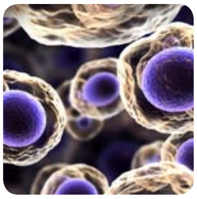
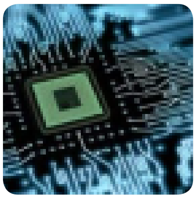
POWER THE FUTURE



9 technical articles that will take you from our world to the future and beyond.



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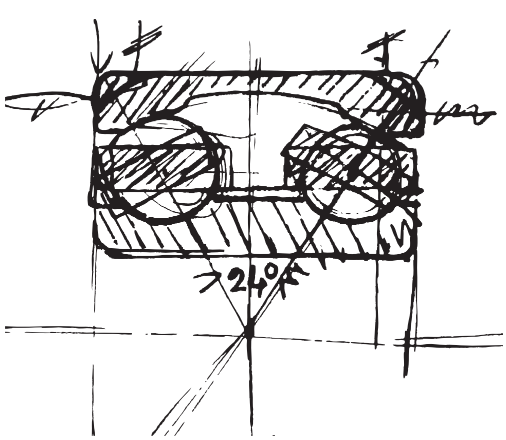
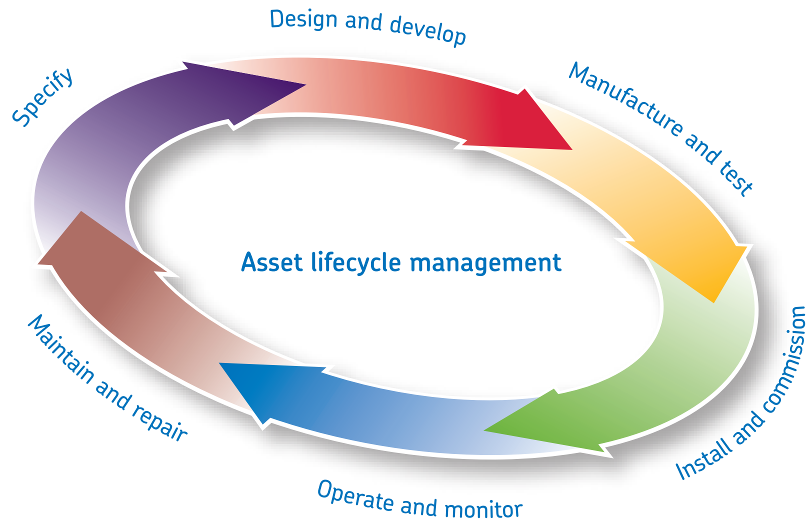
Powering the future

Over 100 years ago, Sven Wingquist invented the self-aligning ball bearing and founded SKF. Since then, we have played our role in helping to reduce friction in the mechanised world, and as a result our business has grown quickly and globally to become a leader in industry. Today, we operate in 130 countries around the world, employ some 48,000 people and have an annual turnover of SEK 71 billion. All of this can be attributed in part to our focus on powering innovation: progressing our products and services, empowering our people and challenging ourselves to constantly push the boundaries of what's possible.

Our business value across all segments in which we operate is to make sure that we keep machine shafts rotating and equipment moving over their expected lifetime. At SKF, we always continue to fine tune products and solutions to bring higher value to our customers and to make them more competitive. This emphasis on developing complete and innovative solutions helps to make machines more reliable, more energy efficient and to also reduce the total cost of ownership for our customers. However, it is also important that we focus with our customers on Asset Life Cycle Management, right from the early design phase through to remanufacturing, and finally, replacement. Therefore, we place an equally vital emphasis throughout our business on assisting our customers after installation and during operation.

Indeed, it is this emphasis on Asset Life Cycle Management that has led to some of our most ground-breaking developments. More than 30 years ago, for example, we made history by developing the bearing sub surface fatigue life calculation, which subsequently became the ISO standard throughout industry. However, as time has moved on and we have gained deeper understanding of the reasons behind bearing failure, we have applied this knowledge and technical experience to further develop this important model. The results of this development will be showcased at Hannover Messe 2015, the world's leading





trade fair for industrial technology, however the notion of continuous improvement that this development demonstrates is evidenced throughout this report.

As technology continues to evolve at an increasingly rapid pace throughout the world of engineering and beyond, it is vital that engineering businesses, including SKF, consider the implications that this will have on their products, services and business models as well as their customers at all levels: factory, machinery and workforce.

All of SKF's new product and service development projects are based on a number of important factors, including extensive experience gathered over many years, a dedicated and efficiently trained workforce that has industry leading knowledge, and a specific intention of where and how a new product is to be used.

The forward thinking culture that we pride ourselves on is essential to remaining a market leader. This is especially true in the engineering sector, where one ground-breaking idea can change the face of a whole product market. Recognising and keeping ahead of industry trends is as much a part of successful development as anything else, which is why we have put together this report, which outlines our vision of the future for the sectors we work in.

So, why this report? Well, we have drawn on our many years of experience to paint a detailed picture of areas within production and manufacturing that we think will experience significant evolution in the near future. We have also combined our efforts with a carefully chosen selection of independent academic and objective industry experts, who have specifically contributed their expertise through a number of fascinating articles.

Through this report, readers will develop a greater knowledge of three main areas of interest that we predict will continue to grow in importance and become more prevalent in the day to day operations of industry. These topics include: The evolution of the factory; the future of intelligent machine design; and the power of knowledge engineering.

The evolution of the factory is a common topic among the engineering sector. Already, although on a tiny scale, we have begun to see the influence of technological advances, such as in the utilisation of smart devices, on factory processes. In this chapter, the factory of the future is discussed, with specific focus

on how it will look, what it will do and how the technology that powers it will work.

Further to the use of smart technology, the role of the Internet of Things is potentially one of the biggest changes that the factory will experience since the introduction of automatic control of machinery. This is why in the second chapter of the report we take an in-depth look at the future of intelligent machine design and the influence of the Internet of Things and concepts such as Industry 4.0.

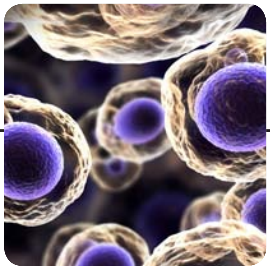
Last, but certainly not least, the third chapter in the report discusses the impact that the increasing reliance on IT, and the resulting data produced, will have on engineering companies and their workforces. It will also highlight the continuing need for innovation to keep up with an ever changing industry by discussing how to capture and deliver value.

By creating an environment that actively encourages improvement and development, through specific management procedures and analysis, SKF continues to lead the market in terms of innovation. Through continuing to nurture industrial activity and development, we in SKF believe we can power the future and unlock the next industrial revolution.

Bernd Stephan

Senior Vice President, SKF Group Technology Development

Bernd Stephan is Senior Vice President of Group Technology Development at SKF. He joined SKF in 1994 and has almost fifteen years' experience of leading business units within both SKF's industrial and automotive businesses and most recently held the position of Director of the Group's renewable energy business unit. Bernd is experienced in engineering as well as product and manufacturing process development and holds a degree in Mechanical Engineering from the University of Essen.




SKF
BeyondZero

The evolution of the factory

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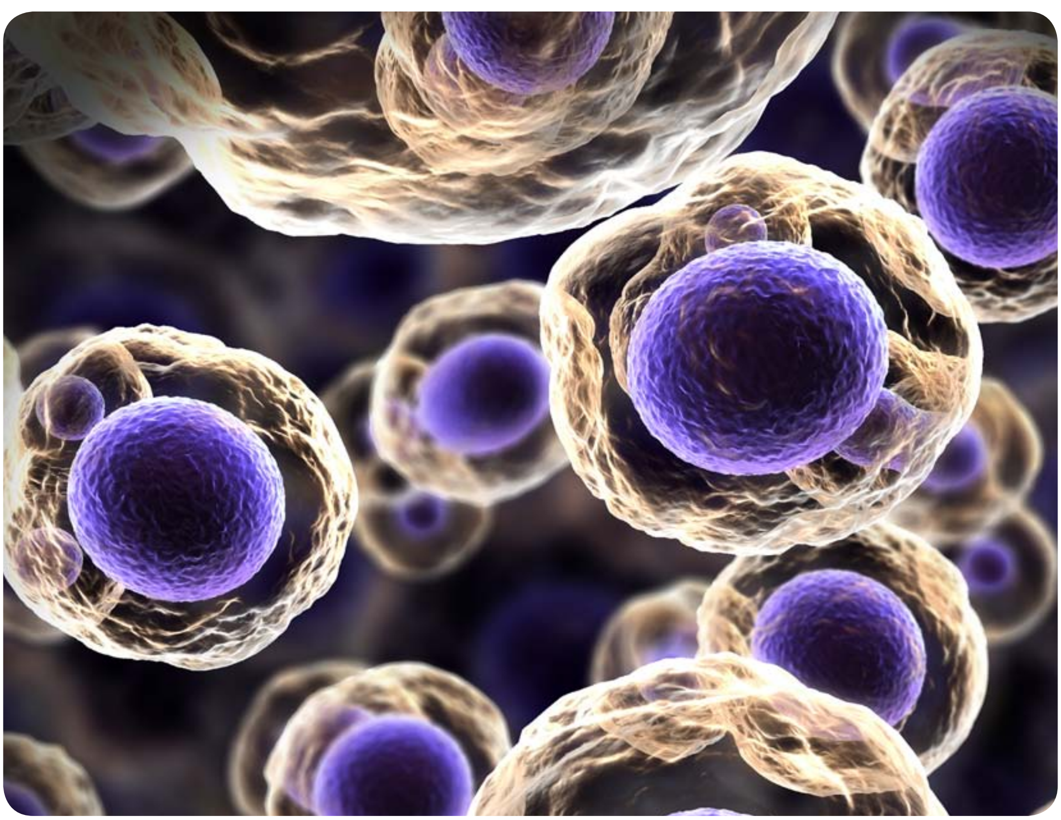
Emerging technologies and future factories



There have been dramatic changes in the world of manufacturing over the last two decades, with the days and years of noisy, dirty factories that relied on out-of-date tools and working practices being consigned to the history books. Even in cases of large scale engineering manufacturing, the work-place is noticeably cleaner and better organised. These changes have largely been driven by improvements in efficiency, higher quality goods and cost reducing methods. The question to ask now is: How will emerging technologies and advances in traditional technology alter the future shape and organisation of the factory? With the widespread use of information and communications technology (ICT), which is creating a diverse blend of technologies and applications, attitudes to manufacturing are already shifting, including the way that the future workforce is developed and trained.

New and emerging technologies

The ubiquitous rise in importance and sophistication of ICT cannot go unnoticed. Processes can be monitored and controlled. Stock at both the input and output of a manufacturing process can now be tracked and the data can be used to maximise efficiency. The machines used in factories can have their condition continuously monitored and this can, and will, have big implications for reducing the cost of maintenance and down-time. This should also reduce the possibility of human error (Dhillon 2014).

The design process itself has changed and there has been a large reduction in the number of design staff and variation in the corresponding infrastructure. This could lead to increased home-working and specialised design teams, or companies, that serve several manufacturing units. References to 'design' will enter the vocabulary of engineers more frequently. It will become part of more branches of engineering, which will no doubt have fairly profound effects on education at all levels.

Of the newly emerging technologies, biotechnology has been enhanced by new developments in systems and synthetic biology, followed by nanotechnology and its applications to materials, medicine, energy and other sectors. It is possible now to predict the need for a new type of factory that could possibly create and manipulate human cells.

Biotechnology has in many respects already started to have a place on the factory landscape, but it has wide variability in size and scope. While there are already large scale operations that turn biocrops into non-food products and energy, there are also small scale yet very high technology factories that create pure enzymes, proteins and biomolecules for medicine and other purposes. These activities will grow, despite public concerns about genetic modification. A common factor across these activities is the increasing importance of interdisciplinary activity and the increasing need for chemical and process engineers.

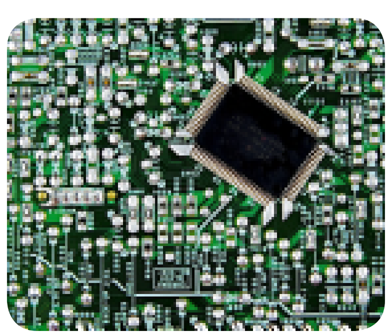
One very likely new development is the development of 'stem cell factories' and later, possible 'replacement organ factories'. However, the business model for these and the way they will be organised and built is yet to be decided. The biotechnology world is very prone to contamination by unwanted microbial, viral and fungal species. Therefore good housekeeping and cleanliness is of paramount importance and most biotechnology factories are and will be characterised by very clean sterile operating conditions, along with careful containment of waste streams.

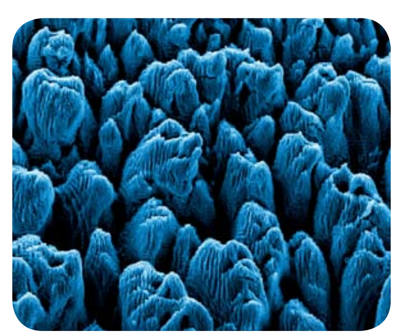
In common with many other chemical processes, such factories will endeavour to make every use of 'waste', including thermal and carbon dioxide for feeding into other processes in the factory. This zero waste, maximum thermal efficiency attitude is becoming embedded in the psyche of process engineers. A good example that is emerging is the use of energy harvesting from waste heat, fluid flow or vibration to provide electrical power for sensors that are now more integrated into the factory plant, often eliminating the need for a lot of cabling but making use of wireless telemetry.

Nanotechnology has the potential to provide significant improvements and changes to materials via an incremental approach as well as to provide truly transformative action in areas such as low energy lighting, new energy storage and energy conversion, and nanomedical developments. There will be a need for a significant scale-up to occur so that nanoparticles and other nanostructures can be mass-produced under tightly controlled conditions and then incorporated into materials and products. This 'journey' is only just starting. We are already aware of the potential hazards of nanoparticles that might be inadvertently released into the environment or workplace, so their use will be strictly controlled and this in itself is going to lead to beneficial new ways to control waste streams emanating from future factories. Furthermore, we have to deal with the economics of introducing new nanocomposite materials even if we are aiming at incremental improvements. In most industries 'cost is king' is the main paradigm and the market will determine if a small benefit in performance can justify an increase in manufacturing cost. There will be a much more detailed Life Cycle Analysis of manufacturing in the future. This is becoming apparent already in the field of composites, because for such materials it is very difficult to recover the original raw materials for re-cycling. As resources become scarce, this might even lead to new concepts of re-cycling factories.

Sectors where new factory concepts will be needed

The pharmaceutical sector is likely to undergo radical changes soon. Many of the traditional methods of preparing new drugs will be retained but in order to ensure quality and keep costs down, the processes will become more automated and incorporate more instrumentation. The introduction of





nanotechnology to synthesise new methods of drug delivery and diagnosis will, in particular, lead to major changes in the manufacture of products. This could be step-wise, with initially an 'extension of life' of existing formulations, by delivering the drug via nanoparticles or nanocapsules. This could be especially true of inhaled drugs. All such nanoparticles will also have a fairly sophisticated 'target recognition' surface layer to ensure they reach the right target in the body. Making the factory process do this reproducibly and in a way that will satisfy regulators is going to be challenging.

The energy sector is going to require new manufacturing methods. Nanoparticles and many biotechnology aspects are going to become central to new methods of storing and generating energy. Most of the new battery advances rely heavily on the development of new materials to store and release charged ions. This requires the integration of new carbon-based materials that can be designed to have huge internal surfaces into such batteries. The drivers for this are not restricted to the hybrid and electric vehicle industry, but spread across energy storage generally, especially for the intermittent renewable sources such as wind and solar.

Nanoparticles for catalysis will also be required in increasingly sophisticated form. There is great potential for making catalysts and reactors to help convert 'spare electrical capacity' into gas, either hydrogen by electrolysis or photoelectrolysis of water and possibly to produce methane from carbon dioxide and water. Catalysts and new specialised reactors will also be needed for gas to liquid conversion, because, like it or not, hydrocarbon fuels are a very effective way of carrying energy.

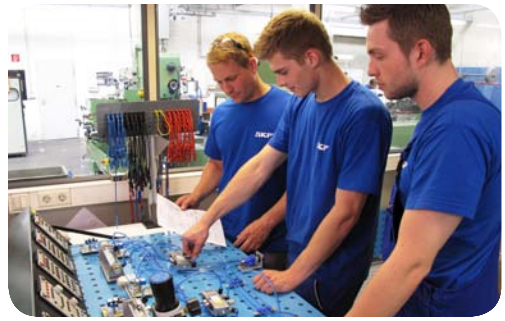
The transport and automobile industry will be placing challenging requirements on new materials to reduce weight and yet maintain strength and integrity. Already there are changes to vehicles in switching from steel to aluminium for lightweighting and this general change may continue. The role of composites to replace steel is especially challenging because of the issue of recycling referred to earlier. The recovery of energy from what is currently waste heat in both the auto and building sectors will lead to new types of heat pumps and other energy convertors.

Training

It is clear that there is a real and urgent need for training people for the factories of the future. There have been a number of European initiatives such as 'Manufuture' and the contrasting situation with the US and Japan has been nicely summarised by Mavrikios et al (2013). Global trends in this area were collated and analysed in a paper by Secundo et al (2013). This identified in particular the societal needs of preserving scarce resources, taking account of climate change and reducing poverty. They also identify the Manufuture programme and the IMS2020 programme being conducted by Europe, Japan, Korea, the USA and Switzerland which addresses all of these issues as well as addressing standardisation, innovation and the all-important aspect of competence development and education.

The UK, for example, is putting in place training at several levels. It is increasing its capacity for early stage training in skills via apprenticeships and there are new special University Technology Colleges being set up to augment some of the Colleges of Further Education. At a higher, graduate level, there are several specialised Centres for Doctoral Training. The gap at present in the UK and elsewhere is probably at the post-experience stage and the provision of courses for Continuing Professional Development. Frankly, this does need to be addressed.

The Engineering and Physical Sciences Research Council (EPSRC) has recently introduced a focussed initiative to improve training and knowledge transfer in the manufacturing area and it has created 16 new Centres for Innovative Manufacturing. This provision for research and development at the early stages of Technology Readiness Levels 1-3 adds to the new InnovateUK Catapult initiatives which cover the higher TRL levels. Currently, there are seven of these based around the country with an investment of £140M over a six year period.



One further aspect that has not been covered so far is the issue of keeping our factories of the future operational. Over the years some form of condition monitoring or preventative maintenance has been adopted, especially in the aerospace and automotive industry. As manufacturing processes become more diverse and automated there will be a need to obviate plant failure and especially human error. The issues are well described in a recent paper by Dhillon (2014).

What are the regional and national policies that are emerging to help develop the Factories of the Future?

There is a broad consensus on the answer to this and there seems to be a common purpose developing.

The European Commission has issued a document commissioned by the European Factories of the Future research Association: 'Factories of the Future' which sets out a detailed roadmap for its Horizon 2020 programme. This document takes a broad look covering technical, societal and organisational aspects.

The UK Government has issued a document commissioned as part of its Foresight Future of Manufacturing project: The Factory of the Future Ridgeway et al (2013). This document recommends:

- More integration of supply chains
- Closer working between industry and UK universities
- Focus on both organisational and technical innovation
- A 'systems integration' view
- Design of reconfigurable factories and operations
- Favourable regulatory framework for new factories, especially in the life sciences
- A UK vision that promotes innovation and encourages networks of talent
- Recognition that there has to be a change of culture.

There is strong evidence that regional policies for creating Factories of the Future is beginning to gain momentum. For example the concept of a modular 'plug and play' approach is being applied in chemical manufacturing at the Bayer Technology Services site in Germany supported by EU funding. The large BASF chemical manufacturing site at Ludwigshafen already provides an example of fully integrated manufacturing where there is a minimum of waste materials or energy.

Clearly the mission to create these future factories is now in place and we face exciting and challenging times to implement them.

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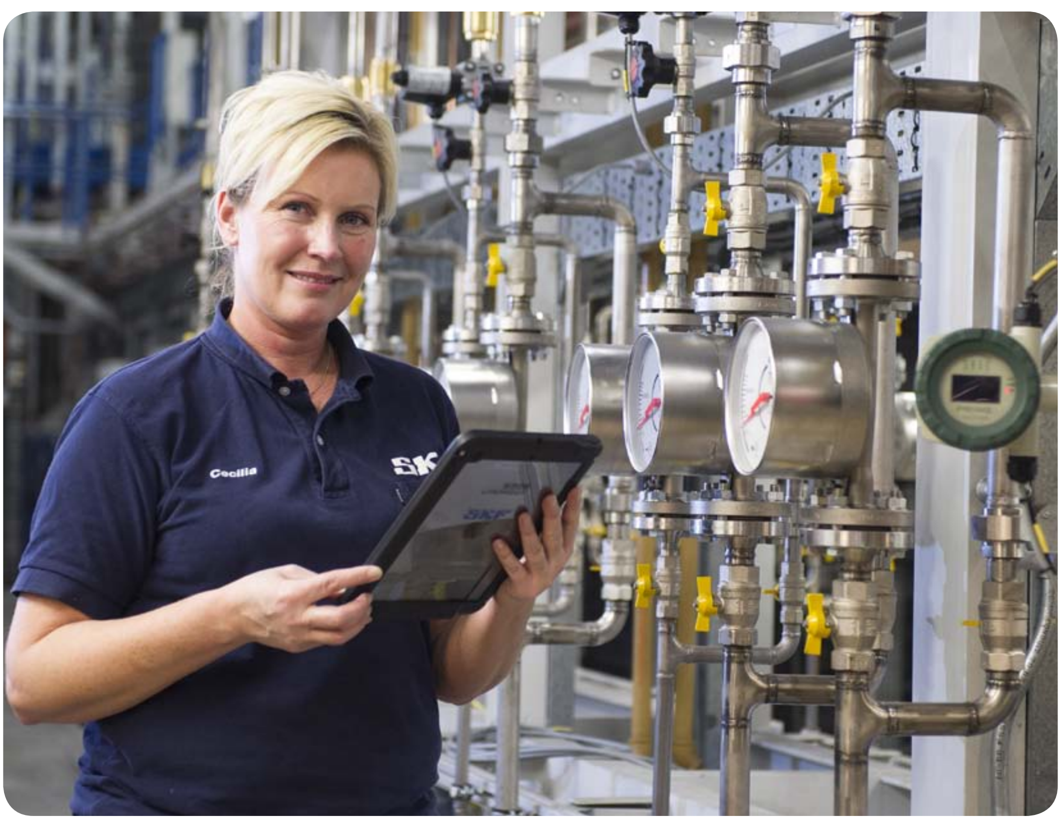
Peter Dobson

Professor Peter Dobson OBE, BSc, MA (Oxon), PhD, C Phys, F Inst P, Member of the ACS, FRCS.

Peter Dobson is a leading expert in manufacturing, advanced materials and nanotechnology. He is currently a Principal Fellow at Warwick Manufacturing Group, (Warwick University UK), sits on several EPSRC panels and committees and consults widely for industry. From 2002 to 2013, he directed the Begbroke Science Park at Oxford University and he has set up a number of spin-off companies. Peter was awarded an OBE in recognition of his services to science and engineering in 2013 and in the same year retired from Oxford University, where he was the Strategic Advisor on Nanotechnology to the Research Councils in the UK (2009-2013).

Author: Christoffer Malm,
Head of Connectivity Room, SKF

The consumerisation of manufacturing IT



Smart devices are a consumer success story. Their portability and power are also helping to 'smartify' the manufacturing industry – and this is just the start, says Christoffer Malm, Head of Connectivity Room at SKF.

Smart devices such as iPhones and tablets have created a consumer revolution. No household, it seems, is without one. Smartphones double up as personal stereos and satnavs, while tablets are used as games consoles and portable movie screens. In business too, tablets are increasingly preferred to laptops, particularly for enhancing engagement during the sales process.

Now they are spreading to the manufacturing and engineering sector, including the factory floor itself. Manufacturers are harnessing the connectivity, portability and computing power of smart devices to 'smartify' the engineering world and create a revolution of their own.

SKF, of course, is at the forefront of this. We have developed an infrastructure that will allow industry users – whether white or blue collar – to embed smart devices into their working practices. Whether for portable maintenance, personal instruction or simply banishing paper, smart devices are helping manufacturing companies boost their productivity.

The potential gains are enormous. We have, for example, seen productivity gains of 12% from engineering staff armed with tablets. It allows them to do their job more efficiently, while accessing and making sense of more information.

Case studies

Apple's App Store already offers more than 30 apps developed by SKF. They have all been channelled through the company's digital innovation catalyst team, known as Connectivity Room. Here, our engineers distil their knowledge and expertise into apps that can help both our own employees and many of our customers. All of these apps take our knowledge and translate it into software, with powerful analytics and IT algorithms processing the data. Smart devices are the window to access this underlying knowledge.

We have, for example, one major US-based customer that repairs large industrial equipment, which often comprises many thousands of components. By law, each step of the process needs to be documented. To date, this has been done with pen and paper, creating a paper trail in case of customer complaints. Now, we have developed a data collection system accessed via a phone- or tablet-based app. The huge paper archive can now be replaced by a database, which the customer can instantly access and make sense of.

Using the new system, information on components is still entered manually because they are from different suppliers. Some components will have a unique ID, while many will not. But it's early days for this kind of system. In future, for appropriate applications, parts might be barcoded or able to broadcast a unique signal – completely removing the need for manual entry. By registering a technician's position on the shop floor, the nature of a particular maintenance procedure, and the time it is carried out, the smart device can automatically create a log history for each part.

We have also developed a number of apps that turn phones and tablets into measuring instruments. These are being trialled at one of our Gothenburg factories to help us carry out maintenance as quickly as possible. With help from an internal positioning system (a kind of factory floor GPS), the app pinpoints the position of maintenance staff on the factory floor. When a machine develops a fault, an alarm is sent preferentially to the nearest person, ensuring the fastest possible response.

Other apps guide maintenance staff through monitoring procedures. Sensors are often connected to smart devices, turning them into measuring devices for vibration, temperature and other critical measurements. Our engineers have taken this a step further, by adding an app that tells the operator where to place the sensor – in order to get the best reading, and better results.

In similar fashion, a system called AliSensor ShaftLaser streamlines the process of alignment. Usually, when aligning, for example an electric motor with a pump or fan, a technician would traditionally carry with them a lot of heavy equipment. Now, thanks to smart devices and the minimisation of sensor technology, the equipment weighs much less. Through the guided support, visualisation and instruction provided by the app, training is heavily reduced and the understanding of what to do and when is made much more clear.

AliSensor ShaftLaser was not developed by SKF, but by GLOi – a Swedish alignment technology specialist that we strategically acquired in September 2014. GLOi developed the integrated shaft alignment solution, based on the iOS operating platform used by iPads and iPhones. The acquisition was part of our business strategy, and illustrates our commitment to this field – and to this type of technology.

Mobile advantage

We have spent more than a year developing a Mobile Operator Support Tool (MOST), which visualises the factory production line and connects machine data in real time. MOST will transform the way that operators interact with machinery, by supplying them with the right information, at the right time and in the right place – via a customised mobile device such as a tablet or smartphone.

Delivering this wealth of information exactly when it is needed will bring multiple benefits. Operators will be empowered to improve manufacturing performance, and to diagnose and make decisions close to the problem. They will be instantly aware of real time manufacturing process data, such as energy consumption and product variability and be able to act on it.

Overall, MOST will help operators overcome many of their everyday problems, leading to greater work satisfaction and greater empowerment.

The ultimate aim of MOST is to make it as easy as possible to do the right thing. As well as delivering process data direct to operators, it will include various instructions – how to re-set machines and equipment, preventative maintenance procedures, and much more. These will now be at the operator’s fingertips, rather than in a manual somewhere.

Even if the information is in another employee’s head, it can be accessed quickly: one feature of MOST is a communications tool that allows operators and managers to text one another in order to solve problems. This feature has proved extremely effective during factory trials in Gothenburg.

From a pure business perspective, getting this connectivity through smartphones and tablets will save enormous amounts of time: we have already rolled out more than 3,500 tablets to employees and customers: each user has saved around 12% of their time every week as a direct consequence.

One of the huge benefits of smart devices is their ability to simplify data by visualising it clearly. As well as giving instant comprehension of large data sets, it could be used to give simple instructions that guide operators through a particular process, and this has already been implemented in a number of SKF's apps (for example, AliSensor ShaftLaser for shaft alignment).

MOST can also identify the presence of humans in the factory. The heat treatment department of our Gothenburg factory is 8,500 m^2, which is covered by a handful of maintenance personnel. As well as pinpointing the closest operator to a particular machine to aid productivity, the smart device can act as a safety alarm. If a 'Where are you?' alert receives no reply, operators can quickly be tracked down – in case they have fainted, for example.

Plain sailing?

There are obvious advantages to using smart devices in engineering, but a note of caution should be sounded. As with any kind of new technology, there are hurdles to leap before it becomes fully accepted. Because there are issues to resolve and minds to change.

Lots of data flows between these devices, which rely on WiFi or 3G. But this extra connectivity raises huge concerns about security. Adding more cloud services outside the firewall introduces a potential weak spot, and companies are keen to ensure their in-house data is not compromised.

These services will be accessed in a number of ways, such as http, https or through new standards. Password protection will be vital, but to make these services usable there needs to be a balance between tight security and ready access. If you build a fortress, nobody will use it; protect it with a single password, and the data could be at risk. In the end, it will be a careful balancing act between the two extremes.

Irrelevant of the type of technology introduced in an enterprise or to customers, it cannot by itself bring about a change in the way of working or improvements to a certain user scenario. The new technology always needs to harmonise with people and processes to be successful. To be truly effective, add value and cause a redesign of way of working or of a specific process requires a vision of what role the smart devices play. The integration and visualisation of information on those devices then becomes the true innovation. This is something that requires a lot of thought, a lot of perseverance and a lot of drive.

You also need to consider the people facilitating the process and therefore potentially using the smart device. How does the smart technology affect them? How does it change their routine and general activities? What is their level of experience of using smart devices?

Questions such as these must be considered to facilitate the adoption of any new technology and to anticipate any potential resistance so that it can be proactively addressed. In some cases these issues will need to be addressed at a much higher level within an organisation, as its culture, values and general attitude at a corporate level to technology will also have a significant impact on how the technology is utilised and ultimately how much benefit it provides.

Information overload?

They key to systems like MOST is making sense of data. Generating information is one thing; managing it is another. In order to take full advantage of this enormous new data set, it needs to be filtered and presented clearly. We'll have top class hardware, smart devices, apps that gather and collect info, and dashboards, but much of the focus will be on maintaining and ensuring the quality of data and working out how to make sense of it.

We need to simplify data visualisation, so the complex information can be instantly understood – and acted upon – by technicians and maintenance personnel. It needs to be a simple interface with powerful data analysis.

Dealing with this data overload will be crucial. Within three years, we'll have to look at wireless AP (access point) management, as it's called in the IT industry, by creating an interface to integrate all the different data streams.

The goal is simple: to present the necessary information clearly, and in real time, allowing recipients of that data to act on it quickly.

At SKF, we have already come some way in our journey into mobility. With technology evolving at such a rapid pace, there is no doubt that in the not so distant future things will have moved even further.

Smart devices will increasingly become the window through which information is communicated. Today, it is done using off the shelf models like iPhones and iPads, augmented by rugged cases to make them IP68 compliant. In future, these will be tailored devices – thinner, more robust and with new features built in.

Smart devices have already proven themselves in the demanding consumer market. If the manufacturing industry were to embrace the technology with the same enthusiasm, just think where we could all be in terms of productivity.

Christoffer Malm

Christoffer Malm, Head of Connectivity Room, SKF

Christoffer Malm is Head of Connectivity Room at SKF. He is responsible for driving mobility solutions for SKF employees and customers forward. As leader of the connectivity team, he works with iOS and Android developers, product leaders and strategic thinkers within the mobile arena to enhance SKF connectivity. Christoffer graduated from Chalmers University of Technology, Sweden, in 2006 with a Master's degree (MSc.) in Electrical Engineering and joined SKF in 2008.

Author: Rob Jenkinson, Director of Corporate Sustainability, SKF

Engineering a sustainable future

As environmental concerns become ever more important to engineering and manufacturing companies, forward thinking organisations can use sustainability to boost profits and business performance, as well as helping their customers and the planet, says Rob Jenkinson, Director of Corporate Sustainability, SKF.

In one way or another, every stage of the manufacturing process has an impact on the environment. This applies whether it's the raw materials a business chooses to use, the energy used in production operations, or the way in which products are disposed of at the end of their useful life. Although it's extremely challenging with current technology and global economic conditions to expect any operation to achieve 100% efficiency and net positive impact, that doesn't mean that as manufacturers, engineers and business leaders we shouldn't set this as a desirable goal.

Although corporate social responsibility (CSR) policies have been around in one form or another for many years, the global financial meltdown in 2008-09 caused many organisations to postpone or cancel many of their environmental initiatives. Others however maintained their focus as they realised the potential bottom line benefits that such policies can have. With the economy slowly recovering, this situation is now changing as more and more business leaders recognise that a strong, consistent and strategic CSR policy, which is embedded into the core values of an organisation, can deliver real and measurable value for each business, its stakeholders, employees and customers.

For companies such as SKF, sustainability has been a core business principle for many years. It forms a key driver for innovation, covering everything from our factory and office construction, to our production processes, use of energy and water, and in the design and delivery of our products and services.

SKF BeyondZero: A new perspective

In 2006, we implemented a new strategy for actively and quantifiably reducing our environmental impact, as well as that of our customers and suppliers. This strategy, named SKF BeyondZero, has become a critical part of our DNA, consisting of two complementary goals. The first is to reduce the negative environmental impact from our own operations and those of our suppliers. The second is to innovate and offer our customers new technologies, products and services that enable them to reduce energy use and waste.

Over the years, as a result of applied research and development in the area of environmental life cycle management, we have acquired a much broader understanding of the environmental performance of our activities, products and solutions. We have learnt about the environmental impact our activities have at the different stages of the value chain; everything from the raw materials selected, how these are utilised and processed, the energy used by SKF products when used in customers' applications and what happens to the products after the end of life. This has made us realise that environmental impacts can be reduced in every stage of the value chain and that the greatest potential is found in the use phase – the way in which our products and solutions perform in each customer's application.

Manufacturing efficiency

In practice, we have been taking significant steps over a number of years to improve our own manufacturing operations. All new factories and logistics centres, wherever they are in the world are built to the latest LEED building standards and the ISO 50001 Energy Management Standard. We have also been working with our key suppliers to help them meet similar levels of environmental responsibility and to reduce the level of energy used in, for example, the energy intensive steel manufacturing process.

In logistics we have been working with our transport partners to reduce the environmental impact of shipping. This includes contractual fuel consumption limitations for road logistics service providers, the decreased use of air freight, a high truck fill rate and involvement in the Clean Shipping programme.

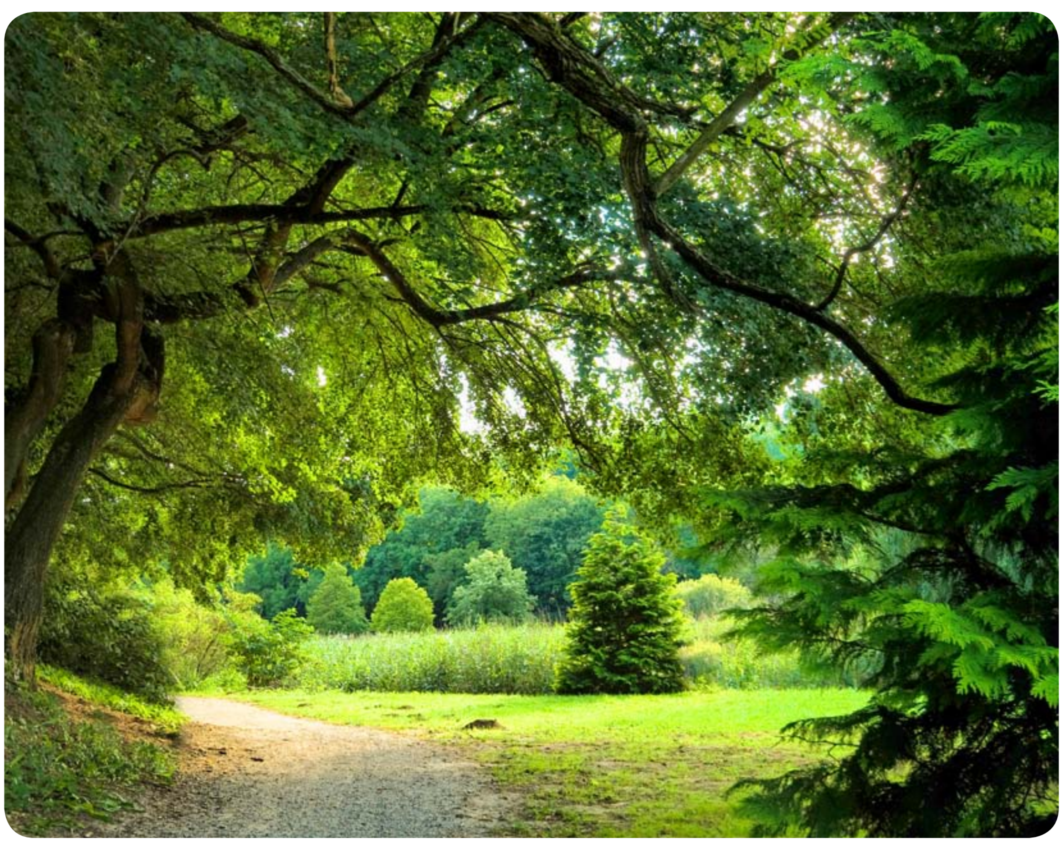
The impact of these initiatives has been considerable. Between 2006 and 2013, when our global sales grew by 20%, we reduced our energy requirements by 13% and our total greenhouse gas emissions, particularly carbon dioxide emissions, from our own operations by a similar figure.

Product lifecycle management

A key component of the SKF BeyondZero concept is management of the life cycle of a product, from initial development to final disposal. Various studies have shown that many products have the greatest environmental impact during their use in customer applications; in terms of total life cycle carbon emissions, this can be as much as 75%.

SKF products that fall within our SKF BeyondZero portfolio, which is growing fast, have to meet tough criteria to ensure that they deliver real environmental benefits to each customer, without affecting product performance, quality or reliability in service. These criteria fall into two categories:

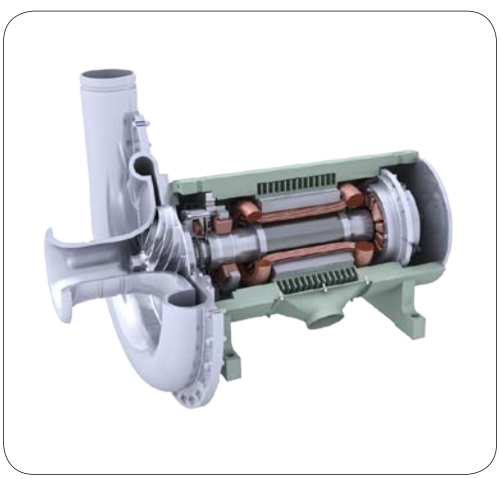
- Designed for environment: the product or solution has to provide environmental benefits in its own right through some inherent characteristics, such as low friction or weight savings
- Applied for environment: the product or solution must demonstrably help to improve the environmental performance of the customer application in which it is used



Typical examples of SKF BeyondZero portfolio products and solutions include energy efficient high-speed permanent magnet motors for use with aeration blowers in wastewater treatment plants. These can reduce energy use by up to 40%, providing both commercial and environmental advantages. Similarly, SKF Sealed Energy Efficient (E2) deep groove ball bearings significantly reduce frictional movement, leading to potential energy savings; although these may be relatively modest for each bearing, when the cumulative impact over time of replacing all bearings used in industrial motors, pumps and fans is considered then these savings can be considerable. Other developments include the fully-sealed SKF ConRo roll line unit for use in continuous casting operations in the steel industry; this can reduce CO_2 emissions by an estimated 1.5 tons per roll line per year.

Becoming smart

The increasingly rapid move towards smart factories, where intelligent devices such as SKF Insight bearings, are used in sophisticated control and automation networks, will inevitably have a major impact on sustainability in the manufacturing sector. In the short term, the ability to smartify production operations will reduce energy and water use, and extend machine life to reduce scrap or waste still further. Longer term, the acquired data and experiences from running smart systems will help companies develop a new generation of manufacturing tools and processes, and may also impact the design and construction of both premises and production lines. In each case there will be the opportunity to re-engineer existing systems to meet the challenges of ever better sustainability in an increasingly tough and competitive global environment.



Rob Jenkinson

Director of Corporate Responsibility, SKF

Rob Jenkinson has been the Director of Corporate Sustainability at SKF since 2010. He began his career with SKF in 1989 and has held a variety of engineering and management roles in a range of countries, including the UK, China, USA and Japan. Rob has been very much involved in the development of SKF's BeyondZero strategy. He holds a Master's Degree (MSc.) in Energy, Environment Technology and Economics and an Honours Degree in Mechanical Engineering.

The future of intelligent machine design

Authors: Professor Detlef Zühlke,
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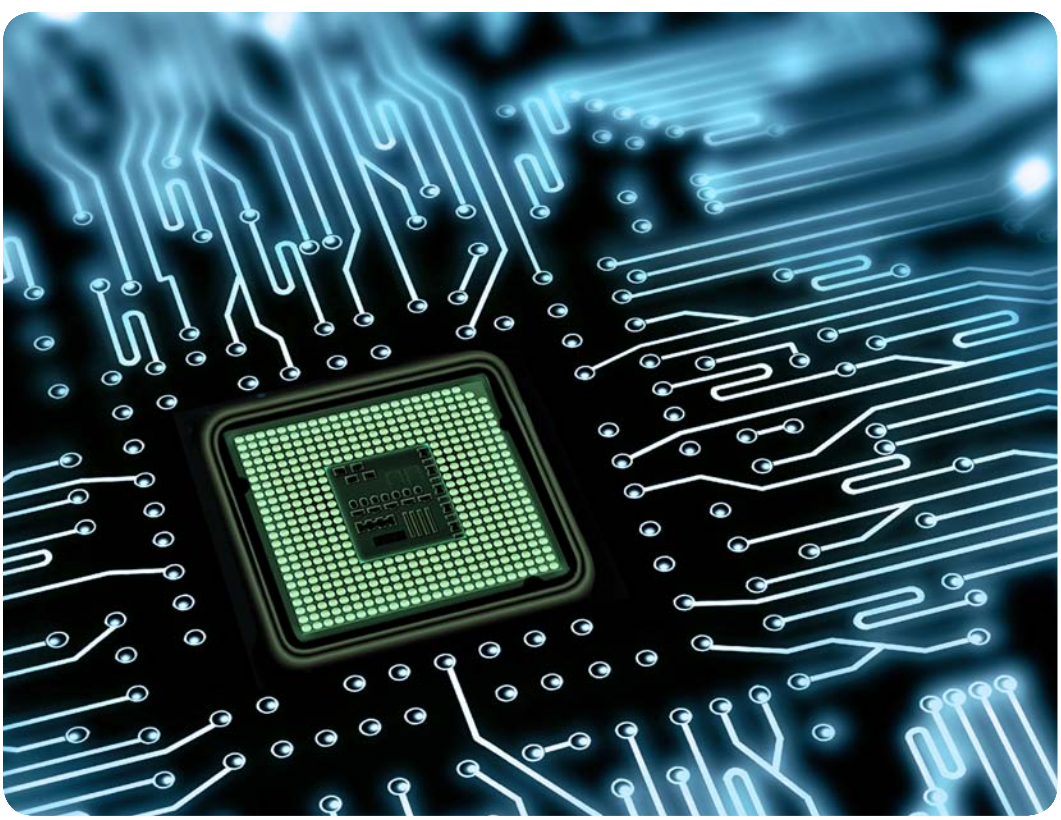
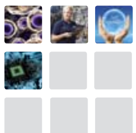
How the Internet of Things will revolutionise industrial production





Under pressure of globalisation, our industry will undergo a period of major challenges including shorter product life cycles, highly customised products and stiff competition from various markets around the world. These challenges are already evident in today's mobile phone market. Product life cycles have decreased to around six-nine months, while functionalities and also complexity of products have steadily increased. A comparable development is currently taking place in other sectors, such as the automobile industry. With products becoming more complex and the product life cycle more limited, computer-aided technologies (CAx) continue to grow in importance during the production ramp-up optimisation and acceleration period. Although the advancement of CAx during the past ten years has enhanced flexibility in the design and planning phases, a similar breakthrough is still anticipated in the actual manufacturing phase. A high product variability aligned with shortened product life cycle requires an agile and flexible production structure, which can be rapidly reconfigured for new product demands. This degree of flexibility cannot be achieved by traditional automation. Instead, modular factory structures composed of smart devices – the so-called 'Cyber-Physical Systems' (CPS) – that are part of the 'Internet of Things' network, are key elements in enabling adaptable production scenarios that can both address and overcome current challenges.

Over the last ten years, we have witnessed a fundamental transformation in our daily life with the emergence and growth of Information and Communication Technologies (ICT). Computers are becoming so small they seem to vanish inside nearly all of our technical devices. Beyond all of this, things communicate in a world-wide network: The Internet.

When we contemplate following this path into the future, we find that nearly all the everyday things will become smart nodes within a global network. This phenomenon is called the 'Internet of Things' (IoT); a trend that will almost certainly find its way into industrial production. The strong bias of the electro-technical and hierarchical world of factory automation will transition to smart factory networks, which increasingly benefit from the advances in ICT and computer sciences. In Germany, a major debate on the fourth Industrial Revolution or, in shorthand, 'Industry 4.0' has started.

Interest has continuously grown since the introduction of this term in April 2011 by Kagermann/Lukas/Wahlster [1]. Under the impetus of a working group formed from experts in the scientific and business communities, a vision has been developed for German industry and provided in the form of recommendations to the federal government. As a result, a research program has been established, with funding of approximately 200 million euros over the next few years. Furthermore, the three major German industry associations (VDMA, ZVEI, and BitKom) have joined forces to create a shared platform to facilitate the coordination of all Industry 4.0 activities.

These actions have contributed to a general hype, which has been promoted mainly via media channels. However, there is also a genuine interest on the part of the manufacturing industries to achieve the sustainable success of this vision. Germany is a high-tech nation and generates a large portion of its gross domestic product (GDP) from the manufacture of goods as well as from the required production equipment. The following section presents the fundamental challenges and changes anticipated in the vision of Industry 4.0.

The vision of Industry 4.0

A distinguishing feature of the new technological environment is the transition to mechatronic systems. Electronics will be a fundamental component of future products, while hardware will be increasingly standardised. The major features determining the functionalities will be created by the software. In this way traditional machine elements are transformed to mechatronic systems. A function can be implemented by mechanics, electronics, or software. The design and production as well as the service therefore require an interdisciplinary team, combining competencies in mechanical, electrical and software engineering.

Smart objects

The key driver for the Industry 4.0 vision is the 'Internet of Things' (IoT). In this vision, all factory 'objects' will have a unique IP address and be integrated into networks. The technical term coined for such an object is a 'Cyber-Physical-System' (CPS) [2]. The traditional production hierarchy will be replaced by a decentralised self-organisation enabled by CPS in the factories of the future. Plant sections and production processes will become so independent and flexible that even the smallest batch can be produced under conditions of rapid product changeover and any number of options.

The machine-to-machine communication enables commands to be issued by the individual machines, for example, to transport a raw product or to use a specific manufacturing service. The product's semantic memory dynamically controls its manufacturing process and therefore allows decentralised mass production at a batch size of just one unit.

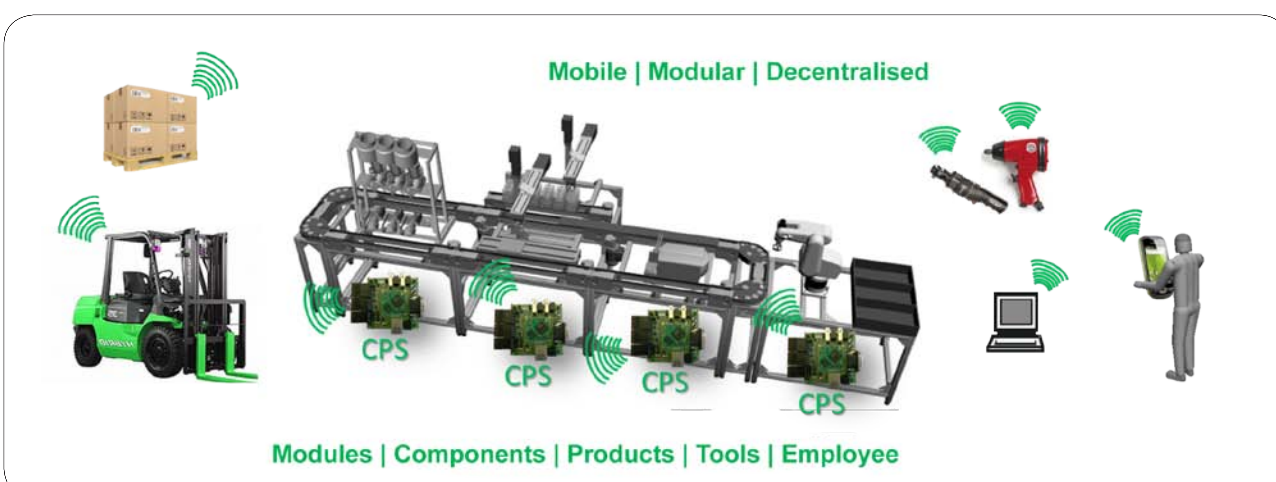


Figure 1: Smart objects – Mobile, modular and decentralised.

Many of these smart elements will be mobile and linked together over wireless networks; which implies losing vital positioning data that was implicitly delivered to us by the 'end of cable' in the old hard wired systems (compare Figure 1). This is especially critical in the area of plant operations. An employee that uses a mobile operating device such as a smart phone, can no longer be located in a specific position. The user may be somewhere on the shop floor, but could also be in the cafeteria. The application must take into account the current position of the employee in order to decipher whether a functionality is currently supported or not. To solve this dilemma, not only indoor location systems with comparable features to GPS will be required, but new rules and methods for the design of context sensitive human-machine interfaces must be found that enable a decoupling of the hardware and operating software currently in use.

New communication architectures

Today's factories follow a strict, hierarchical information structure. At the upper layers, we find the enterprise resource planning (ERP) system, which is installed above the plant control systems (MES and NC/PLC). At the lowest layer, the sensor and actuator systems of the plant, the so-called field devices. Although, in recent years these layers have been increasingly integrated with one another, the major system integration has taken place in the horizontal direction, not the vertical. A network of CPS will inevitably require a new approach to architectures. The common pyramid-like structures characterised by strong horizontal networking as well as weak vertical communication will be replaced by a domain-oriented network structure, which in principle, enables any number of paths across all information layers of the factory.

Plant systems built on the principles of IoT and CPS will make today's PLC systems superfluous, because each end device will communicate with every other even if located at a different layer. The specification of process logic (also known as orchestration) will take place in the network, not in a dedicated control element.

New programming paradigms

Today, program controls turn for the most part on the hardware structures that are generally based on rules and standards that are 20 or more years old. In the future world of networked self-organising CPS, hardware and control logic must be strictly separated. Several paradigms already exist in this respect. For example, the service-oriented architectures (SoA) or the multi-agent architectures (MAS).

Both approaches encapsulate and abstract the hardware functionality and contain mechanisms for self-organising systems. Furthermore, a series of programming models already exist that permit the specification of control logic or orchestration. However, such approaches require a high degree of knowledge in computer sciences, which complicates the implementation at shop floor level by people not trained in this area of expertise. In this respect, the migration of such architecture paradigms from the upper factory layer where they are already partially deployed, through the mid-layer MES systems is the most promising path, which also takes into consideration the technical backgrounds of the personnel involved.

In today's production planning and control process, the control system design comes at the end of the planning phase as it relies on the results of the mechanical and electrical designs. The programming of the logic controls does not begin until the control terminals are selected and it is decided how these are to be wired. Abstraction concepts like SoA can be useful in severing the relationship with the initial implementation hardware and to create reusable software components.

Establishing a new engineering workflow is necessary to provide the hardware independent, functional, and top-down planning approach required. The traditional planning domains have to be more closely integrated, especially in the early planning phases, in order to provide alignment later on in the planning process. Systems engineering approaches can help to support the interdisciplinary tasks, as successfully demonstrated in the aerospace technology sector.

Creating a transparent presentation is therefore a challenge due to the complexity of the planning results and the interrelationships among the associated disciplines. This will require practical procedures for an incremental, model-based engineering strategy to be achieved, as well as the appropriate modeling languages, data formats, and tool chains.

The goal for future smart factories must be the removal of the media gap between the CAx/PLM environments and the actual functioning plant. The PLM tool needs to possess the capability to generate complete system descriptions, which can convert directly into executable control services. The code must then enable both simulation of a virtual plant as well as the set-up and operation of the actual plant.

Standards

As described in the basic model, the strict separation of hardware and functionality can only be successful if based on standards. A CPS element must be built in a similar style, at least in terms of information technology, as a LEGO building block. In other words, the element must communicate on the basis of standards at all layers of the ISO/OSI 7-layer model. At least the transport layers 1-4 already rely on many established standards such as the various IEEE 802.xx or Internet Protocol IP standards; the respective standards for the application-based layers 5-7 will only arrive under massive market pressures. It's evident that no manufacturer is attracted by the idea of turning its products into interchangeable LEGO blocks. The current debate on a standard process in the area of industrial wireless networks (e.g., ISA100) or the device description specification language (e.g. FDT) indicates both resistance and a conflict of interests. At least there appears to be a promising implementation approach with OPC UA for layers 5-6 that more and more manufacturers and users are willing to accept.

Security

A distinguishing feature of future factory control systems is the use of IP-based networks at all layers. This facilitates the import of data from a field device to the higher level ERP system without any problems. However, this can put the factory at risk to ever more powerful cyber-attacks through the use of open protocols. STUXNET and

Figure 2: Mobile devices and smart assistance systems in the immediate future of production.

other malicious software (malware) make it absolutely clear the threat is a real one. A CPS-based production environment can ultimately be implemented successfully only if the high standard of security and trust in this technology comes from within the business. This demands not just technological solutions, but perhaps more importantly, organisational measures. A definitive answer to the security question will be a key subject along the way and requires proposals from industry, research, and government.

What is the immediate future going to look like?

It is predicted that this version of the Industry 4.0 vision will find its way into future production environments in around 10 to 15 years. In respect to all the questions that need to be answered and to all the research work that needs to be done, it will still take time until such holistic manufacturing scenarios are universally implemented and accepted in our industries.

Figure 3: Demonstration plant for future production in the SmartFactoryKL.

Consequently, first elements and first objects, suitable to the vision, will travel along an evolutionary road before finding their way into practical usage. The availability of information in high resolution and the reduction of media gaps constitute the foundation to enable versatile, transparent production environments. Already available auto-ID technologies can help to track elements and represent them in the digital world. Mobile devices such as laptops, tablet-PCs or SmartGlasses provide immediate access to enterprise knowledge from almost everywhere and anywhere – within the business and beyond. Accordingly, decisions and actions can be based on comprehensive and accurate information and reactions will be faster, supported by smart assistance systems, as shown in figure 2.

The technology initiative SmartFactoryKL – as a manufacturer-independent demonstration and research platform – has already taken a huge step towards the Industry 4.0 vision by developing and deploying solutions which enable flexible production structures, addressing the current industrial challenges. Within its network of more than 30 industrial partners, the SmartFactoryKL tests and develops innovative information and communications technologies and their application in a realistic, industrial production environment. Within the latest project, a ground-breaking production line was developed in a joint effort with industrial key partners (see Figure 3). The production line is completely modular and allows a plug-and-play integration of new manufacturing modules. The plug-and-play functionality is achieved on the basis of a set of mechanical, electronic and information technical standards defined by the SmartFactoryKL and its partners.

Outlook

No technological revolution has ever been initiated in haste. More often the upheavals take place over a period of several decades in an evolutionary transition driven by advances in multiple technical areas (technology-push), but also as a result of new market demands (market-pull). It is highly likely that the current movement towards Industry 4.0 will have a similar evolutionary aspect lasting several decades. A positive aspect is that Industry 4.0 is providing a clear vision which both manufacturer and end-user can successfully adapt to. The scientific insights of the IT environment are being closely linked to the requirements of the production environment. This demands the interdisciplinary cooperation of traditionally separate disciplines.

Human beings however, will be the most important factor in this transition process. If the three previous revolutions are analysed, it is evident that human needs and living standards have been the main driving force behind the changes. When these requirements meet the right technological boundary conditions, it seems to result in fertile fields for innovative changes. Since the third Industrial Revolution, more commonly known as the Digital Revolution, many innovative technologies as well as political changes have influenced the way people live with one another. Characteristic examples include the ending of the Cold War, the opening of global markets – especially China's – together with technological progress (for example, the Internet and smart devices).

Humans not only have the important role of technology driver, but also the role of the driven. Modern ICT leads to a sharp acceleration in all business processes, and does so in a global context. Offers to supply production plants and services can be sent around the world in seconds, while global syndicates can instantaneously be formed to supply solutions. More efficient and integrated logistics systems on land, sea, and air can deliver goods to customers in much shorter times. In order to succeed in the competitive global

environment, production systems need agility and the ability to transition rapidly. This will be made possible by the advances in ICT. People will need to plan, implement, and operate ever more quickly in this new systems environment. Only those nations of the world that manage to adjust the training and education of their citizens in a timely manner to the new realities will be successful within the global marketplace.

Europe is in a good position in this respect. The EU is among the world's leaders in the fields of research concerning networked embedded systems, semantic technologies, and the design of complex cyber-physical systems. Herein lies a great opportunity for the European industries to take a technological quantum leap and master the challenges of the global market.

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Detlef Zühlke

Prof. Dr.-Ing. Dr. h.c.

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M. Sc.

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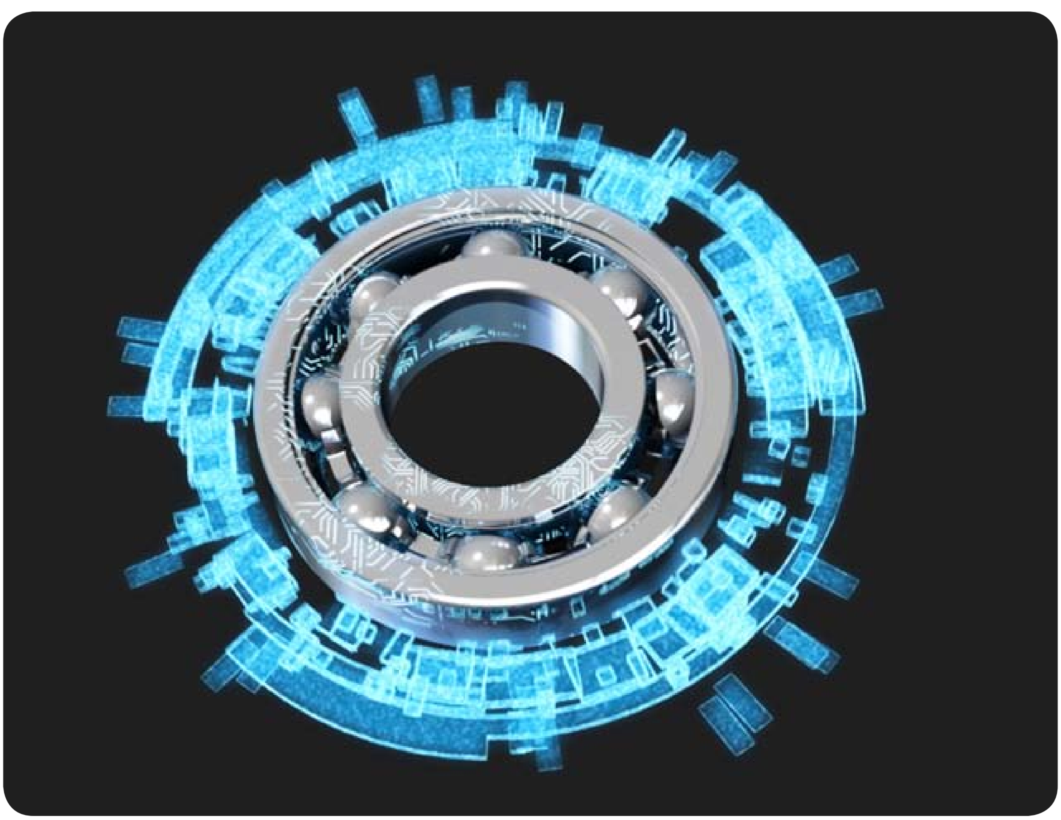
Author: Filippo Zingariello, Director of Global Strategic Development, SKF

Bearings with brains make intelligent machines



Revolutionary intelligent bearings technology will underpin the creation of intelligent machines, says Filippo Zingariello, Director of Global Strategic Development at SKF.

Defining an intelligent machine is no easy task. In the early days of computing, it was thought to be a computer whose answers to questions were indistinguishable from those of a human being. In this sense, the word 'machine' was taken to mean 'computer'. If you search for 'intelligent machine' on Google, you'll still find lots of futuristic work in this vein.

The McGraw-Hill Dictionary of Scientific & Technical terms defines it like this: 'A machine that uses sensors to monitor the environment and adjust its actions to accomplish specific tasks in the face of uncertainty and variability'. Cited examples include industrial robots equipped with sensors and self-guiding vehicles that rely on vision rather than painted lines.

Within engineering, we think of an intelligent machine as a mechanical system that can take care of itself: a machine capable of accurate self-diagnosis that can quickly communicate its condition to an operator so that the problem can be resolved as soon as possible. It could be anything from a high-end car to a complex machine on a factory floor. This is the subtext to 'uncertainty and variability': as well as reacting to changes in its environment, an intelligent machine must look after itself, so that it can continue to work at maximum efficiency.

This is not to suggest that an intelligent machine is maintenance-free – that really is a futuristic dream – but it uses its in-built intelligence to detect potential problems and streamline maintenance intervals and procedures. All mechanical parts are prone to failure, of course. The trick is to detect this proactively, as part of a planned condition monitoring regime, and take action in advance, rather than waiting for the machine to fail and then spending time and money repairing it.

Intelligent machines will rely on several critical factors. The most important, by a long way, is information. Without data, there can be no intelligence or diagnosis. This data

needs to be gathered, transmitted for analysis, and processed, which, in turn, requires sensors, data transmission and computing power. At SKF, we already have extensive experience in all these areas, and are ready to take it to the next level.

SKF Insight introduction

The immediate answer might at first simply appear to be enhanced condition monitoring, adding an array of sensors to a machine in order to read its vital signs, then transmit them over WiFi to a central point. But a far more effective solution now exists in the shape of SKF Insight: it collects and transmits process data independently from inside the very heart of a machine using a fundamental engineering component: the bearing.

SKF Insight turns a simple bearing into a diagnostic powerhouse, by embedding into it a tiny, self-powered wireless sensor that transmits real-time information about process conditions. It takes condition monitoring far beyond what was previously possible. The technology, launched at Hannover in 2013, required three years of intensive research, including making the sensors smaller, over-coming power generation challenges and developing unique packaging for the sensors and electronics.

Conventional condition monitoring detects the early signs of failure by measuring vibrations caused by changes on the bearing's surface. But this means that damage has already begun to occur. Rather than identifying this deterioration, SKF Insight detects the conditions that cause bearing failure before they can have an effect, and makes this information instantly available to operators.

Miniature electronic circuits, powered by the motion of the bearing itself, transmit this process data via a wireless link. There is no need to supply external power. This makes the technology supremely unobtrusive, because there are no wires 'in' to provide power, or wires 'out' to deliver the signal. This means it will work in places that would previously have been impossible. Just imagine trying to take signals out of a rotating gearbox, for example: it would be a complete mess, with entangled wires everywhere. With SKF Insight, signals can be taken from anywhere, and we are already developing solutions in challenging applications in wind turbines and steel manufacturing.

We developed SKF Insight because we know that bearings rarely fail in service under normal operating conditions due factors such as subsurface fatigue. Instead, the cause of failure is usually misuse or neglect: insufficient lubrication, for example, or running the bearing under conditions outside those originally specified. SKF Insight's embedded sensor measures the critical parameters that cause early bearing failure, such as lubricant contamination, or temperature, allowing operators to take corrective action while the machinery is still operating. The direct result is that expensive, disruptive failures are avoided, which reduces the total cost of asset ownership and extends machine operating life. It also makes it simpler for engineers to gain a far more detailed appreciation of the varied causes that can affect the calculation of bearing life.

By applying sensors directly within the bearing, SKF Insight identifies the risk of failure before even microscopic damage occurs.

SKF algorithms and diagnostics can identify duty excursions, lubricant contamination and lubrication problems, allowing operating conditions to be modified, and so avoid damage before it occurs.

By integrating SKF Insight with asset diagnostic and bearing health services, we can send information on actual operating conditions to cloud servers for remote diagnostics, enabling a better understanding of the risk of future damage and failure.

Rethinking maintenance

SKF Insight gives maintenance engineers a powerful new tool to keep machinery in prime condition, giving them capabilities way beyond traditional condition monitoring. It means that maintenance can be carried out at exactly the right time (we can even call it 'adaptive maintenance'), rather than being guided by a strict schedule that is unrelated to the actual condition of the machinery or its components.

The intelligent wireless technology inside the bearing allows bearings to be configured in smart networks, which communicate via wireless gateways. The gateway can be local to the machine or to the plant.

System information is provided to the customer for analysis using SKF @ptitude Analyst, or sent via the SKF cloud to a remote diagnostic centre. From here, dashboards and reports can be supplied to the plant operator, machine manufacturer, SKF or any other authorised person with internet access. The inclusion of SKF in the list of 'recipients' is an important one, as its assistance in gathering and interpreting the data will be vital thanks to the deep bearing and machine knowledge existing in SKF.

Because the bearings are self-contained they can be used right in the heart of a machine, where it was previously impossible to embed sensors. This is a huge step forward in real time condition based maintenance, and provides a vastly improved understanding of the operating environment. Having such a deep knowledge of operating conditions – in real time – could even make it possible to upgrade a machine, extending its life or power rating beyond its initial specification.

The sensors communicate through each other, and the wireless gateway, to create a 'mesh network', providing both machine-wide and plant-wide information.

SKF Insight makes condition monitoring more widely applicable, especially where it might previously have been considered impossible. Because of this, it is being tested in industries including wind power, rail and steel manufacture.

Tough conditions

SKF Insight also offers huge potential benefits to industries like wind energy, where the cost of maintenance is astronomical. In some offshore wind applications, changing the main bearing on a wind turbine is so expensive that it undermines the business case for building the turbine in the first place. Used here, intelligent bearings could monitor loads and lubrication conditions in service, giving plenty of time to prevent the development of damaging process conditions.

We are already working with customers to develop SKF Insight for wind turbine monitoring. It measures dynamic bearing information in the true operating state, then wirelessly communicates it to remote monitoring centres or local maintenance crews. The solution being considered will monitor bearing speed, vibration, temperature and lubrication. Most importantly, it can be retrofitted, so could enhance the operational potential of both new turbines and the many thousands that are already in operation worldwide.

A similar solution, further in the future, is being developed for wheel end bearings in the rail segment. These critical components are normally changed at set intervals, regardless of their condition. SKF Insight creates a cost effective way of collecting condition monitoring data so that service bearing life, and change-out intervals, are determined based on actual, rather than predicted, operating conditions.

The ability to monitor and transmit information on operating conditions will bring about a revolution in bearings, in terms of maintenance planning, total cost of ownership and maximising machine efficiency. Bearings have long been considered the heart of rotating machinery. Now, by imbuing them with intelligence, SKF Insight makes them the brain as well. It goes beyond traditional condition monitoring, into what might be called 'future reliability' – identifying potential problems before they occur, and taking immediate corrective action.

SKF Insight is already being put to work in high-end applications such as wind turbines. But consider the machine that we spend most of our time with: the car. Think about all the problems that could be avoided with this kind of advance intelligence, and you can see why the technology embodied within SKF Insight is truly a revolution – joining both bearings and condition monitoring.

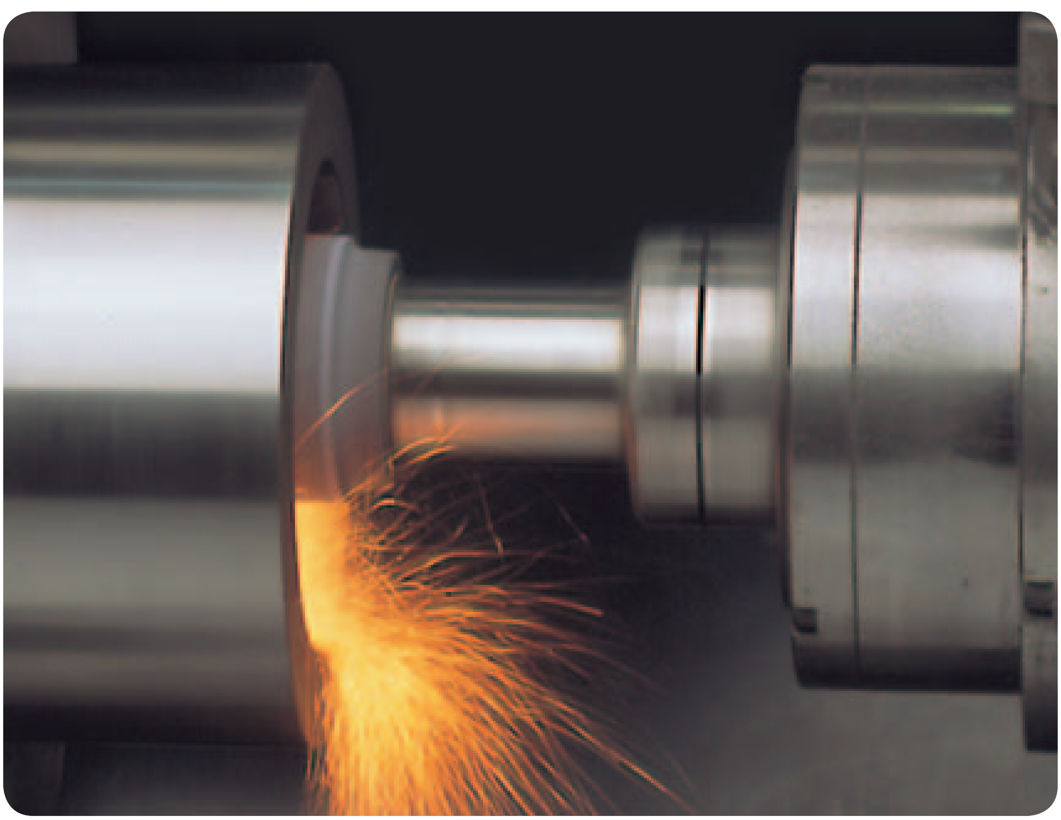
Filippo Zingariello

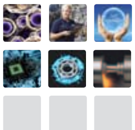
Director of Strategic Development, Group Technology, SKF

Filippo Zingariello is Director of Strategic Development, Group Technology at SKF. He is responsible for strategic programmes and directives, such as the creation and development of new Global Technical Centres in India and in China, and responsible for Global Metallurgy and Chemical laboratories. Since September 2013, he has been leading the SKF Group initiative to commercialise and industrialise SKF Insight solutions. Filippo gained a Masters degree (MSc.) in Engineering from Politecnico di Torino and joined SKF in 1988.

Author: Ulf Sjöblom, Director of Group Manufacturing Development, SKF

Intelligent grinding





With technology evolving at such a pace in the manufacturing industry, even established processes such as grinding can be revolutionised, says Ulf Sjöblom, Director of Group Manufacturing Development at SKF.

Precision grinding of bearing rings and rollers is an established process, which has been applied, tested and analysed over many years. Until recently, the common view among many grinding companies has been that the technology is close to its peak, and that there is little scope for new or significant technical development.

At SKF, millions of bearing parts are ground every year at our factories around the world, and this has led our engineers to take a different approach. They've combined their knowledge engineering skills with the power of the latest intelligent machine technologies. The result is a major step forward, which is bringing greater precision, faster cycle times and even better product quality to the grinding process.

In a typical bearing grinding machine the quality of produced rings and rollers deteriorates during the life of the grinding wheel, as it steadily wears. As the wear of the grinding wheel progress, the quality variation of the ground component surfaces increase; typically, in bearing rings and rollers this manifests itself as a change in surface roughness and in diameter and taper dispersion. In addition, inconsistence in the quality of incoming parts will also result in a bigger variation.

This has inevitably led to compromises in manufacturing processes, to ensure that product quality remains at the highest possible level. In practice, as each grinding wheel wears, the speed of the grinding machine has to be reduced to maintain the correct level of quality. Production capacity is therefore often determined by the slowest speed to ensure that quality demands are met.

The SKF engineering team knew that with the right control technology, considerable advances could be made. The starting point was to capture the many years of knowledge and experience of the company's grinding experts, and to match this with a detailed understanding of the grinding process; this included the physical interaction between grinding wheels and the different bearing components, and the mechanical and electronic functionality of each grinding machine.

SKF engineers then began to develop a solution that utilised the latest advances in intelligent machine control, sensors, software and process monitoring techniques.

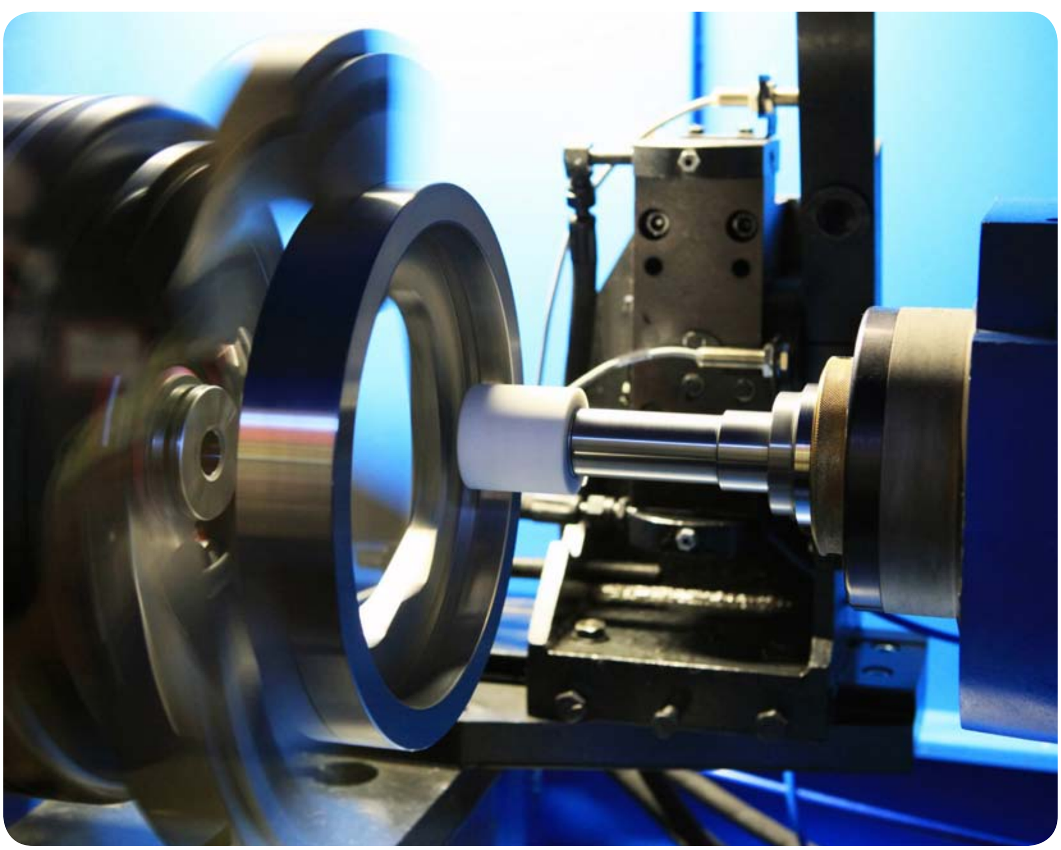
The result is the Intelligent Grinding System (IGS), which incorporates a range of process sensors and measuring devices that provide information, including acoustic emission, grinding power and grinding force, to a sophisticated machine controller.

This allows the system continuously to assess the process condition for each grinding wheel and to make automatic and instant adjustments to the machine settings. In practice, this means that every component has a unique set of grinding parameters, yet is identical in terms of finished quality to every other part manufactured on each machine. The IGS produces consistent, defect-free parts yet at cycle times that are faster than anything that could have been achieved previously.

Such a system would have been impossible a few years ago, because control devices were insufficiently powerful to monitor and control the grinding process in real time. Now, IGS is capable of interpreting data, making intelligent decisions and adapting to machine operating conditions in milli-seconds. The result is faster machining, even greater accuracy and improved output, without the need for human intervention.

For IGS to realise its full potential it has to be used with the latest generation of grinding machines, which themselves are being produced using similarly sophisticated and intelligent manufacturing technologies.

It is this extraordinary integration of precision engineered mechanical and electronic machine systems, with the new generation of machine intelligence, which is enabling SKF to transform the face of grinding technology, delivering production line efficiencies and real customer benefits.



Ulf Sjöblom

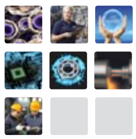
Director Group Manufacturing Development, SKF

Ulf Sjöblom is Director of Group Manufacturing Development and is responsible for the manufacturing related R&D for the SKF Group. He has a degree in Metallurgy and joined SKF in 1984. Ulf has held various managerial position in both manufacturing and in R&D and has been responsible for a number of industry assignments, mainly at universities and institutes in a position of responsibility on advisory and scientific boards.

The power of knowledge engineering

Author: Valentijn de Leeuw, Vice President,
ARC Advisory Group

Engineering or asset information?



The vision that triggered transformation

In 2005, Thomas Tauchnitz of Sanofi-Aventis, a leading pharmaceutical company, published an article in a German edition of Automation Technology in Practice, titled 'It's time for an Integration of the Process Design, Engineering and Plant operation processes'. The article consists of a vision and strategy for implementation of the concept using computer software. Dr. Tauchnitz explains three basic requirements shall be respected: every information is generated and maintained at only one location, existing knowledge is reused where possible and the software tools stay interfaced while the production plant is in operation.

Tauchnitz sketches the workflow from process design using process simulation software, the transfer of the resulting process information to a computer-aided engineering tool (CAE), common to all engineering disciplines involved in front-end and detail engineering. He explains how modular engineering – concept known for many years – should be implemented: standardised modules comprising all its functions are built, maintained and instantiated for a particular engineering task.

As an example a reactor module would contain temperature and pressure measurement and control, valves for material transfer, level control, safety equipment and automation, stirring etc.. The corresponding equipment lists, design documentation, safety procedures, testing and qualification procedures would be part of the template as well. Instead of engineering every new equipment, replacement, modernisation or repair action from scratch, the engineer would only deal with adaptation, and integration in a larger system and have more time for optimisation of the design and improvement and maintenance of the modules.

Concurrent or collaborative engineering?

Today several intelligent CAE systems provide the possibility for several disciplines during plant engineering to work on the same equipment, from their own perspective and using their own typical way of viewing their work: process flow diagrams (PFD) for process engineers, piping and instrumentation diagram (P&ID) for automation engineers, isometrics for piping, etc..

When several engineers work on the same item, this type of tool helps in maintaining the integrity of the engineering data. For example if a process engineer changes the maximum temperature or flow rate in a tube, then the pump that should displace this fluid should have specifications that can handle these maxima, and if it cannot, the tool will create alerts for the pump specification. Similarly the pipe diameter should be able to handle the flow rate, and so on. Beyond handling rules, these systems can also handle authoring workflows, including submission, review and validation statuses for changes.

While for engineering procurement and construction companies (EPC's), concurrent engineering may have been a standard practice since the beginning of the use of CAE tools, in some owner-operator (OO) companies a sequential engineering was the norm. Enabling multiple disciplines to work on the same design item has economical, organisational and social implications.

Social and cultural aspects

When introducing concurrent engineering, or collaborative sequential engineering using a single engineering data repository, people need to become familiar with new processes and technology. What could be more challenging is that they are required to share their information, their ways of working, and their rationales for making decisions. They sometimes have to learn to collaborate, which includes listening to other's opinions, defining agreed upon on rules and responsibilities for the different contributors, negotiating, collaborative problem solving and resolving conflict constructively.

This transformation can create some disturbances, as people have to leave their comfort zones. It can create conflicts and fail, if it is not properly managed. The engineering managers, who are ultimately responsible for a successful change need to have people and change management skills. They can be assisted by change consultants, but for a sustainable implementation they will need to acquire these skills to coach their collaborators long after the change has been implemented. This is not optional, because not only the work climate, but also the productivity depend on it.

The people in an organisation behave according to collective beliefs and rules. In teams these are called norms, for the organisation it is referred to as culture. Some of these rules and beliefs are implicit, that is, they are not explicitly stated although they are operational; some may be unconscious and several may be conflicting with the formal rules and principles of the company. Changing culture successfully requires discovering the reality and making it explicit, then creating a vision that bridges the business objectives and the collective needs, and gradually implementing a new culture and sustaining it. A handbook or training can help with this, but it requires the leaders to meet with people, listening to their ideas and concerns, explaining, acting on their feedback, involving them in work design, and recognising their efforts in making the change happen.

Organisational and economic impact

Although intelligent CAE may enable concurrent engineering, not all engineering organisations use it. ARC did an informal study a few years ago among subsectors of the process industries, ranging from large continuous petrochemicals to pharmaceutical manufacturing on several continents. The survey indicated that around half of CAE users are organised for a fair or high degree of concurrent engineering, but that a third prefers to use sequential engineering. The purpose of several engineering disciplines working concurrently on the same design item is to shorten project time. However users agree that this increases error and iterations that ultimately increases the total effort. EPC's may not have the choice when under great time pressure, but for OO's conceptual engineering design is not on the critical path, and can afford to have longer project duration to save engineering effort. An economic optimisation that balances project cost with value from earlier operational readiness would probably show an optimum at an intermediate degree of concurrent engineering. Users indicated during the same survey that increased engineering productivity of five up to 50% can be achieved, related to time gains and increased data accuracy, depending on the degree of concurrent engineering used, however this comes at the cost of a significant investment in modular engineering and workflow modeling (see below).

Concurrent and collaborative engineering may cause small detail adjustments to workflows, and definition of responsibilities of individuals that may also surface as frictions on a human level (see above) but technically the organisation would not be affected in a major way.

Modular engineering and modular process technology

Reuse of information and knowledge is a way of increasing engineering efficiency. The second 'Tauchnitz principle' to reuse knowledge as much as possible implies standardisation on proven modular designs. These are ready to use engineering information for process units or sections, composed of process equipment, instruments, control, piping, pumps, mechanical agitation, etc.. An engineer picks such a unit or process section, rather than have to re-engineer the sections, and can concentrate on the performance of the process. When standard modules are lacking, documentation should describe solutions for the engineering tasks that have been used. Challenges related to modular engineering are the considerable investment in creating the modules. For OO's this is an investment that can pay off over time but for EPC's this could be uneconomical unless the EPC can standardise on a single tool and has the capability to export designs to the CAE tools their clients prescribe.

The F3 Factory project, financed by some 25 companies and the EU, and comprising seven industrial case studies, ran from 2009 until 2013, with the goal to overcome the disadvantages of large-scale continuous processing (high capital investment and rigidity) and small scale-batch processing (inefficiency) and combine the respective advantages by introducing efficiency to multi-purpose, multi-product facilities; and

flexibility to world-size continuous facilities. Research objectives included:

- Provide more compact and less costly process designs that lower environmental impact to support 'process intensification'
- Develop standardised, modular, plug-and-play chemical production equipment capable of handling many chemical processes
- Develop engineering methodologies for intensified processes

The project has delivered many promising results and several modular processes have been developed. All have demonstrated significant gains in both cost and sustainability.

The idea is that, to scale up production capacity, a manufacturer needs only to add standardised, small-sized units; rather than engineering a larger plant. This reduces engineering cost and time, and reduces equipment cost even further because larger series of equipment can be built. The concept requires a new engineering approach that optimises the process within the constraints of a choice of standard modules, rather than tailoring equipment to the process.

The trend is to produce smaller quantities, introducing gradual improvements in product and process and responding flexibly to market demands. This provides the potential to exploit the flexibility of a plant designed for a range of operating conditions, and thus for designing equipment to fit an expected range, rather than a single optimum. The use of adaptive production optimisation and quality management systems in line with the latest Food and Drug Administration (FDA) Current Good Manufacturing Practice (CGMP) guidelines will be favorable in these conditions since they will absorb process modifications and variability in processing conditions when some or all of the end-product remains identical.

The use of the modular production concept would eliminate a range of engineering and validation tasks, since varying production rates can be handled by adapting the number of production lines required to produce the required quantities. Similar projects have been done at the Massachusetts Institute of Technology (MIT), in the USA in collaboration with manufacturers.

Industrial Internet of Things initiatives such as Industry 4.0, or the Industrial Internet Consortium, have led the industry, in particular the sector producing by batches, to think about how to implement reconfigurable production lines that can respond to varying demands and constraints. This requires new concepts and standards to integrate equipment ad-hoc and in close to real time, including their automation and operations management software components.

Modular engineering approaches discussed above, greatly facilitate the engineering of modular process technology and we expect the usage of modular engineering to increase sharply in the near and mid-term future. The batch-oriented industries will be the first ones to adopt the approach, and we expect that also large continuous processing companies will start thinking about rationalising their engineering, construction and operational paradigms and applying these concepts.

e-qualification and e-compliance

There is more to Dr. Tauchnitz' vision. The analysis of risks related to the process and the equipment on the product quality, should be reflected in requirement specification, testing and qualification plans. This analysis can be done systematically based on information in the CAE tool, and its workflow can be fully automated in such a system. Test and qualification results can be linked to equipment requirements via the risk analysis and so the process reaching from specification to compliance can be executed in a paperless manner, and can be built efficiently as an extension to intelligent CAE systems.

Some providers are pioneering this approach with visionary companies today, creating significant benefits from efficiency and accuracy. ARC expects that this functionality will become mainstream soon, as the compliance pressure for all industries increases constantly, and companies need to respond to this pressure by creating additional efficiency.

Integrated engineering

The Integration of the Process Design, Engineering and Plant operation processes and third Tauchnitz principle: 'the software tools stay interfaced while the production plant is in operation' have also major implications, both for EPC's and OO's.

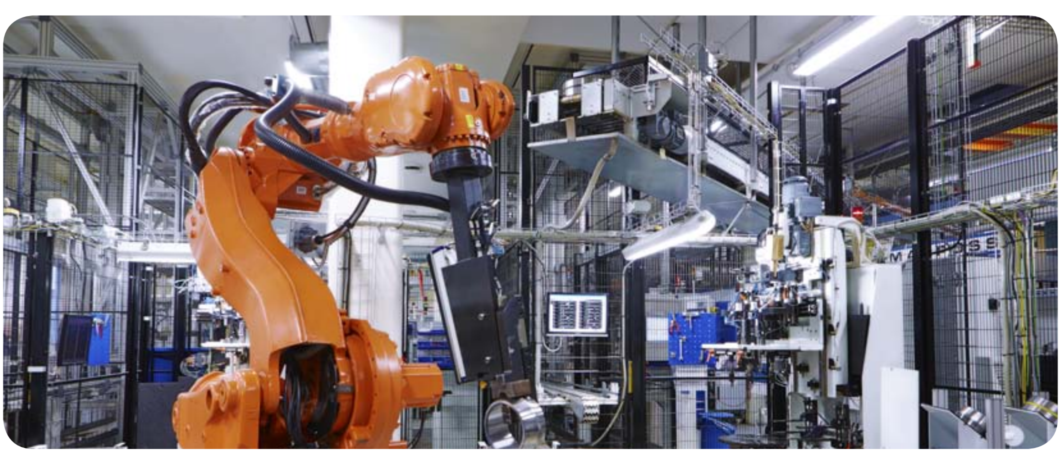
During design and build phases our customers tell us that the exchanges between EPC and OO have become more frequent and intense over the past years. OO's want to stay on top of choices made by the EPC during the design trajectory, review progress and co-manage and co-own the work. More and more these exchanges use common intelligent CAE tools that enable parties to share, visualise and discuss design work.

Even more significantly, the so-called handover from EPC to OO at commissioning happens more and more in electronic formats. The traditional paper documentation was cumbersome and time consuming to discover and master, and close to impossible to keep up to date. Today more and more OO's want an electronic, intelligent asset information data set, reflecting the 'as-built' situation, to be able to keep it up to date during the plant's life cycle. This is not only efficient from a resource point of view, but it is also more and more a regulatory requirement to be able to produce up to date asset documentation, and demonstrate compliance.

From the point that the plant starts up for the first time after being built or revamped, at least two distinct, complementary activities use asset information. Engineering uses plant information to plan for changes or improvements such as debottlenecking, heat integration, quality improvements or other projects. Simultaneously, maintenance uses the data to trouble shoot, repair, order spare parts, and so on. If asset information is not maintained during operation and maintenance of the plant, its accuracy gradually degrades over time, and when engineering need to start a project they lose precious months in discovering what the actual state of asset is, rather then working on the engineering task.

A major benefit of using intelligent CAE tools is therefore their usage across the plant lifecycle, and the integration of engineering, operations and maintenance processes using a single, up-to-date asset information data. Hence, engineering and asset information become indistinguishable and 'as-built' information is transformed into 'as-maintained' information.

Processes and work design need to be adapted, to make sure that engineering and plant changes are captured in the CAE or Asset Information repository. Also here a culture change is necessary, along the lines of what was described above for engineering organisations.



Based on client testimonials, we believe that users can gain several man-months of engineering and maintenance time per plant. Benefits related to safety incidents and emergency situations are more difficult to quantify. In major accidents the availability and quality of information to base decisions on have proven to play a critical role in making correct decisions and reducing damage, injuries and fatalities. The opportunity cost alone of production stops related to asset information will easily justify the effort of implementing integrated engineering.

Interoperability with control and other systems

But this is not all. Dr. Tauchnitz pushed the vision further by stating that a generic model for DCS and PLC programming should be part of the CAE tool. Via a universal interface the programs could be exported to various automation brands, and be compiled within the equipment, with the goal of reusing standardised programming modules within different types of equipment. The author also extends his concept to configuration of production systems, such as MES or Operations Management.

Both for EPC's and OO's this creates major time savings in engineering control systems. For OO's, during the operate-maintain phases of the plant, the benefit would be even more important. OO's generally use several control system brands and could benefit from a uniform engineering approach for multiple brands. As control systems are updated and changed in the field, a challenge arises in keeping the asset/engineering information accurate. The user organisation NAMUR (www.namur.net) has responded to this challenge by defining a standard data format for exchange between process control systems (PCS) and CAE tools (NAMUR Recommendation NE 150, published in October 2014). Dr. Tauchnitz recently reported about a set of demonstrators implementing this data exchange format for a DCS tag, between four CAE systems (Aucotec, Bentley, ESP, Siemens) and three PCS systems (ABB, Siemens, Yokogawa). This opens a highway of possibilities and benefits for users and system vendors alike. The initial momentum used to create the demonstrators should be maintained. Users should require their full implementation by an even larger number of vendors, and its usage should pay off for users in terms of engineering efficiency, for CAE vendors by an increased market size, and by PCS vendors, because of a more favorable life cycle cost.

The interoperability with MES or Manufacturing Operations Management (MOM), is still a dream for the future, as is also a bidirectional exchange with process simulation. If those subjects would be pursued, another wealth of benefits would be in reach. The work on the bidirectional interface between CAE tools and PCS shows that what was regarded as unlikely can become reality very quickly, when vision, interpersonal skills and multi-party cooperation coincide. The same is true for interoperability between CAE and MOM or process simulation.

Standardisation

Finally, Thomas Tauchnitz develops the vision for enterprise-wide standardisation and implementation, reduction of the number of systems and interfaces, organisation for centralised maintenance and support and promoting company wide knowledge management. This aspect of the vision has not received much attention yet, but from experience and client case studies on implementation of MOM applications, we know that this approach decreases the total cost of ownership of an application, and thereby shortens payback periods, and increases net added value. We therefore strongly recommend paying attention to this point.

Conclusions

Up-to-date, accurate, easy to access engineering and asset information during the full plant life cycle brings significant engineering efficiency benefits for EPC's and OO's, that users of these systems estimate to be between 5 and 50%, depending on their initial efficiency and the degree of concurrent engineering. Users were spread across various process industry subsectors ranging from petrochemicals to pharmaceuticals.

Intelligent CAE systems enable concurrent and collaborative engineering. Engineering efficiencies are obtained because of an accurate, up-to-date, data repository that all engineering have access to at any point in time. These systems help with maintaining engineering information integrity.

Concurrent engineering reduces project duration but diminish the engineering efficiency gains. Every company or organisation should determine its optimum ratio of concurrent versus sequential engineering.

The 'as-built' (or 'as-revamped') asset information can be maintained in intelligent CAE systems, that become an 'as-maintained' asset information repository, that both engineering, operations and maintenance use and update, to make optimal decisions. This so called 'integrated engineering' practice increases operational efficiency and safety. ARC estimates that companies will save up to several man months engineering time per plant per year.

Major efficiency gains would be obtained when users would stimulate CAE and PCS vendors to implement the recently published standard NE 150 for bidirectional data exchange between the two types of systems.

Standardisation on systems, methodologies, modular engineering and processes, reduces the total cost of ownership, increases productivity, and reduces training costs.

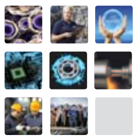
Valentijn de Leeuw

Vice President, ARC Advisory Group

Valentijn de Leeuw is Vice President of ARC Advisory Group, a group of industry leading specialists in manufacturing and supply chain solutions. His speciality areas include organisational change, business process improvement, value-based performance and knowledge management. Valentijn holds a PhD in technical sciences from Delft University of Technology (NL) and a Master's degree (MSc.) in Chemistry from Utrecht State University, Holland.

Author: Dr. Alejandro Sanz, Head of Group Technology Intelligence at SKF

The power of knowledge engineering in action



To power the future, companies must make technology innovation an integral part of their business success, explains Dr. Alejandro Sanz, Head of Group Technology Intelligence at SKF.

Sustaining industrial leadership after more than a century of operation is a welcome challenge to SKF. Embedding knowledge engineering in services and products requires a continuous renewal of your own competences, as well as challenging yourself to go beyond the point where others stop. The question is, how do you generate, deliver and capture value based on the opportunities offered by new developments in technology?

Our business objective is to bring new knowledge and innovative value propositions to generate critical improvements in reliability and productivity for all our customers. To develop new advanced systems, solutions and services, the innovation cycle has to be continuous and loop endlessly. This can be a difficult task to achieve, but as we hope to show using our experiences at SKF, it can be integrated within existing processes to create real and sustainable business benefits.

The outside-in approach

Several factors should determine the innovation policy and management that a company implements. These include assessments on the economic effectiveness of technology investments, internal attitudes to innovation, legislation frameworks and the timing and future role of technology in industrial performance. Inevitably, these analyses are to a certain extent based on estimates of future behaviour, which gives rise to uncertainty and an associated level of risk.

At SKF, we developed the Strategic Innovation Analysis (SIA), which anticipates new market or service trends as well the expectations of the market to ensure that the company is consistently delivering value. We have recognised that strategic decisions on innovation cannot be undertaken without an intimate understanding of the relationship between the company's internal set-up (in regards to innovation, markets, managerial attitudes, technological and human resources, capital structure, etc.) and the opportunity space created in (or imposed by) the market. [1]

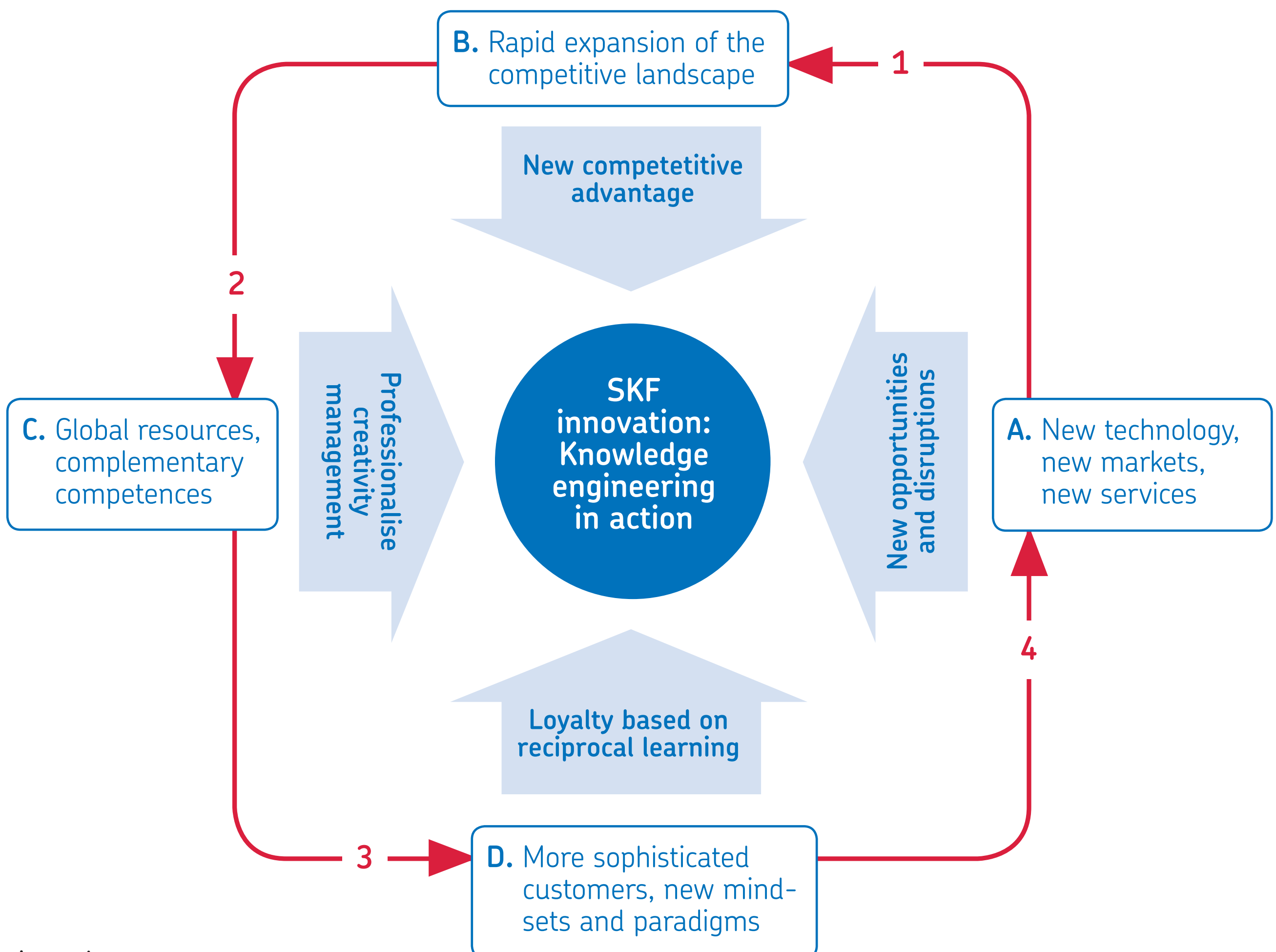
The company must anticipate, assimilate and integrate market trends and expectations. The external context of forces that a company has to understand includes market needs, legal and economic frameworks, competitive benchmarking, technological opportunities, and new business opportunities.

Taking the classic outside-in approach, SKF developed professional technology intelligence and intellectual asset business units to continuously monitor technology trends, the positioning of customers, competitors and markets as well as systematically screening for new partners or targets for mergers and acquisitions.

Entrepreneurs and startups are responsible for some of the most innovative and disruptive technologies and value propositions. It was once said by Nonaka [2] that, "Creativity is about divergent thinking and innovation is about convergent thinking". Following this line of thought, it can be argued that for large established businesses, having direct involvement with entrepreneurs and startups provides fresh and unorthodox approaches to technology and business. This concept is one that SKF has embraced and we have found that during discussions between our experienced business leaders and younger, smaller startups we are able to combine the best of both worlds to disrupt the market.

This type of venture involves taking non-traditional approaches to business strategy with the purpose of creating significant value to market and customers. With SKF's approach, an average of 70 startups per month are evaluated, assessed and benchmarked. Our management team receives specific updates not only on the key focus areas of interest but also in a blue-sky view. This identifies

Figure 1: The framework determining the innovation imperative. Based and modified from [1]



Legend

1 to 2 Outside-in approach
3 to 4 Inside-out approach
A Strategic Innovation Analysis & Management (SIA & SIM)
B Technology Intelligence & Ventures
C Continuous Innovation Management (CIM): Creativity and the GTCs
D Short stories of joint innovations

new and radical business concepts that, when combined with our own brand-promise, could lead to very different types of new offerings.

This kind of outside-in approach starts with the long term opportunity in mind by creating a new competitive space. The outside-in approach requires a holistic view of emerging trends and needs to lead towards a systematic delivery of a portfolio of concrete business growth opportunities. [2]

The inside-out approach

By comparison, the inside-out approach to innovation involves several levels of analysis, creativity and co-operation. However, the common theme that is at the heart of this approach is to think globally, but act locally.

A company's style of innovation management stems from its employees' attitudes to innovation. A deep rooted acceptance and encouragement of innovation is vital for such a culture to flourish within an organisation. At SKF for example, our focus has always been on problem-solving and invention since day one. This is evidenced in our development of the self-aligning bearing to solve the problem of bending shafts – which in turn invigorated the overall market for bearing technology. For us, knowledge engineering isn't just a motto but is market recognition of a continuous series of improvements that we have made ever since our founder Sven Winguist designed his first commercial invention. [3]

Over the years, continued sustainable investments in research and development have been critical to the growth of SKF as a company and brand. The establishment of our Engineering and Research Center (ERC) in Nieuwegein, the Netherlands, was extremely important not just for us, but for the engineering world at large, as it has inspired the development of disruptive technology such as hub bearing units and the creation of the bearing life theory that has been adopted industry and worldwide. For us, the spirit that initiated our first innovation – one of using invention and knowledge to solve a specific problem – is still at the very heart of our business.

Another important aspect of internal analysis is a screening and scrutiny of internal potential in terms of technology and resources. It's important to allow a degree of flexibility in the process, to clear a path internally for any possibilities that might arise. Using SKF as an example, innovation is considered one of the strategic pillars for the future growth of our entire business. Each of our business areas has been assigned a challenge: to create completely new and game changing offers to demonstrate future value-based leadership. To reach the growth targets that our business strategy demands, there is a need to identify and integrate internal resources while providing visible support from management to the initiatives.

As part of this inside-out approach, we launched several activities with the aim to overcome the fact that in large organisations, talented people can be located anywhere and everywhere, however they are often not connected with each other and usually lack the right network to support this. Our methodology is based on a creative process where employees, no matter where they are located globally, can submit and develop creative ideas into solid business proposals. They can do so either by using an online internal communications tool or participating at specific workshops. To give some structure to the creative process across SKF, specific strategic parameters or goals are dictated by our various business units.

All ideas that are submitted are vetted following the Real-Worth-Win methodology created by the Harvard Business School [4]. A shortlist is presented to a final evaluation board, made up of business unit directors as well as employees from product development and manufacturing. They then use the same methodology to further whittle down the selection. Any idea that is selected by the evaluation board gets the green light for forming a dedicated development team and further maturation at a dedicated boot camp. The owner of the idea is put in charge of forming an inter-functional team to attend this camp. To avoid discouragement, it's also important that feedback is provided for any ideas that aren't developed further.

The boot camp comprises of two weeks of intensive activity and includes participation of any relevant figures at a management level. The first task of this team is to develop a vision of the market. This includes an opportunity/fit analysis followed by the identification of key strategic choices. The second phase of the boot camp focusses on timing and business qualification, as well as preparation of a pitch to management at a divisional level. This initiative has proven successful in bringing valuable ideas from different countries and integrating international and complementary teams in projects with real value and impact.

A final part of our 'think globally, act locally' philosophy has been to physically expand the global footprint of SKF. We set up organisations that specifically concentrate on innovation and emerging disciplines and practices of engineering. These organisations include Group Technology Development (GTD), Advanced Development Centers (ADC) and Global Laboratories (GL). Our Global Technical Centers (GTC) give us a solid technology presence in key geographies and their activities include research and development, lab-pilots, prototypes, full-scale demos, platform integration and local specialisation.

The recipe and rules for successful innovation

In our experience, having a process that is rigorous yet flexible and interactive is key to encouraging creativity and innovation.

Figure 2 gives a view on how the different elements of innovation fit together like gears in a machine. During the development of mid-long term technology projects, it is important not to lose contact with market expectations and evolutions, particularly as new opportunities may often be uncovered during the length of such a project.

The future positioning of the company is put into execution by coordinating two types of innovation management: Strategic Innovation Management (SIM) and Continuous Innovation Management (CIM).

CIM integrates knowledge solutions from within SKF into tools, systems and service; SIM uses portfolio sources (R&D, alliances, joint ventures, partnerships) to ensure a constant renewal of the value proposition of the solution being developed. The two approaches integrate competences and knowledge from different domains to develop successful solutions. We measure our results against market and customer expectations.

One key thing that we have learned is that leaders in innovation defy convention to explore new areas. Innovation and creativity efforts must be persistent and disciplined to bring the benefits of ideas to markets in a consistent way. However, real success comes from taking into account the constraints and goals of others and integrating them with your own with one single purpose in mind: to power the future.

Application examples

The highest level of value can be provided when SKF co-creates value by working directly with customers in the most demanding projects. We have found that our depth of industry knowledge compliments the new and emerging fields of engineering and related services, often to produce some of the most outstanding results. The following examples demonstrate how SKF has been able to expand the horizon of what is possible by collaborating with its customers.

Reliability in any condition and place

Operation and maintenance constitutes a significant proportion of the cost of running a wind turbine – up to 40% of the acquisition price over the lifetime of a machine. Individual repairs are also potentially very costly. For this reason, turbine manufacturers and maintenance service providers are keen to adopt any technology that helps to reduce maintenance and downtime.

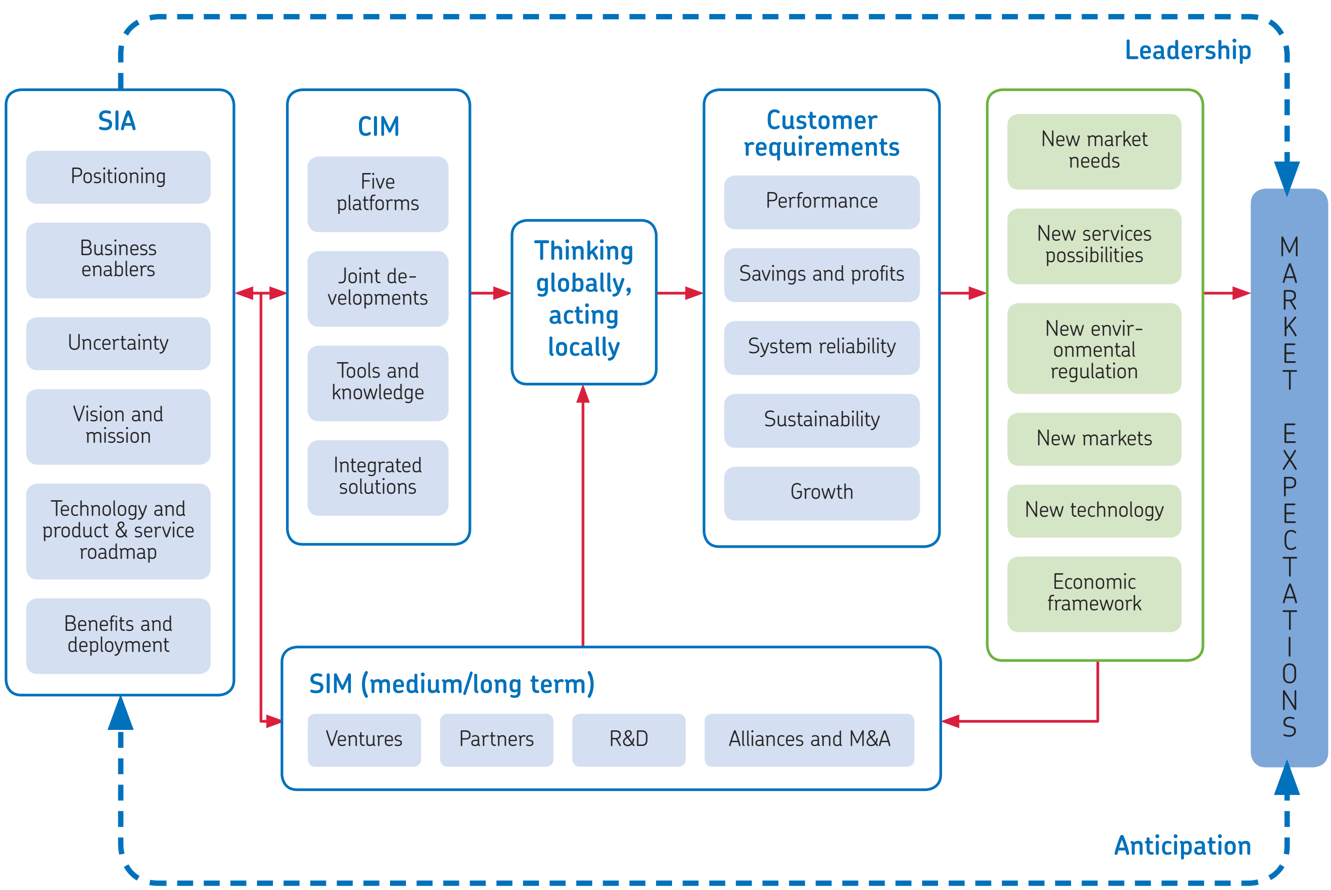


Figure 2: The continuous loop of the power of knowledge engineering in action

Black oxidation treatment has been proven to improve the reliability of bearings in a wind turbine [5]. This surface treatment process delivers improvements to performance at reasonable cost and was identified as the optimal solution to improve operational reliability. Black oxide provides protection against tribochemical attack, reduces the permeation of hydrogen and increases the resistance against moisture damage, such as standstill corrosion. In addition, it has been proven that black oxdised bearing steel surfaces extend the range of safe operating conditions compared with uncoated bearing steel surfaces.

Turbines operate in aggressive environments, so sealing is another key element to improving their reliability. Rubber excluder seals can wear out quickly as they are unable to handle the rough counterface surfaces and limited lubrication conditions common to turbine main shafts. If they fail, they leave main shaft bearings more exposed to contaminants that can cause equipment failures, unplanned downtime, and higher kW costs per hour. In many cases, replacing rubber excluder seals up-tower is very difficult or next to impossible.

The HRC1 axial excluder seal is designed to overcome these challenges. This seal is made of a special H-ECOPUR, an SKF-developed polyurethane material with excellent abrasion resistance and tear strength. The result is an axial excluder seal that delivers significantly extended service life and contaminant protection for increased wind turbine reliability and reduced maintenance costs.

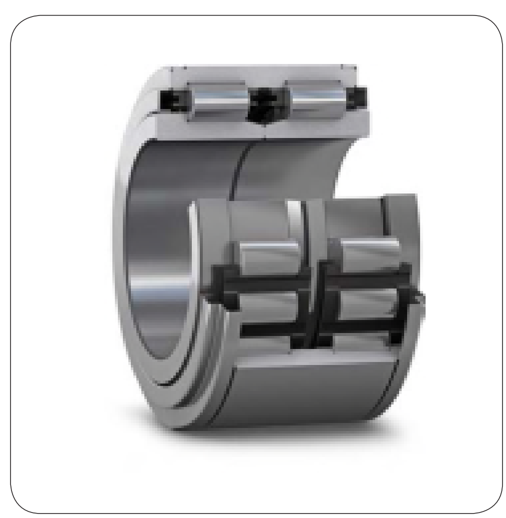
Working closely with a prominent wind turbine manufacturer, SKF subjected the HRC1 axial excluder seal to an extended field trial. Following installation on 40 separate 2.5 MW turbines, the seal operated continuously under real conditions. This field trial helped confirm that the axial excluder seal provides drastically extended service life compare to conventional rubber excluder seals.

Keeping the rail industry on track

Since the turn of the century the increasing demands faced by China's transportation companies have provided great opportunities and interesting challenges. China's Very High Speed Train, which at 380 km/h is the fastest train in the world, is one such challenge. The producers of the train asked SKF to explore the possibility of extending the service interval of the bearing from 800,000 km to 1.3 Mkm. In response, SKF created the new CRU 130X240 bearing solution, which achieved a stable temperature over the full test mileage of 1.3 Mkm and at speeds of up to 420 km/h.

For the next generation of passenger trains, with speeds of 160–250 km/h, SKF has developed a new tapered roller bearing unit (TBU). The new unit increases bearing service life by up to 40% compared with existing solutions. In addition, lab tests indicate a 30% friction moment decrease, while patented heat treatment SKF Xbite improves overall robustness and performance of the bearing. This next generation bearing unit helps OEMs and end users to increase safety and maximise profit.

Developed directly due to customer demand and collaboration, SKF's Compact Tapered Bearing Unit (CTBU) has an axle load rated to 45 metric tons, which means that operators can increase profitability by hauling more product with the same length/configuration train. This CTBU from SKF is the only heavy haul bearing rated to 45 ton operational axle load on the market. This represents a transportation capacity increase from existing 35.5 ton axle suitable for existing or new wagon fleets.

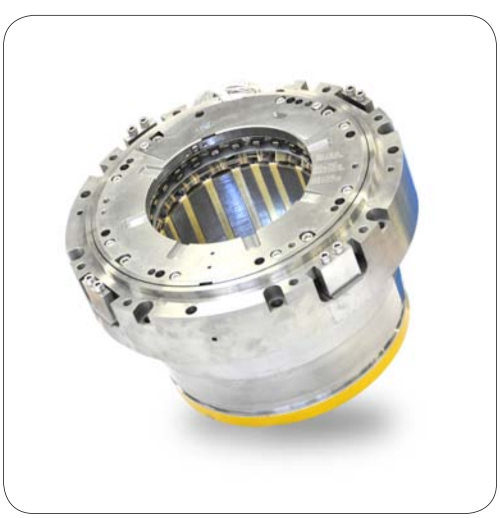


There is nothing conventional in traditional energy production

Although often referred to as traditional forms of energy, there is nothing conventional when it comes to safely extracting and conveying oil and gas from the harshest of environments. The first subsea production units will be commissioned on the Asgard gas field in 2015 thanks to the development of Active Magnetic Bearing (AMB) technology, which was only possible due to the close collaboration between SKF and leading energy companies.

Although it seems that fracking is an emerging form of energy production, SKF has been responding to demands for high pressure fracking valves for many years. For each customer and valve design, SKF developed unique low torque ball and roller screw bearings leading to high reliability valve sub-systems. Several thousands of these solutions have been implemented since and have proven to provide remarkable performance. This engineering know how and enduring technologies are now being used for the development of higher pressure applications, up to 15,000–20,000 psi.

Within the highly demanding exploration and drilling environments, critical applications that require traditional encoding are a major source of productivity losses due to exposure to the toughest conditions. To solve this problem, SKF used its experience of robust sensing integration to develop a solution that is ideal for the application. In addition, the same technological competence and robustness has been applied to the specification, installation, operation and analysis of thruster monitoring systems, which have been approved for use for longer periods between maintenance by international certification bodies.



Alejandro Sanz

Group Technology Development, SKF

Alejandro Sanz is Head of Group Technology Intelligence at SKF. He is responsible for identifying and assessing new technologies and venture opportunities for future markets. Alejandro's team supports strategic decisions on SKF market-technology positioning, licensing, alliances, joint & corporate ventures and acquisition prospects. He has a PhD in Material Physics and joined SKF in 2003 to manage the science and technology activities in SKF, following a decade in industry.

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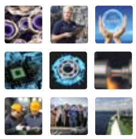
Ship shape – condition monitoring in the marine industry



Condition-based maintenance has worked wonders in manufacturing: now SKF is accelerating its CBM offerings to the marine industry, says David Johansson, Head of Strategy and Portfolio Management at SKF.

Condition-based maintenance (CBM) is a tried and trusted technique within the world of manufacturing. It helps to improve the overall machine efficiency and ensures timely and accurate repair of machines by keeping a constant watch on their condition, and identifying errors before they can cause problems.

Any industry that uses a lot of independent machines can derive enormous benefit from CBM. For this reason, at SKF we see considerable potential for CBM in the marine sector. For example, the needs of marine customers are similar to those in manufacturing: improving maintenance procedures, boosting uptime and cutting costs. However, the industry's natural conservatism coupled with reliability, stringent regulations and ever tougher economic conditions, means that the take-up of CBM has been relatively slow.

SKF has been working with OEMs in the marine sector for many years, helping them improve the performance of their machinery. Following our strategic acquisition of Blohm + Voss Industries (BVI) in Germany in 2013, we are now in a position where we have far greater exposure to the end user market thanks to its worldwide leading network of sales and service partners. BVI is a leading supplier of marine components including sterntubes, seals and hydrodynamic bearings, and works closely with shipyards and marine operating companies.

In many respects, the BVI acquisition has also allowed us to accelerate and improve our CBM services to the marine sector. Customers will benefit from SKF's expertise as a knowledge engineering company in combination with BVI's focus on shipbuilding and ship operations. In particular, we're now developing even more advanced condition monitoring systems, which are based on much broader end user feedback and application data. Together, our solutions will help to address future challenges in the ever changing environment of the marine industry.

Cutting costs

Shipbuilding is under as much pressure as any other manufacturing sector, while ship owners are also trying to make their operations as lean as possible. They must minimise cost, by for example optimising trade routes, reducing cruise speeds and improving fuel efficiency to protect operating margins.

Although cost-conscious ship owners might see CBM as an unnecessary expense, the reverse is in fact true. By investing in the CBM technologies that are already widely used and proven for reducing machine operating and maintenance costs in the manufacturing sector, ship owners and operators can benefit from the efficiencies that arise from greater machine reliability; in many instances this can have a positive impact on the number of days that each vessel can remain at sea.

The early adopters of CBM have been the highest value vessels, such as cruise ships, and those used in the oil and gas sector. Increasingly, however, we are seeing the implementation of CBM technology in a far wider range of cargo ships, large and small.

Traditionally, a ship used in the offshore sector is brought into dry-dock every two and a half years for a complete overhaul of on-board machinery; for merchant ships generally this period is longer, at around five years. In each case, every day that the ship is in dry-dock represents lost revenue.

Investing in automated condition-based monitoring systems could potentially delay the need for these major overhauls – meaning that a ship will undergo fewer major maintenance operations during its lifetime and spend more time at sea. Routine repairs can also be carried out with more confidence, and be planned so that they can be completed while vessels are in port or at sea, so that they do not affect normal operations.

Data can be gathered in a number of ways. On-board engineers can use instruments such as SKF's Microlog handheld devices to carry out portable data collection, or use online systems, where fixed sensors mounted in dangerous or hard to access areas are hard wired back to a central on-board control room. Data can therefore be analysed by ship engineers or, more commonly for critical equipment, be transmitted to a shore-based facility for interpretation by remote experts.

Bandwidth issues

Of course, there are some key differences that do not translate directly from the manufacturing to the marine sector. One is the availability of network or satellite bandwidth.

By its very nature, condition monitoring generates large amounts of data. In a manufacturing environment, with on-site analysis, data overload is rarely a problem. On-board ship, once the vessel is out of reach of land based communications networks, it is impractical to send such high volumes of data over satellite links, especially if it has to compete for bandwidth with voice or other more critical communication. Information must therefore firstly be carefully analysed and filtered, with only the most relevant data being transmitted for on-shore analysis.

Environmental push

And it's not just maintenance data that's important. CBM is increasingly moving into performance monitoring too. Ship owners require a large array of information, such as fuel consumption and emission levels to optimise operations.

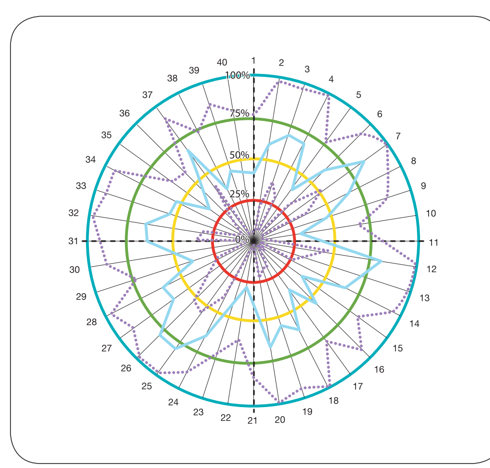
New solutions are emerging to help meet these needs. For example, BVI's Turbulo BlueMon is an emission monitoring system that records everything in one place. By linking to GPS position data, the system helps compliance with marine MARPOL conventions, so that if a ship is approaching an area with higher emission standards a warning can be sent to the bridge so that emission levels can be rechecked. Data remains available for 24 months, allowing later verification of compliance.

This and other systems are effectively filling in the ship's logbook automatically – the kind of operation that is likely to become far more common in future. Fitting this technology to an entire fleet would allow a ship owner to benchmark its environmental performance against industry standards, or identify the best performing crews and vessels.

There is a further benefit of centralised data collection, in that it helps to overcome a common trend within the marine industry – that of engineers rotating between ships, with knowledge of individual vessels inevitably being lost as staff move on.

Needs analysis

SKF can also provide a Client Needs Analysis (CNA) to ship owners, helping them to improve on-board maintenance procedures. The CNA is a survey of around 40 questions, which are put to the maintenance operations team. It takes a full day of interviews to gather the relevant information. SKF then generates a score of a company's maintenance performance, often revealing immediate ways to boost procedures and cut costs. In addition, the report provides a roadmap for future improvements. CNAs are widely used, and proven, within manufacturing, but still in their early days in the marine industry. Nonetheless, they can be an excellent first step in planning the introduction of an on-board CBM solution.

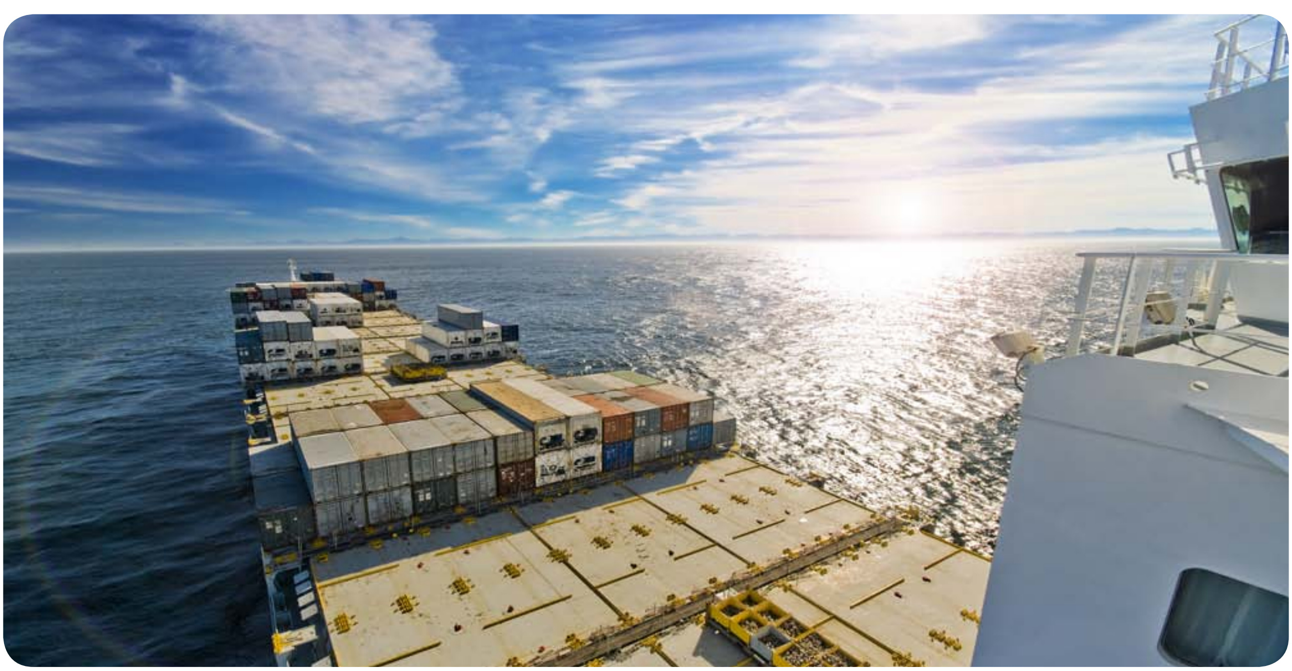


Where next?

The marine industry will not adopt CBM overnight. The main focus of marine engineers is reliability, as a means of optimising vessel availability; this has historically been carried out using visual or time-based maintenance inspections, so changing the culture will take time.

Change will be driven by economic pressures and by ever tougher regulations on, for example, emission controls and machine safety. It will also be driven by companies such as SKF entering into strategic alliances, with the goal of developing new and innovative technologies that offer ship-wide and fleet-wide condition monitoring.

Perhaps the biggest challenge faced by marine engineers is to manage multiple on-board machines; indeed, in many instances there are so many machines, from many different suppliers, on each ship that it's much like a floating factory. For SKF, with our background in manufacturing, plus our experience and alliances in marine applications, we are able to offer knowledge engineering solutions that help OEMs improve the performance and reliability of their systems, and enable ship owners and operators to increase the time that each vessel spends profitably at sea.



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