£48,227.50
Energy/Renewables/Nuclear	£44,357.56
Food & Drink/Consumer Goods	£44,168.64
Automotive	£40,673.75
Academia	£39,204.00
Defence & Security/Marine	£38,837.14

Scotland, Wales or Northern Ireland

Chemicals & Pharma/Medical	£51,944.44
Energy/Renewables/Nuclear	£51,828.57
Oil & Gas	£48,500.00
Food & Drink/Consumer Goods	£48,000.00
Aerospace	£45,285.71
Rail/Civil & Structural	£45,250.00
Defence & Security/Marine	£43,047.62
None of these	£40,552.63
Academia	£39,666.67
Automotive	£39,363.64
Telecomms & Utilities/Electronics	£37,250.00
Materials	£36,250.00

South West (England)

Energy/Renewables/Nuclear	£52,000.00
Defence & Security/Marine	£49,740.00
Chemicals & Pharma/Medical	£48,733.33
Aerospace	£48,633.93
Food & Drink/Consumer Goods	£46,350.00
Oil & Gas	£46,307.69
Telecomms & Utilities/Electronics	£44,236.84
Academia	£42,714.29
None of these	£40,753.62
Materials	£40,428.57
Rail/Civil & Structural	£39,833.33
Automotive	£38,933.33

London or South East

Oil & Gas	£66,636.36
Materials	£59,857.14
Automotive	£56,954.17
Energy/Renewables/Nuclear	£56,259.26
Food & Drink/Consumer Goods	£52,555.56
Chemicals & Pharma/Medical	£51,453.13
Defence & Security/Marine	£51,229.17
Rail/Civil & Structural	£48,639.02
None of these	£47,790.91
Aerospace	£46,773.58
Academia	£46,500.00
Telecomms & Utilities/Electronics	£44,630.00

Sector	Average Salary (£)	Average Age	% content with salary	% happy in current job	% considering change of job	% likely to stay in industry for five years
Academia	44,774	46.3	34.1	56.5	47.6	81.2
Aerospace	47,752	45.7	32.9	49.8	42.3	83.5
Automotive	48,967	43.7	35.7	52.2	49.4	85.6
Chem& Pharma / Healthcare	50,890	47.6	35.1	54.4	39.6	82.5
Defence & Security / Marine	47,968	45.3	31.6	47.1	46.6	83.3
Energy / Renwables / Nuclear	52,653	44.6	39.6	54.2	48.3	81
Food & Drink / Consumer Goods	48,155	46.7	33	54.7	46.6	77
Materials	47,130	45.3	29.2	53.1	46.9	78.1
Oil & Gas	53,913	45.9	35.3	50.9	47.4	83.9
Rail / Civil & Structural	45,871	44.1	25.3	39.2	53.5	77.2
Telecomms & Utilities / Electronics	44,504	46.2	31.5	52.6	48.2	82.1

3. sectors

Engineers working across all sectors of the UK and overseas have seen a very modest year-on-year decrease in their salaries, down from £48,197 in 2017 to £47,896 in 2018.

Once again, the highest salaries can be found in sectors producing the nation's energy and fuel, with the oil and gas industry top of the table at £53,913, compared with £54,461 in 2017. This is followed closely by the energy, renewables and nuclear sector, where engineers earned £52,653 on average in 2018, compared with £51,953 in 2017.

At the bottom end of the pay scale, engineers in academia once again took home the lowest average salary, at £44,774, up slightly from £43,809 last year. But despite their lower earnings, just as in the past two annual surveys, academics are the most content in their jobs. Of those surveyed, 56.5 per cent said they were happy in their jobs, compared with 61 per cent in 2017 and 56.1 per cent in 2016.

Engineers in the energy, renewables and nuclear sector, meanwhile, are happiest with their level of remuneration, with 39.6 per cent claiming to be satisfied with their pay, followed by those in the automotive industry (35.7 per cent).

Of those surveyed, engineers in the chemicals, pharmaceuticals and medical industry were the least likely to be considering a change of job (42.2 per cent), and the most likely to feel valued in their role (44.8 per cent).

Engineers in the automotive sector are the most likely to see themselves staying in the industry for the next five years. Not everyone can be happy with their chosen lot, however. Engineers in the rail, civil and construction industry, for example, are by far the least happy in their job (39.2 per cent). What's more, they are also the least satisfied with their pay, with only 25.3 per cent claiming to be content with their salary, an even lower figure than last year (29.3 per cent).

Rail and construction engineers are also the least likely to feel valued in their roles (30.4 per cent), and among the least likely to believe they will stay in the industry for the next five years (77.2 per cent). They are also the most likely to be considering a change of job (56.7 per cent).

Engineers in the food and drink and consumer goods sector are also among the least likely to see themselves staying in the industry.

In terms of time off, holiday rates are once again highest in academia, where 36.1 per cent of engineers receive 26-30 days paid leave, and the same percentage receive 31 or more days.

Outside academia, engineers in the materials

45.8

average age of a UK engineer in the survey

88.6%

describe themselves as white

7.2%

of engineers responding to the survey were women

	% that feel valued in current role	% that do not feel valued
	40	23.5
	30.9	32.9
	43.3	30.6
	44.8	26.8
	34.5	33.5
	42	25.9
	40.8	27.9
	39.6	32.3
	38.2	24.9
	30.4	34.2
	40.2	27.1

industry are most likely to receive over 30 days of paid holiday (13.4 per cent), followed by those in the automotive industry (12 per cent).

Engineers in the food and drink and consumer industry are least likely to receive more than 26 days of paid leave (31.4 per cent), followed by those in the telecoms and utilities sector.

Overall, 47.4 per cent of engineers taking part in our survey said they receive a bonus, but the sector with the highest percentage of professionals receiving a bonus is the materials industry (59.8 per cent). The least likely to receive a bonus, once again, are engineers in academia (9.3 per cent).

When it comes to qualifications, as in the previous two surveys, the energy, renewables and nuclear industry has the highest percentage of graduates, at 57.8 per cent, compared with 58.6 per cent in 2017.

4. gender and diversity

The gender pay gap has hit the headlines recently, with firms employing over 250 staff members forced for the first time to publish the difference between average salaries for male and female staff.

In engineering, our survey suggests that for female engineers, the pay gap with their male counterparts has widened significantly this year.

The average salary for female engineers responding to our survey is £35,801, down from £38,109 in 2017. This is based on a similar sample size and spread of seniority to our 2017 survey.

In comparison, the average salary for male engineers in 2018 is £48,724, compared with £48,886 last year. This means that the gap between male and female pay in engineering has grown significantly, from around £10,000 in 2017 to approximately £13,000 this year.

As previously, this gap can partly be explained by the difference in seniority among male and female respondents. Just 2.4 per cent and 11.3 per cent of male respondents describe themselves as graduates and junior engineers respectively, compared to 10.2 per cent and 20.3 per cent of female respondents.

In contrast, 45.8 per cent of male respondents describe themselves as senior engineers, compared to 30.5 per cent of females, although the proportion of male and female managers is very similar, at 31 per cent and 30.1 per cent respectively.

Even more worryingly though, male engineers at all levels of seniority are paid more than their female counterparts. Female graduates and junior engineers earn an average of £27,552, for example, compared to £31,051 for male engineers, a gap of around £3,500.

The gap jumps to around £10,000 for senior engineers and managers, amongst whom females earn £38,688 and males £48,466. But it widens even further at director level and above, where women earn £46,053, and men £73,595, a huge difference of £27,542.

The gender imbalance within the engineering profession is also showing no signs of shrinking.

Despite the best efforts of numerous engineering bodies, the percentage of female engineers responding to our survey is just 7.2 per cent, up from 7 per cent in 2017, 6.5 per cent in 2016, and 5.5 per cent in 2015.

Among the individual sectors, the industry with the highest percentage of female engineers is once again academia, where 12 per cent of respondents are women, followed by telecoms, electronics and utilities, on 8.7 per cent.

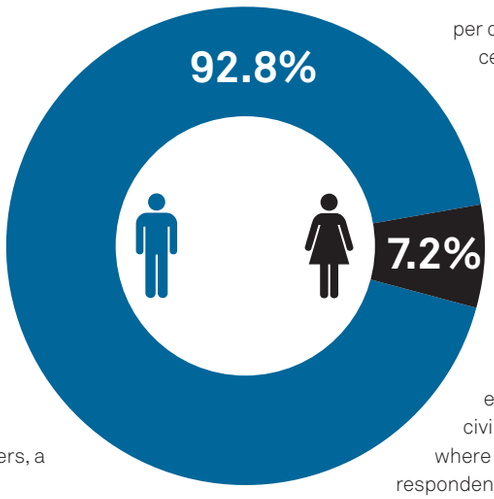
At the other end of the scale, just 2.6 per cent from the consumer goods and food and drink sector are female, followed by the defence, security and marine industry, on 3.7 per cent.

Around half of female and male engineers are happy in their jobs, although perhaps unsurprisingly a higher percentage of men (33.2 per cent) than women (25 per cent) are satisfied with their pay.

The diversity gap in engineering continues to narrow only fractionally year-on-year, with 88.6 per cent of respondents describing themselves as white in 2018, compared with 89.3 per cent in 2017 and 92.1 per cent in 2016. This year 8.1 per cent describe themselves as black, Asian or minority ethnic, compared with 7.3 per cent in 2017 and 6 per cent in 2016. Once again the individual sector which attracts the highest percentage of black, Asian and minority ethnic engineers is the rail, civil and structural industry, where 13.5 per cent of respondents describe themselves as non-white, up from 11.5 per cent in 2017. This compares with the defence, security and marine industry, where just 3.5 per cent describe themselves this way, up from 2.1 per cent in 2017.

The diversity gap can also be felt in the salaries being earned by engineers of different backgrounds, where once again those respondents describing themselves as non-white earned almost £10,000 less than their white peers. The average salary among non-white respondents is £38,610, while white engineers are earning £47,896.

The diversity gap continues to narrow only fractionally



Average salary by gender by seniority

	Junior	Senior	Director
Male	£31,051	£48,466	£73,595
Female	£27,551	£38,688	£46,053

Making strides to help change people's lives

Dr Nadine Stech tells Jon Excell **about the challenges of engineering advanced prosthetic legs and the satisfaction in getting it right**

As an engineer growing up and studying in Stuttgart, Dr Nadine Stech always imagined that she was destined for the automotive industry. But in an unexpected change to the script, a random lecture in biomechanics ignited a passion that has seen her play a major role in the development of one of the world's most advanced prosthetic legs.

Stech, now a senior control design engineer at Basingstoke-based Blatchford Group, joined the noted prosthetics specialist as an intern following that fateful lecture and has been there ever since. "What I liked about it was the interaction between the human and the machine," she told *The Engineer*. "It's a great example of how engineering can change lives."

And Blatchford certainly has an illustrious past when it comes to changing lives. Founded in the 1890s, the firm came to prominence making prosthetic legs and orthotics for soldiers who had lost legs or been injured in the two world wars. Then, in the post-war years, it steadily ticked off a series of technological milestones: pioneering the use of carbon fibre materials in the 1980s and, a decade later, introducing the first microprocessor-controlled prosthetic knee.

All of these developments helped refine and improve the performance of lower-limb prosthetics. But it was the launch of its Linx system, a project in which Stech played a major role, that perhaps represents the firm's biggest technological step forward.

Developed for above-the-knee amputees, and weighing 2.4kg (just under half the weight of a natural human leg), Linx combines four microprocessors and seven situational awareness sensors across the knee and ankle joints. These collect and analyse user, activity and terrain data that is then used to continuously adapt the leg's performance by adjusting resistance in its hydraulic and pneumatic actuators.

Critically, the system is the first of its kind to fully integrate the leg and the foot. While a number of manufacturers, including Blatchford, offer separate microprocessor-controlled feet and knees, Linx is the first lower limb prosthesis to combine these into a single system in which there is full information exchange between the two joints.

"The leg's performance is determined by the data gathered by both the foot and the knee," explained Stech. "For instance, the foot is great at sensing surfaces because it's in contact with the ground, whilst the knee is better for cadence and different step detection."

This means, for example, that if sensors in the foot detect a slope then the foot can instruct the knee to increase the level of damping. Or, when a user stops walking, the sensors will detect this and increase the resistance in all of the joints, enabling the amputee to stand still, confident that the device will support them. This latter feature, said Stech, represents a particularly significant advance for amputees, as the ability to distribute weight equally across the prosthesis and the intact limb can help the intact side remain healthier.

One of the big challenges to achieving this seamless exchange of data was figuring out what data should be shared and when. "You can share a lot of information but it might not be relevant," said Stech, "so it's about finding how high the level of information needs to be within the joints so that it's still meaningful. It's a real-time system so you can't allow information to be delayed or take too much time as that would influence the knee action."

> "It's a great example of how engineering can change people's lives"

Another key challenge, and one which was critical to commercialising the technology, said Stech, was finding a way of fitting all of the sensors, actuators and electronics into such a lightweight and compact package. Indeed, the somewhat unique packaging requirements meant that many of the components on the leg – such as the hydraulic cylinders, electric boards, and springs – were developed in-house.

Stech added that it is the forensic attention to areas like this that differentiates Linx from the numerous research projects also looking at intelligent limbs. "In

research, you might have one or two users and you're customised for those, but commercially you need to make it as robust as possible to have a large base of customers.

Even if researchers are coming up with good ideas, it's still a very long way to get it to something you can commercialise. I think it's unique that we have found a way to get system integration in a robust manner to cater for a large group of amputees."

The company's testing regime is a good illustration of this, with legs typically tested continuously for three to five million cycles, roughly equivalent to the expected three-year life of the device. As well as ensuring that Blatchford's engineers can be confident that the legs will meet the rigorous demands of real-world use, these tests are also a valuable opportunity to evaluate ongoing refinements to the design, to, for example, make it lighter.

For a product of this kind, functionality and performance is clearly the number one concern. Nevertheless, Linx is a striking-looking device, and has, said Stech, been carefully designed to be a desirable hi-tech product that consumers can be proud to wear.

Indeed, while wearers of prosthetic limbs have often opted to cover them up in the past, Stech has detected a shift in attitude following the headline-grabbing achievements of the athletes competing in the London 2012 Paralympics. "There was a lot of stigma, but the thinking has changed since the Paralympics," she said. "Some of our patients want to show it off instead of hiding it away with cosmetics."

Beyond the aesthetics, another major area of development is the so-called human-machine interface: the socket system used to secure the prosthesis to the amputee's stump. Interestingly, despite all of the incredible engineering housed within the Linx leg, this most critical mechanical interface remains relatively untouched by the march of technology.

The design of the socket itself is still a heavily manual process, and the user's experience of the technology is highly dependent on the skills of the individual socket clinicians. "At the moment it's very hands-on and based on the knowledge of the clinician," said Stech. "I can remember amputees telling me 'it's taken me a while to find a good socket clinician and I'd like to stay with them'."

Addressing this challenge is, she said, a real hot topic in the prosthetics community, and Blatchford has been working with researchers at the University of Southampton on the development of an intelligent socket liner that uses integrated pressure sensors to measure the pressure and pulling forces at the interface between a patient's stump and socket of their prosthesis. Such a system could, she said, enable clinicians to optimise socket fit more quickly and accurately.

Currently, Linx has around 300 users. Although some of these are in the UK, the device - which costs around £30,000 – isn't available via the NHS and the biggest market for the technology is in North America.

It's no surprise that enabling the widespread adoption of expensive technologies like Linx is a major challenge. But Stech believes that new approaches to design and manufacturing may one day help overcome some of the barriers to broader adoption of similar systems.

One promising avenue of research in this area is the MovAid project, a cross-disciplinary initiative co-ordinated by Blatchford and involving 13 partners from across industry and academia.

Now in its third year, one of the key aims of this initiative – which is funded through the EU's Horizon 2020 programme – is to look at how sensing, scanning and 3D printing technology could be used to speed the design and manufacture of highly personalised orthotics and prosthetics.

This could enable the technology to become more widely available, said Stech: "If it becomes cheaper to do systems you can give that back to the customer."

01 Stech monitors a Linx prosthetic user – the device is constantly being improved to make it more responsive

02 The different parts of the Linx communicate with each other so that they can adjust to the terrain

Global reach of show increasing for 2018

Biennial event will be barometer for how aerospace is facing up to Brexit, as well as being the usual spectacle

Running from 16 to 22 July, the 2018 Farnborough International Airshow is expected to provide the backdrop for the announcement of a host of multi-billion dollar deals, and the launch of a number of major innovations.

According to the show's organisers, the biennial show is expected to build on the success of its 2016 iteration, which generated $124bn in orders and featured more than 1,500 exhibitors from 52 countries

Alongside the exhibitors – companies ranging from small suppliers to major OEMS and drawn from across the aerospace sector – visitors to this year's event will find a number of additional features, including an Innovation Zone bringing together the best in advanced engineering universities, research and technology organisations. The Space Zone also makes a return after its introduction in 2016.

This show will feature a new Aerospace 4.0 Zone, which will offer visitors the chance to explore the digital technologies transforming manufacturing across a range of industries. Organisations including Deloitte, Frazer-Nash Manufacturing and SAP will all be on hand to help visitors understand how the latest digital technologies can be used.

As always, the show will also feature a packed flying display – with manufacturers including Boeing, Airbus, Dassault, Bell and others all expected to showcase aircraft.

Meanwhile, a packed conference programme will include insightful keynotes, panel discussions and topical presentations from the industry's leading innovators.

Significantly, in a sign that companies are perhaps beginning to look beyond Brexit, this year's event also boasts a major international presence – countries such as Mexico, Turkey and the US will be vying for business alongside a significant European presence from Germany, France and Spain. This year's show will see the largest presence yet from China, with 70 per cent growth in participation since the 2016 show.

Meanwhile, Japan has also increased its presence with a second pavilion, joining Malaysia, Korea and Indonesia, and underpinning the airshow's role as a key gateway into the lucrative Asian aerospace market.

Commenting on this, Gareth Rogers, CEO of Farnborough International, said: "The airshow has always served as a valuable economic barometer – from the billions of dollars in deals announced through to the level of attendance, and coming just eight months ahead of Brexit, the strategic importance of this year's event cannot be underestimated."

The show opens to the public for the weekend of 21-22 July. Tens of thousands of people are expected to attend the event to watch the legendary flying display and get up close to a huge variety of aircraft, from fast jets to jumbos. Innovation is a major theme for this year's show and there are a number of inspiring and engaging exhibitions from organisations such as, for example, the Winchester Science Centre and Brooklands Museum. ■

> "The strategic importance of this year's event cannot be underestimated"

Farnborough is a key platform for new launches and industry networking

11 June
1858

Striking a historical note

The Big Ben currently silenced is the second bearing the name

Anybody visiting Parliament Square at the moment will see a lot of disappointed tourists. One of the main things they will have come to see – the clock tower of the Houses of Parliament, universally (but erroneously) known as Big Ben – is sheathed in scaffolding with only one face of the clock visible.

And if they were hoping to hear the famous Westminster chimes, and the bell that is actually called Big Ben ringing out the hours, then they are also unlucky. Owing to essential repairs, the tower will be sheathed and the chimes silenced until 2021, apart from on special occasions such as New Year's Eve.

Perusing our archive, we came across a small entry – just one paragraph – full of interesting and very little known facts about the bell. The first eye-catching thing was that it was referred to as "Big Ben the Second". There are no further details on why this should be so in the article itself, but a little research has uncovered some history.

The first bell for the tower, a 16.3 ton hour bell, was cast in Stockton-on-Tees on 6 August 1856, and the name of Sir Benjamin Hall, a Welsh civil engineer and politician who served as MP for Marylebone from 1837, and who oversaw the latter stages of the rebuilding of the Houses of Parliament, was inscribed upon it. Sir Benjamin being a famously tall man of the time, it is thought that the bell was named after him and even then the tower was also known as Big Ben, though at the time it was properly named St Stephens Tower (it was officially renamed the Elizabeth Tower in 2012).

In fact, nobody knows whether this naming is true. Another story is that it was named after a contemporary heavyweight boxer called Benjamin Caunt. When the bell was cast, the tower was not yet finished, so it was mounted for testing in nearby New Palace Yard. During testing, however, the bell was cracked beyond repair. A new bell was ordered and the commission given to the Whitechapel Bell foundry near the Tower of London – still in existence and open for fascinating tours, although the foundry itself closed just over a year ago, holding the record as the oldest manufacturing company in Great Britain.

Enter Big Ben the Second. *The Engineer* tells us that the bell was nicknamed "Victoria" and was "tastefully ornamented with Gothic tracery in low relief". Inscribed upon the bell were the words "This bell… was cast by Mr George Mears, of Whitechapel, for the clock of the Houses of Parliament, and the direction of Edward Beckett Denison QC in the 21st year of the reign of Queen Victoria, and in the year of our Lord MDCCCLVIII".

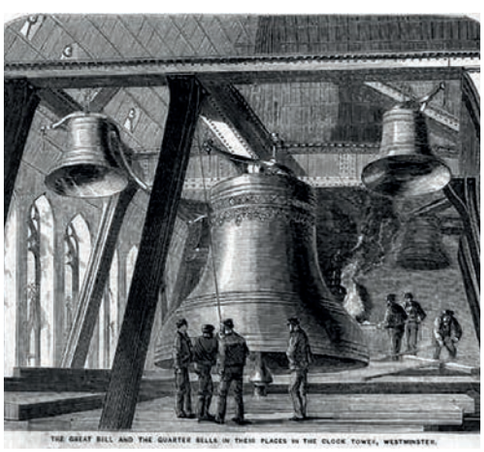
The weight, the article tells us, was 14½ tons, one and three-quarter tons less than its ill-fated predecessor (these are, of course, Imperial tons). It was 7ft and 3in high, and 9ft in diameter at its mouth. This was not smaller than the previous bell, but the shape was different. "The head is more rounded, and the waste more sloped in," the article records.

The spot on the bell where the hammer was to strike was half an inch less in thickness than the old bell, we are told. Already at this point, *The Engineer* records that the bell was faulty in tone, ringing at nearly F rather than E natural. "The tone of the new bell is stated to be so full of sound that even a slight stroke with a common switch makes it ring with a tolerable tone, and the vibration, after being struck with the clapper, gradually settles down like the sound of a trumpet dying away."

The clapper had also been cast, and weighed about six hundredweight, half as much as the clapper for the previous bell. Returning to our research, the new one cracked in September 1856: according to George Mears, immortalised on the bell's inscription.

Denison (an irascible man, whose obituary we have also featured in our archive section) had used a hammer of more than twice the maximum weight specified to strike the bell. It was out of commission for three years and the hours struck on the lowest toned quarter bell instead while it was repaired.

The repair was a remarkable piece of improvisation: a square piece of metal was chipped out of the rim around the crack and the bell rotated so that the clapper struck in a different point. The tone of the bell changed irreversibly, and the crack is still in place to this day. Nobody calls it Victoria, though. SN



Past and present: there have been two Big Bens, as our archives reveal

Word of the issue

Anthony Poulton-Smith explores origins of the word ‘gear’

There are at least four uses for the word ‘gear’.

In the 1960s, the Beatles used ‘gear’ as a synonym for ‘fab, desirable, excellent’ – linked to ‘gear’ meaning clothes. This usage is no longer in vogue, and to use it to refer to one’s attire is also unlikely to be heard in the 21st century.

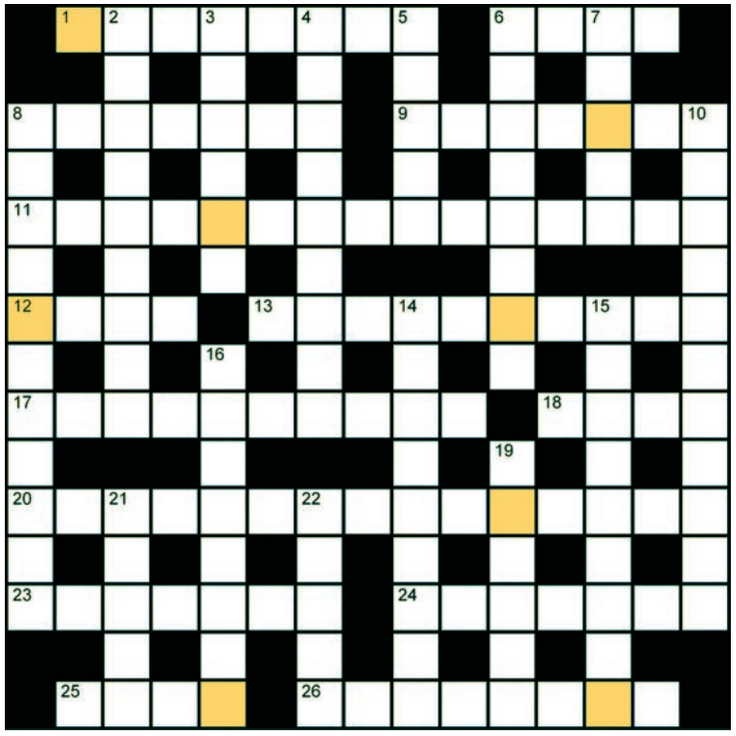
Reference to attire dates from at least the late 12th century and can be traced to nearly all Germanic languages, from a Proto-Germanic root garwjan ‘to prepare, equip’.

By 1420 the ‘attire’ sense had been transferred to the harness and tackle employed when using a horse as a mode of transport, either to pull or to ride. A century later and the same word is used for the toothed cog (the third use). Thus, this is derived from the sense of ‘equipment’.

Now that we understand the evolution of the word, it is easy to see how, by 1670, ‘gear’ could be heard referring to the male genitalia - a fourth use for the word.

Bigpicture

Brabham is back with the BT62, a £1m track-only hypercar that is set for a limited production run of 70 vehicles from facilities in South Australia. The BT62 is said to boast a power-to-weight ratio of 730ps per tonne, a dry weight of 972kg and is powered by a Brabham naturally aspirated 5.4 l capacity V8 engine.



Prize crossword

When completed rearrange the highlighted squares to spell out a run-down apartment house. The first correct answer received will win a £20 Amazon voucher. Email your answer to **jon.excell@centaur.co.uk**

Across

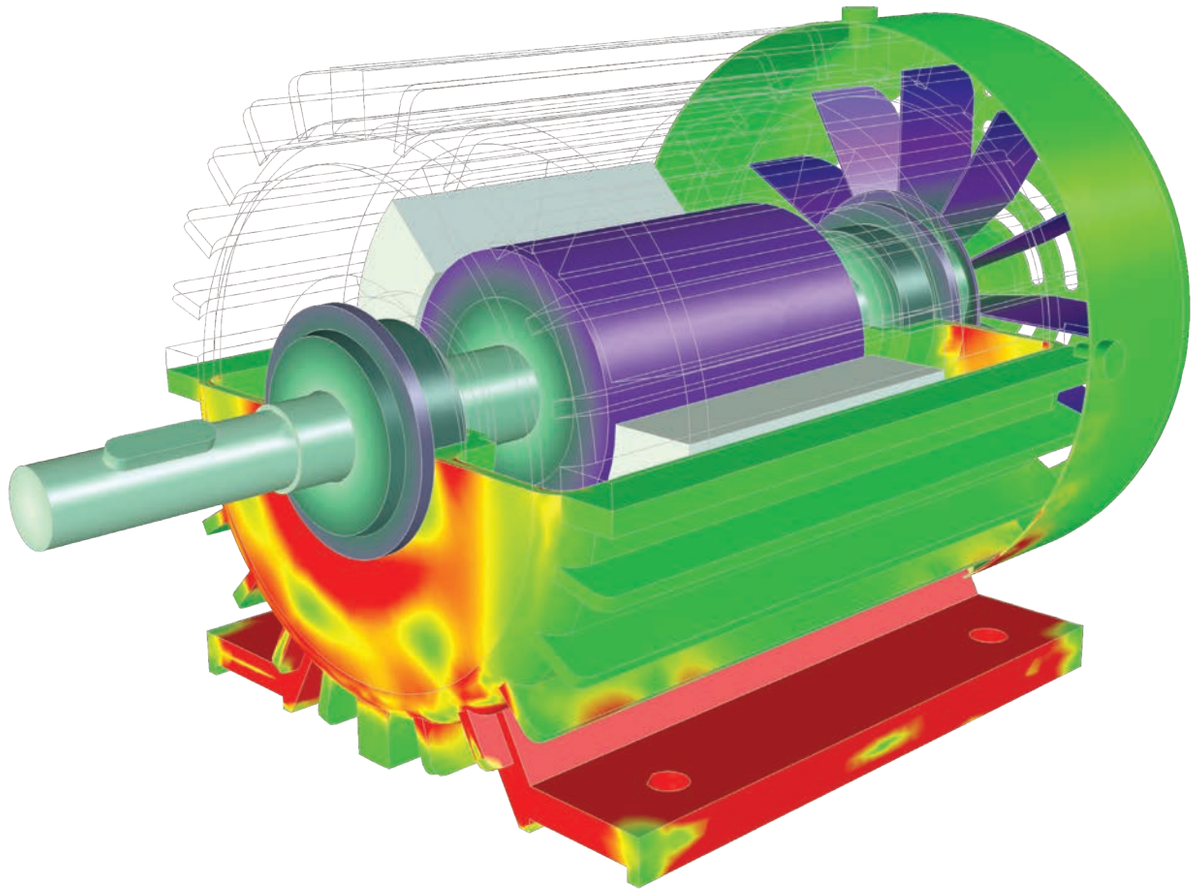
1 Toiletries that emit a fragrant odour (8)
6 Flow intermittently (4)
8 Move ball close along the ground (7)
9 Protective cover from the weather (7)
11 Building for students (9,6)
12 Greek God of love (4)
13 A small compartment (10)
17 Pass into by permeating (10)
18 A major manufacturing city of the Ukraine (4)
20 Large building at Heathrow (7,8)
23 Enfold completely (7)
24 Period of archeology with metal tools (4,3)
25 Imperfection in piece of wood (4)
26 List of employees and their salaries (8)

Down

2 Remove power from device (6,3)
3 Flowing back (6)
4 Gallant or courtly gentleman (9)
5 Improperly forward or bold (5)
6 Cutting a way through (8)
7 Underground railway in Paris (5)
8 Cause to become widely known (11)
10 Safety device in a boiler (6,5)
14 Farthest region or point (9)
15 Position oneself (9)
16 Illuminated powerfully at night (8)
19 Flat and even (6)
21 Separated or cut with a tool (5)
22 Knock over (3,2)

May’s highlighted solution: Mansion. Winner: **Stephen Dolan**

Invented in the 1800s. Optimised for today.



Visualisation of the von Mises stress distribution in the housing of an induction motor by accounting for electromechanical effects.

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