Sensors For Blades—Stress Reduction For Wind Turbines

By Christian Hackl

Encouraged by an IP-savvy university institute director with an entrepreneurial spirit and positive feedback from industry sponsors, a team of young researchers decided to bring their fibre optic measurement technology to market. Access to the university's patent portfolio and research facilities, together with the business experience acquired by one of the co-founders, paved the way to the creation of fos4X. The young company decided early on to focus on applications for wind turbines, and their patents turned out to be crucial in a market of mostly large players. The company was acquired in 2020 by PolyTech on the basis of its innovative technology and IP portfolio.

fos4X provides streaming analytics using fibre-optic sensors on the rotor blades of wind turbines.

A University Research Project

The five co-founders of fos4X—Lars Hoffmann, Mathias Müller, Thorbjörn Buck, Rolf Wojtech and Markus Schmid—all did their PhDs at the Institute for Measurement Systems and Sensor Technology at the Technical University of Munich (TUM) under Professor Alexander Koch. The team's research on optical sensors and their potential application in different industries included glass fibre sensors for use in medical technology (minimal invasive surgery, guided by robots) and space technology (shape reconstruction of antennas on satellites), as well as sensors for detecting lightning strikes on wind turbines.

The idea of starting a company arose shortly before Lars Hoffmann was due to complete his PhD. The research project he and his colleagues were working on was funded by the German Research Association for Power Transmission Engineering (Forschungsvereinigung Antriebstechnik e.V.), and representatives of some of the member companies of the association were accompanying the sponsored research projects as sparring partners. However, due to the financial crisis in 2008, there was no chance of finding investors prepared to finance a start-up with new and untested technology. After finishing his PhD, Lars left to join a management consulting company, but continued to meet up with his colleagues at the institute, who kept him informed about the latest research results.

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Thanks to Professor Koch, who is also a qualified European patent attorney, all the members of the research group had become aware of IP at an early stage and were quick to develop ideas about possible IP rights creation. This led to the first patent application in 2009. At the time, the technology worked well in the lab, but was lacking in robustness and was still too expensive. The research carried out by the team showed the limits of the technology and made it clear what further developments and testing were needed.

Funding and Establishment of the Start-Up

At their informal meetings, Lars and his former colleagues came up with the idea of applying for a German government start-up grant under the "EXIST" funding programme,[1] which covers living expenses, materials, equipment, and coaching for one year. However, to qualify for this grant, two requirements had to be met: first, there had to be at least one business-savvy person in the team, and second, the start-up would have to reach a deal with the university on IP access and on continuing to use the university laboratories.

Takeaway: Business Competence Is Key

It is essential for the founding team to have access to business competence. The technology transfer office cannot provide this, as it is not part of the start-up's operational team.

1. *exist.de/DE/Programm/Exist-Gruenderstipendium/inhalt.html.*

Having agreed that, should the grant application be approved, he would quit his job, Lars Hoffmann rejoined the team in 2010, soon after the formation of the start-up fos4X, thereby ensuring that the first EXIST programme requirement was met. The second requirement was met when fos4X signed a contract with the university which ensured that the company would profit from the IP rights originated at and held by the university. In 2012, an exclusive licensing deal with the university was concluded for the patent applications filed by TUM. The contract was negotiated on behalf of TUM by BayPat, a centralised technology transfer office working for 33 different research organisations in Bavaria.

Fostering IP Awareness and Technology Transfer at Universities

"I encourage all my research students to think about IP protection from the outset. Six successful start-ups are living proof of how important this is!"

Alexander Koch
Co-inventor, TUM Professor, and European Patent Attorney

Professor Koch is well-known for his technology transfer affinity. He has always been keen on co-operation with industry, with a view not only to gaining third-party funding, but also to identifying the potential industrial application of any research results, including the option of establishing start-ups. He places equal emphasis on the two "currencies" of academic research: publications and patents. Sometimes this is seen as a conflict—and if in doubt the emphasis is mostly put on the publications, but if it is done in a smart way, both publication and patenting can be combined by filing patent applications before publication.

Although the members of the founding team did not receive any structured training on IP during their regular studies, they were able to profit from Professor Koch's input on potentially patentable research results at weekly roundtable meetings with him. Professor Koch's experience as a European patent attorney even led to an agreement with the administration of the university that allowed him to bypass the usual channels and write patent applications himself. The fact that there have already been six start-ups from his institute proves how successful this approach has been.

First Steps

The success of their application for the EXIST grant meant that the team could continue to use the university labs for their initial development activities and to benefit from being part of Professor Koch's institute.

Following the publication of a university press release,[2] which was issued at quite an early stage in the product development process, the team received positive feedback from larger, established market players such as Siemens, Nordex, and Repower, who were very interested in this new technology, and in particular its application in wind energy, as this was a new solution to the major problem of the dynamic load monitoring of rotor blades and ice detection on wind energy converters. As a start-up, the fos4X team would have had a hard time making contact with the right people in the big companies, but the press release meant that the big companies came to them.

Takeaway: Patents Provide Credibility

Patents can work as an initial indicator of professionalism and competiveness when a young start-up with new technology becomes visible to established companies.

To further increase their visibility in the wind energy market, the team participated in a number of start-up competitions. Soon after, they were able to run the first tests of their sensors on test benches for rotor blades, and then, in the summer of 2011, the sensors were installed for the first time on a real wind powerplant.

In the summer of 2012, the team moved out of the university, but continued their co-operation with the institute, both in academic terms (*e.g.*, student involvement in company-supported master's and PhD theses) as well as funded joint research projects. They also kept their access to the university's technical infrastructure, including testing equipment. Not long after, they concluded their first contract with Nordex to supply measuring systems for active load reduction for large wind turbine installations.

Until 2016, fos4X's sensors were installed exclusively on existing wind turbines, mainly to detect ice formation on rotor blades and to measure their vibration and acceleration. This was a small market niche with good profit margins. Additional income was generated by a number of individual projects, such as the examination of blades in test benches and the application of sensors in the automotive industry.

Financing Growth and Preparing for Exit

Although it had always been the founders' aim to develop a platform technology with possible applications in different industries, it was only once the company changed its business strategy to focus primarily

2. *www.ei.tum.de/mst/forschung/faseroptische-messsysteme/.*

on wind energy applications that they could scale up their business and produce high-quality, competitively priced products.

Despite the first products being installed at customer sites in 2011, it was not until 2016 that fos4X finally got its first high-volume contract for standard equipment of all rotor blades of a certain wind turbine manufacturer. This was due to stringent safety requirements in the wind energy market, requiring a lot of tests and certifications. Nevertheless, fos4X successfully managed to continue raising money for growth throughout this time.

Takeaway: Solid Patent Protection Combined With Early Turnovers Help Secure Financing

Solid patent protection is a prerequisite for many investors looking to invest in technology start-ups. However, cash-flow-generating activities at an early stage can help to provide funds until market introduction and are also positive signals to investors.

Financing Milestones

- 2011: EXIST programme funding
- 2012: Pre-seed (convertible loan)
- 2013: Seed (first share capital investment)
- 2015: Series A1 financing
- 2017: Series A2 financing
- 2018: Series B financing (EUR 8.5 million), alongside a strategic re-positioning

The funding and financing allowed fos4X to grow to around 100 employees, resulting in a revenue of EUR 11 million in 2020, when the company was acquired by PolyTech, a Danish manufacturer of products and systems for the wind power industry. PolyTech is now integrating fos4X and continues to develop its intelligent sensors and software solutions. IP was an important factor in the negotiations leading to the acquisition. fos4X had an impressive IP portfolio and a highly professional IP and innovation management system. Its IP manager and innovation manager are now responsible for these activities in PolyTech, ensuring that the whole group can benefit from their experience and expertise.

The Technology

The main problem that the initial research addressed related to wind-induced stress on the mechanical compounds of wind turbines, which is critical for the elements of the construction and for its lifespan. This is why a methodology or technique was needed to monitor this stress and lower it.

The state-of-the-art sensors back then were electrical. However, this type of sensor can be destroyed if lightning were to strike the rotor blades. Also, they can only measure up to 0.3 percent of the deformation, whereas the materials used for wind rotor blades (GFK, CFK) are subject to elongation that is 10 times greater than that of steel when yield stress is applied. This means that they cannot be used to measure elongation in these materials. Another reason why electrical sensors are not ideal for application in wind turbines is the number of load changes—several million—they can measure over their lifespan. However, wind rotor blades can experience up to several hundred million load changes over their lifetime, so electrical sensors cannot cover the entire lifespan.

The solution was to change from electrical to optical sensors that send out white light (whole spectrum) in a glass fibre fixed to the rotor blade. After hitting a fibre Bragg grating (inscribed in the optical fibre) only light with a certain wavelength is reflected and measured. A load applied to the rotor blade will change the wavelength of the reflected light. By measuring this shift in the wavelength, the load applied to the blade at this area can be measured. Only a small number of sensors (between two and five) are needed per blade, with the sensors themselves being easy to install.

Figure 1: Blade Load Monitoring On Wind Turbine Rotor Blades

The Market

The market for wind turbines is global, with five major producers based in Europe and the US (Siemens, General Electric, Vestas, Nordex, and Enercon), as well as several large players in China. Over time, all the top ten companies worldwide have become customers of fos4X, with the highest sales figures being recorded in Europe. Since the foundation of fos4X's Chinese subsidiary, there has also been a marked increase in sales in the Chinese market, with somewhat close to EUR 5 million in sales to Chinese companies in 2020.

There are a number of competitors in the field of sensors for rotor blades and software for controlling wind power installations, but they have traditionally been active in different industry segments with different customers. fos4X was able to provide end-to-end solutions, from sensor to wind turbine connector, at

competitive prices. Of all the major players, only one failed to choose fos4X, as, being a young company, it scored low on company stability.

While patents provided fos4X with protection against competitors and copycats in all the main markets, the situation was different in China, where it couldn't solely rely on patent protection, and where excellent customer service and high speed are important. On one occasion, the company noticed an identical clone of one of their sensors being showcased by a competitor at a trade fair in China. fos4X used the available legal remedies, but as it was already promoting its next generation of sensors at the same event, the illegal copies did not affect its business.

Takeaway: Fencing Off Copycats

Timely IP protection and enforcement of IPRs, complemented by short innovation cycles and operational excellence, are the best shield against copycats.

Managing IP

In addition to the exclusivity of the licence for the university-owned patents, which gave fos4X early access to the technology, the deal included the option for a transfer of ownership for these basic patents to the company, which was duly exercised in 2018, making the company even more attractive for investors.

Following the decision to focus on wind energy applications in 2016, fos4X re-evaluated its patent portfolio. It was decided to sell one patent, which was considered non-core to the business, but of potential interest to the railway industry. Backed by discussions with manufacturers of railway equipment that were approached by fos4X, a joint feasibility study was conducted with one of the interested companies. However, it would have taken a long time for significant earnings to be realised—too long for a start-up with totally different expectations regarding return on investment and active in a different business sector. So, the two parties agreed on a business case with respective cash flows and, based on these discounted cash flows, a price for the patent. This one-off payment was important for fos4X, coming as it did at a critical time after some of the co-founders had left the company, making it difficult for fos4X to get additional funding from investors. The benefits of the patent sale in 2016 encouraged fos4X to accelerate its patenting activity and helped to convince investors of the importance and benefits of the increased patenting activity.

Takeaway: Monetising IP

While core IP has strategic value and should be prioritised, the transfer of non-core IP provides an opportunity for rapid monetisation. See Figure 2.

Patent Portfolio for the Digital Future

In addition to the optical compounds, the applicable software has become increasingly important for manufacturers of wind turbines and their customers. fos4X's software applications calculate input variables for the control and operation optimisation of wind turbines using sensor data fusion, classical model-based methods, and methods of machine learning. Today, fos4X employs more software developers (about a third of the workforce) than hardware developers, which has resulted in a rise in software-related inventions, for example for control processes. In its R&D activities, fos4X placed great emphasis on applications of its technology and the integration of hardware with software components. This did not mean a change in IP strategy but led to more patent applications and patents on computer-implemented inventions.

fos4X's patent portfolio continued to expand as its new software solutions grew in importance. At ac-

Figure 2: Retrox Dashboard

quisition, fos4X had a portfolio of nearly 200 patents in about 80 patent families. Patents helped to secure technical leadership and defend the company's position. By constantly monitoring the patent activities of relevant third parties it was able to file a notice of opposition whenever necessary.

Under its patenting policy, the company always started with a PCT application, followed by a European application claiming protection in the main countries in Europe, as well as validations in China and the US. Where a particular patent was less important, protection was secured in Germany only. A dedicated decision-making group consisting of the CEO, the CTO, and the full-time IP manager met biweekly to discuss IP-related issues. A structured process was in place along the innovation pipeline, starting with the selection of employee ideas. Employees did not have to write full invention disclosures for all of their ideas, only for those that received positive feedback. Decisions on which ideas to develop further, what should be discussed with the external patent attorney, where to validate a patent, how to handle competitors, and which cost-related factors to take into consideration were discussed at these biweekly meetings. See Table 1.

Some of the EP applications listed are still pending and no decision to grant has been taken. Granted patents may also undergo an opposition or appeal procedure, in accordance with the procedures laid down in the European Patent Convention, which could limit the scope of protection of the patent. All legal events are published in the European Patent Register and can be accessed via *www.espacenet.com*. ■

Available at Social Science Research Network (SSRN): *https://ssrn.com/abstract=4099738*

Further technology transfer case studies can be found at *epo.org/case-studies.*

Figure 3: Technology Transfer Timeline

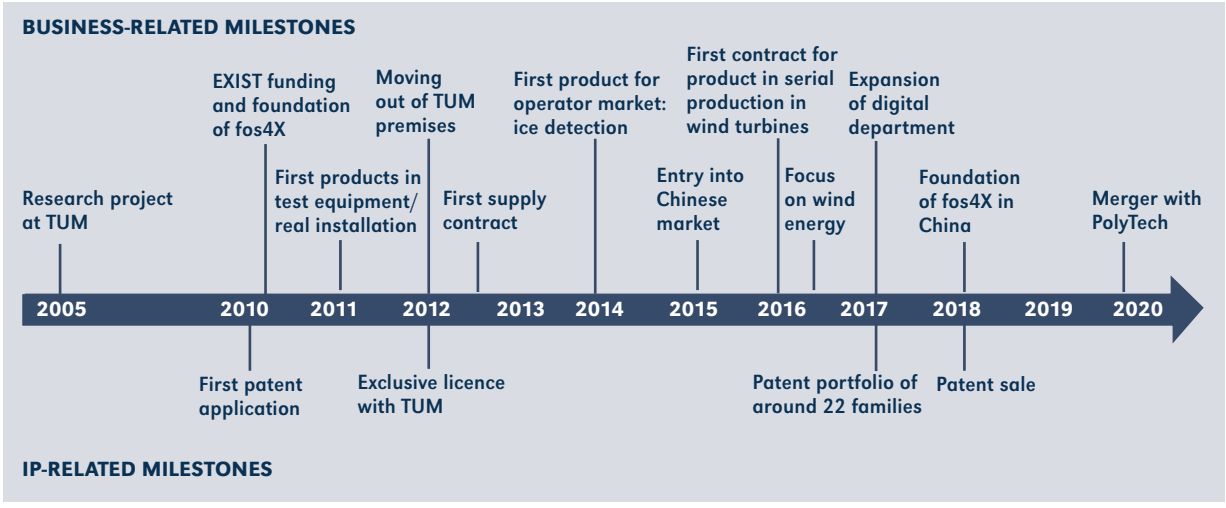

Table 1: fos4X's Patent Portfolio

EP Patent number	Title	Priority Date
University as applicant		
EP2475971A1	Device for reading out a spectrally selective optical measuring sensor and measuring device	09.09.2009
EP2855930B1	Method for installing sensors in rotor blades and installation device	05.06.2012
EP2898216B1	Method and device for monitoring operating states of rotor blades	18.09.2012
EP2856096B1	Optical measuring system with polarisation compensation as well as corresponding method	05.06.2012
fos4X as applicant (example)		
EP2856097B1		
EP3717318A1	Method of compensating optical fibre measuring systems and optical fibre measuring systems	05.06.2012

Sensors For Blades

Source of IP

Alexander Koch

- Professor, TU Munich, R&D project leader and co-inventor
- European patent attorney, drafts patent applications himself

Lars Hoffmann

- Former PhD student, co-founder of fos4X, re-joined the team after having gained business experience

Mathias Müller, Thorbjörn Buck, Rolf Wojtech, Markus Schmid

- Former PhD students and co-founders of fos4X

TU Munich

- Public research university established in 1868, where the IP was created
- Gave fos4X access to university infrastructure, including laboratories, and issued press release soon after its foundation

Tech Transfer Catalysts

BayPat

- A centralised technology transfer office working for 33 different research organisations in Bavaria
- Helped to negotiate the contract for TUM

German Research Association for Power Transmission Engineering

EXIST funding programme for start-ups

- Provided initial funding

IP Commercialisation

fos4X

- University spin-off formed in 2010
- Concluded an exclusive licensing deal with the university for the patent applications filed by TUM
- Offers professional fibre optic measurement technology and measurement solutions for wind turbines
- 100 employees and around EUR 11 million revenue in 2020 together with a patent portfolio of nearly 200 patents in about 80 patent families.
- Acquired by PolyTech in 2020

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Photos: fos4X
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