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Radical Technological Innovation: Case Study of the Friction Disc by SKF

by Florian Wohlfeil[1]

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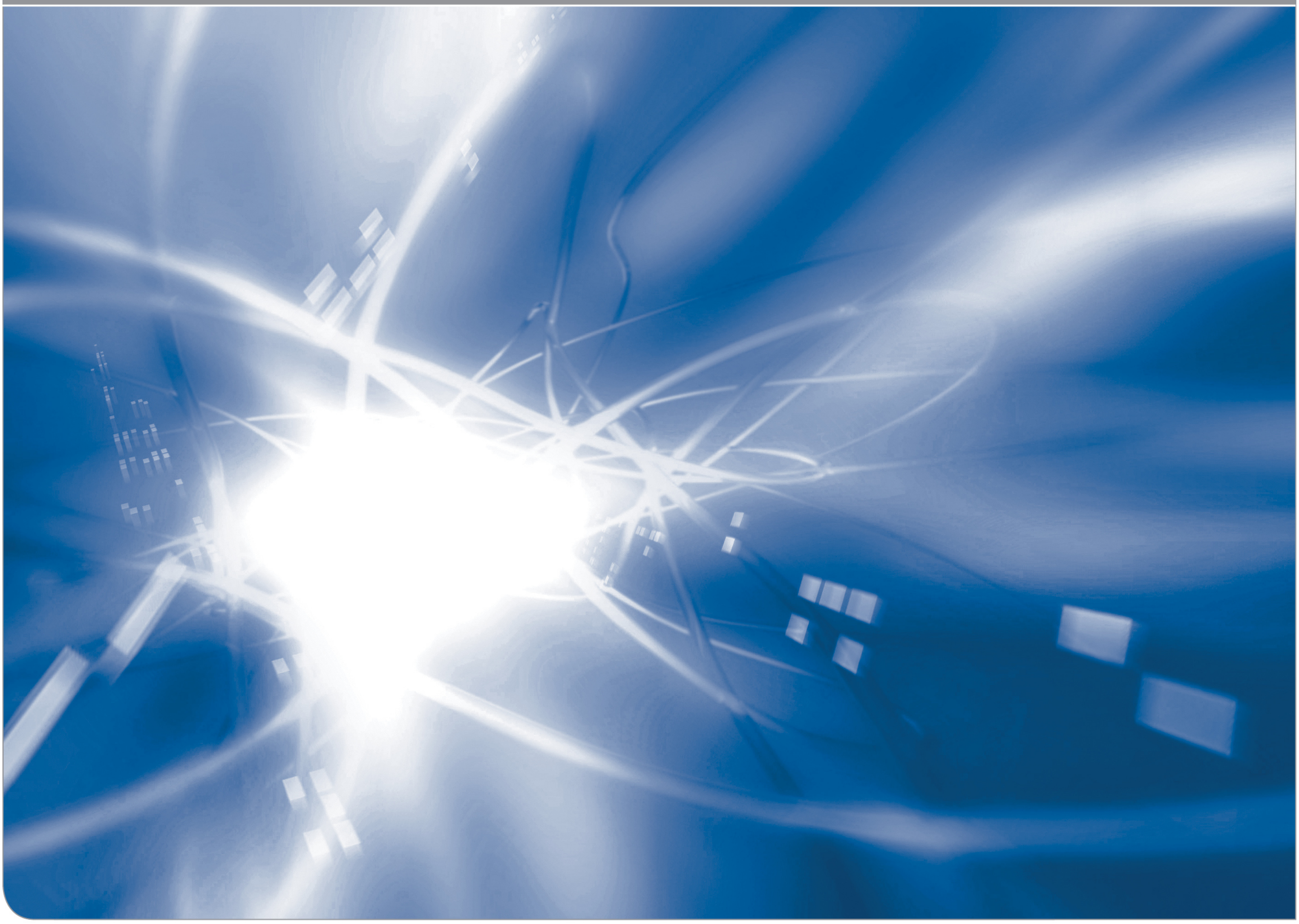

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Impressum

Karlsruher Institut für Technologie (KIT)
www.kit.edu

2015

ISSN: 2194-1629

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Abstract

To stay competitive on a long-term basis, it is essential for technology driven companies to create and employ radical technological innovations. This is an important, complex, and difficult undertaking. To shed some light on the key factors that determine success a concrete case of radical technological innovation will be studied. SKF engineers developed an innovative coating system for highly loaded flange couplings to increase the friction coefficient between the contact surfaces. By implementing such a system, the power transmission capacity of the corresponding drive train of e.g. wind turbines could be significantly enhanced. The study focuses on the technology and the target market of the innovation, the organizational characteristics of SKF, the entrepreneurial team, the innovation process with the subsequent success being analyzed.

Table of Contents

Technology

The requirements for power transmission within the industrial drive branch increased over the recent years. To satisfy this demand SKF engineers developed an innovative coating system for highly loaded flange couplings to increase the friction coefficient between the contact surfaces. Consequently, the frictional locking and correspondingly the power transmission could be significantly enhanced. In general, there are two influencing variables of the frictional locking: the friction coefficient and the normal force ($F_R = \mu \cdot F_N$). SKF addressed the frictional coefficient with the Friction Disc (Gläntz, 2011).

A defined sum of sector shaped elements each with three holes forms a ring-type device (cf. Figure 1). This device with an optimized friction coefficient is inserted in a bend-proof flange coupling and fastened with screws. The two flanges match up with the ring-type device. They are designed with through holes and threaded blind holes for mounting (Gläntz, 2011; Baumann, 2009, p. 35).

Figure 1: Friction Disc (Gläntz, 2011)

The contact surfaces of the two flanges are required to have a certain degree of Ra-roughness. The sector shaped elements of the ring-type device are coated with a galvanic hard-dispersion layer (cf. Figure 2) on both sides (Baumann, 2009, p. 36; Horling *et al.*, 2009, pp. 2–3).

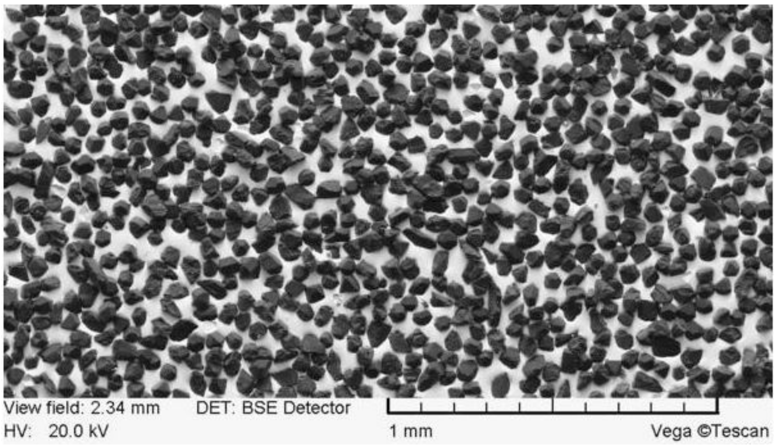

Figure 2: SEM picture of the coating with integrated hard particles (Gläntz, 2011)

This hard-dispersion layer is galvanically applied in two layers on the surface of the ring-type device which serves as a coating substrate (cf. Figure 3). The first nickel layer has a wetting purpose (Baumann, 2009, p. 36). Thus, the second nickel layer has a much better basis for adhesion. This coating layer contains hard particles. The thickness of the two layers corresponds to approximately half of the average grain size of the particles. As the coating layer consists of galvanically applied nickel, the coating substrate is simultaneously protected against corrosion. The adhesive force of the nickel causes a solid embedding of the hard particles within the layer (Baumann, 2009, pp. 36–37; Horling *et al.*, 2009, pp. 2–3).

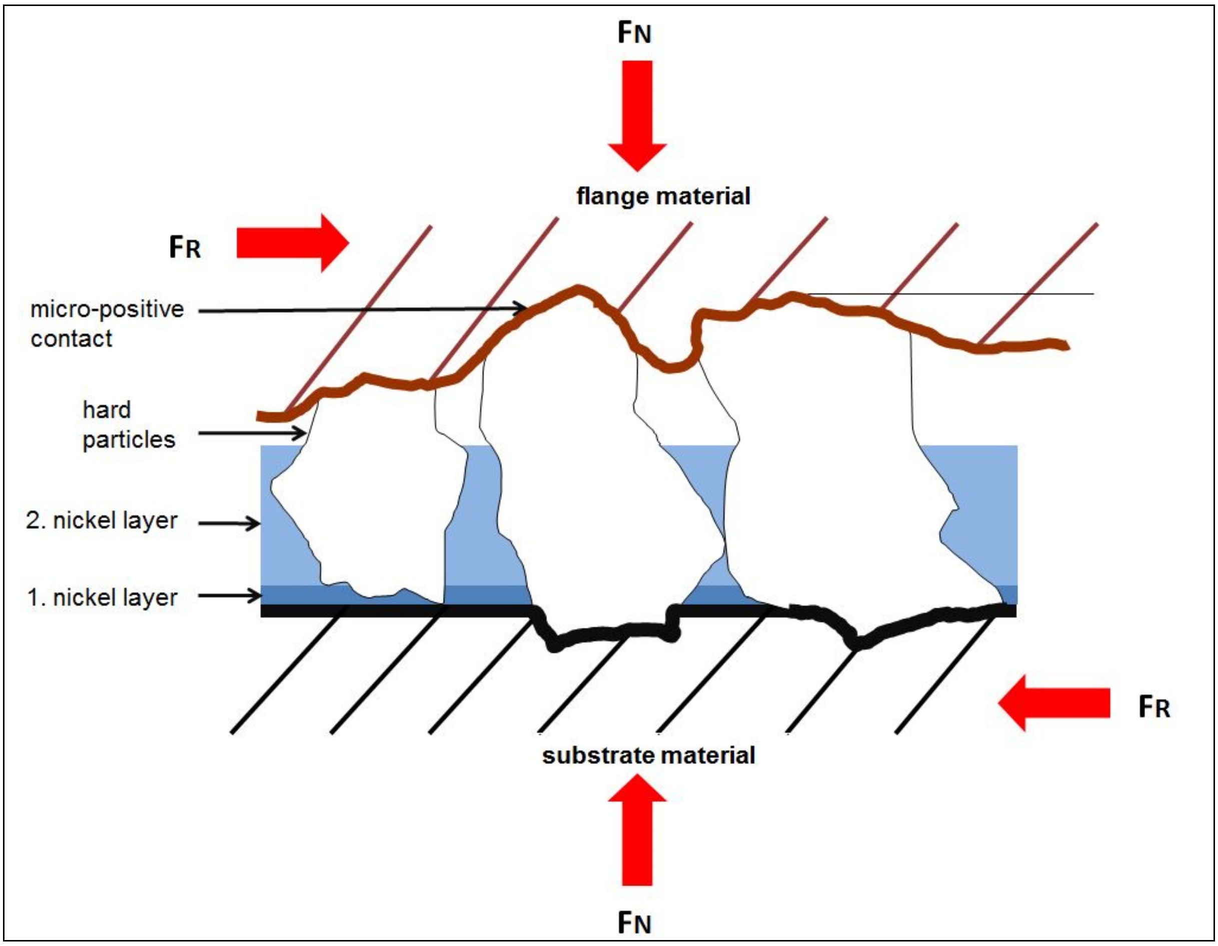

Figure 3: Schematic diagram of the coating (Baumann, 2009, p. 37)

It is advantageous to use a substrate material that is harder or at least equally hard or has a higher tensile strength than the material of the flanges. Thus, the particles rising up out of the coating layer would primary press into the flanges and not into the substrate material. As the flange material of spheroidal-graphite cast iron has been defined by SKF's customer, SKF took a high-strength cold forming steel as substrate material (Baumann, 2009, p. 38, 2009, p. 43; Horling *et al*., 2009, pp. 2–3).

If the coated ring-type device gets screw-fastened with the flange coupling, the hard particles will be pressed into the flange material. Thus, a mechanical interlock – a micro-positive contact – will be attained between the device and the two shaft ends (Baumann, 2009, p. 38).

Based on a conservative approach, the friction coefficient μ of the Friction Disc is 0.65. Further tests revealed even higher results showing that the SKF solution offers a high level of performance reserves and security against slipping. Furthermore, the long-time behavior and variation of the friction coefficient after several assembly and disassembly procedures was tested. It was found that the friction coefficient differs just slightly and the first prototypes withstood the practical test of two years without notable damages (Gläntz, 2011).

Table 1: Technical Data of the Friction Disc (Baumann, 2009)

Friction Coefficient	μ ≥ 0.65
Contact Pressure	80 – 150 MPa
Coating Layer Material	Nickel
Substrate Material	Cold Forming Steel
Flange/Shaft Material	Spheroidal-Graphite Cast Iron

Feasibility and Maturity

The Friction Disc is a mature product that was introduced to the market in 2009. By 2014, every wind turbine of SKF's customer in the 3.3-MW-class was equipped with the discs and a middling three-digit number of pieces have been sold. This is the result of a cooperative and intense development of SKF and its customer. The performance of the Friction Disc meets the customer requirements in all aspects and this was proven by field tests. By 2014, the Friction Disc was a certified product and the friction coefficient of 0.65 has been certified by an accredited certification organization (SKF, 2014a, 2014c).

Technological Alternatives

The Friction Disc is meant to increase the friction coefficient and thereby the power transmission capacity of the flange coupling. Investigations show there is just one other alternative in the market that is based on the same technological principle – 3M Friction Shims. Of course another possibility is to just use the blank flange coupling instead on any intermediate objects. By 2014, this became the de facto standard in the market. Another credible technological alternative is the application of shrink discs. In this technology comparison the focus will be on hydraulically adjustable shrink discs, especially as the ease of assembly has great advantages for the current application. Furthermore, some original equipment manufacturers utilize friction increasing pastes or coatings on the face side of the flanges. However, this is a complex process and is not considered to be a robust method. Consequently, the latter alternative will not be taken into account within the paper at hand (Gläntz, 2011; Baumann, 2009, p. 1).

3M Friction Shim

The functional principle of 3M Friction Shims is very comparable to the Friction Disc technology of SKF. It is based on diamond particles embedded in a Nickel matrix. The coating is applied on thin steel foils. 3M serves three shims versions. For the application of flange couplings, the largest foil version is more suited. Thereby, the Nickel matrix has a thickness of 14 to 22 µm and the particles have a mean size of 35 µm. The complete thickness of the shim corresponds to 0.185 mm. At mounting, the diamonds are pressed into the counter surface and micro-positive contact is generated. According to 3M, static friction coefficients µ of up to 0.6 are possible. This creates the possibility for lightweight compact designs while the potential load and peak torque in bolt connections could be increased (3M, 2015b, p. 2, 2015c, 2015a).

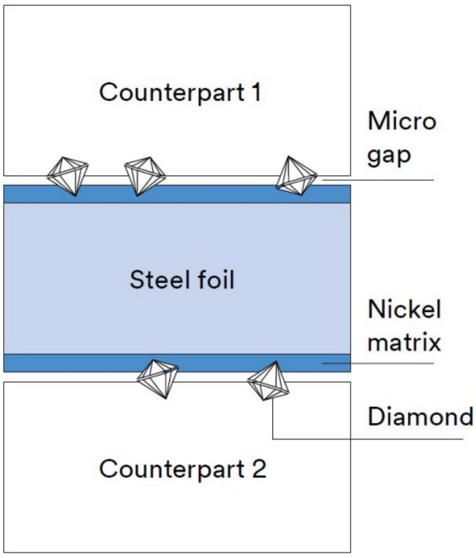

Figure 4: 3M Friction Shim (3M, 2015a, p. 1)

Blank Flange Coupling

Flange couplings, in particular rigid non-shiftable types, are used to transmit the operating torque in industrial drive trains by frictional connections. A defined amount of screw connections generate a preloading and thereby a strong joint between the two flanges that ultimately transmits the power. Most common is the material combination of steel-steel or steel-cast iron. In case of blank flange couplings, according to technical literature, the friction coefficient for these material combinations range from $\mu = 0.12$ to 0.2 (Gläntz, 2011; Baumann, 2009, p. 1).

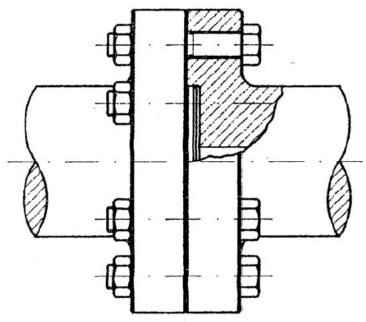

Figure 5: Blank Flange Coupling (Kurzawa, 1993)

Shrink Disc

Shrink discs produce force-fit shaft-hub connections. In case of linking the rotor with the generator shaft within the drive train of a wind turbine, the shrink disc has to be integrated into the generator shaft.

Due to the tapered surfaces of the exterior components the inner diameter of the shrink disc will be reduced by axial displacement. A corresponding interference fit between the shaft and the hub is generated. Thus, the shrink disc is not within the power flux as the torques and forces are transmitted at the joining surfaces of the shaft and the hub by force fit (Ringfeder, 2015). The required preload will be applied hydraulically. It is possible to use a hydraulic hand pump, as only a small amount of oil is needed to generate the required pressure (Michel, 2011).

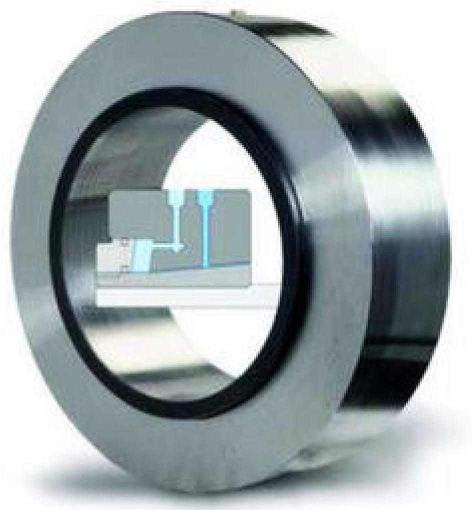

Figure 6: Shrink Disc (Michel, 2011)

Relative Advantages

To gain the relative advantages of the SKF Friction Disc compared with the alternatives, eight evaluation criteria have been established in consultation with a team member of the Friction Disc project at SKF: power transmission, robustness of solution, downsizing potential, cost saving potential, assembly/disassembly process, resistance to environmental impacts, design leeway, and price. The analysis is carried out with respect to the blank flange coupling as this is the de facto standard joint in the field.

Power Transmission

Power transmission is dependent on the strength of the joint between the shaft and the hub. The working principle of the joints of the Friction Disc, the Friction Shim and the blank flange coupling is the same as all are based on the use of flange couplings and correspondingly frictional connections. As mentioned before, the two influencing variables of frictional locking are the friction coefficient and the normal force. The friction coefficient of the Friction Disc equates to a value of at least μ = 0.65. In comparison, 3M Friction Shims may have a maximum static friction coefficient of 0.6 and the friction coefficient of blank flange couplings ranges from μ = 0.12 to 0.2. If a comparable normal force is assumed for these three options, the Friction Disc has the highest value, followed by Friction Shims and the blank flange couplings. The shrink disc on the other hand, is generating an interference fit, which results in the transmission of a very high level of torque (Gläntz, 2011; 3M, 2015b, p. 2; Michel, 2011).

Robustness of Solution

Especially in the case of highly loaded drive trains of wind turbines the robustness and reliability of the applied solution is vital. Based on a conservative approach, the friction coefficient of the Friction Disc equates to μ = 0.65 with this value having been certified by an accredited certification organization. Further tests showed even higher results with the conclusion being that the SKF solution offers a high level of performance reserves and security against slipping. Furthermore, the long-term behavior and variation of the friction coefficient after several assembly and disassembly procedures was tested in a demanding application of wind turbines. It was found that the friction coefficient just differs slightly and the first prototypes withstood the practical test of two years without notable damages (Gläntz, 2011). 3M Friction Shims have been applied, tested, and certified by an accredited certification organization within the automotive industry. However, this solution has not been approved yet for the more demanding application of wind turbines that is characterized by a completely different load distribution (3M, 2015b, p. 2). Blank flange couplings are the conventional standard approach and are thus reliable. But in case of increasing the power range of the turbine, the main dimensions and particularly the screw connections have to be redesigned. This is partly due to higher specific loads, which may lead to a critical level on individual components (Gläntz, 2011). However, shrink discs provide a robust solution in the given power range and do not require any maintenance (Ringfeder, 2015).

Downsizing Potential

As the power class of wind turbines has increased massively over recent years, keeping the weight of individual items within the nacelle under control has become an important issue. Higher power transmission requirements lead to the need for more bolted joints and thus, bigger dimensions of the flange coupling. The SKF Friction Disc could help to solve this challenge. For the wind turbine of SKF's customer, it was possible to significantly reduce the number of bolted joints at the same power transmission capacity. Thus, the main dimensions of the flange, the gearbox housing, and the neighboring bearings could be reduced resulting in a significant weight reduction (Gläntz, 2011). Equally, the usage of 3M Friction Shims enables a reduction of the component sizes and weights and hence the weight of the complete drive train. Compared to the Friction Disc, this reduction is less due to the lower power transmission capacity (3M, 2015b, p. 1). Concerning the high component weight of shrink discs, there is no overall weight reduction potential. Instead, the overall drive train becomes heavier when using shrink discs (SKF, 2014c).

Cost Saving Potential

Due to the reduction in dimensions resulting from the Friction Disc and the Friction Shim, a considerable amount of costs for the individual components could be saved. Furthermore, shrink discs and the Friction Disc have lower requirements regarding the surface tolerances.

Thus, certain cost savings during the production process of the shaft and the flanges could be realized (Ringfeder, 2015; SKF, 2014a; 3M, 2015b, p. 1).

Assembly/Disassembly Process

One key customer requirement is the multiple usage, at least five to six times, of the utilized components. Consequently both, the assembly and disassembly processes are important factors for the re-usability of a potential solution. When using conventional flange couplings, the assembly process requires specialized tools to generate the required preload. In case of disassembly, specialized tools are also needed, as the joints have often experienced severe wear or even massive seizure. The Friction Disc allows comparatively easy, cost effective assembly and disassembly procedures. For hydraulic shrink discs both processes are even easier as the use of hydraulic hand pumps allows straight forward easy handling. Friction Shims on the other hand are not as simple to handle. In particular, fixing during assembly is more difficult. In general, multiple usage is possible, but sometimes the foils stick at the flange surfaces and are not easy removable (Gläntz, 2011; SKF, 2014c; Ringfeder, 2015; SKF, 2014a; 3M, 2015b, p. 1).

Resistance to Environmental Impacts

The joint fit has to resist environmental effects like moisture, contamination or salty air. Correspondingly, blank flange couplings face some problems as these influences could ultimately lead to seizure. Friction Discs and Friction Shims are comparatively insensitive against contamination and even friction-reducing media. In case of shrink discs, the fitting surfaces have to be cleaned before mounting. However, at run time no dust, contamination or moisture should reach the functional surfaces (Gläntz, 2011; Ringfeder, 2015; 3M, 2015b, p. 1).

Design Leeway

The required safety factors for wind turbines with given external forces and torques give just little leeway for designers to create innovative solutions. Thus, the blank flange coupling concept and equally the shrink disc concept dictate the corresponding embodiment design. In contrast, the higher power transmission capacity of the Friction Disc and the Friction Shim allow new opportunities to be realized within the design process. As the Friction Disc is able to transmit higher forces and torques than the Friction Shim, the Friction Disc reached the highest level of the four alternatives regarding design leeway (Gläntz, 2011; SKF, 2014c; 3M, 2015b, p. 1).

Price

With regard to the price level, the whole technical system has to be considered in the evaluation. Therefore, the price for a standard flange coupling has to be added to the prices of the individual components of Friction Shims and Friction Discs. Thus, the lowest price is generated by blank flange couplings as no additional components are required. Compared with the Friction Disc, 3M Friction Shims are cheaper. Shrink Discs exhibit the highest overall price (SKF, 2014c, 2014a; Baumann, 2009, p. 1).

Overview of the relative Advantages of the Friction Disc

To gain a better overview of the relative advantages of the Friction Disc, the different technological alternatives have been evaluated with respect to the degree to which they meet the eight evaluation criteria on a ten point scale (cf. Figure 7).

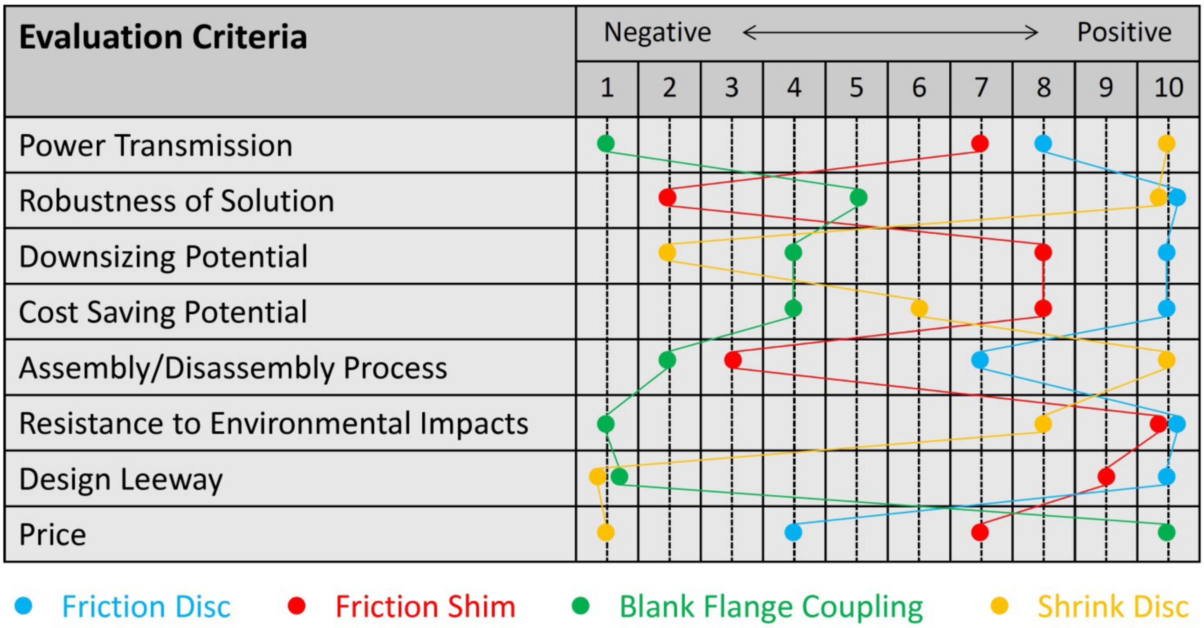

Figure 7: Overview of Relative Advantages of the Friction Disc (Wohlfeil, 2015)

The unique advantage of the Friction Disc compared to its alternatives is the great downsizing potential for the wind turbine that ultimately can lead to a huge cost saving. The Friction Disc offers much leeway for the designer and opens up great opportunities to create new and innovative solutions. However, the corresponding price of the Friction Disc has to be considered.

Regarding the global trend of massively increasing power classes for wind turbines, particularly offshore, the Friction Disc offers a great opportunity for keeping the overall weight within the nacelle to a minimum. In general, it is essential for the ultimate success of a radical technological innovation to clearly address the key requirements and needs of the target market. Therefore, the specific target market of the Friction Disc will be assessed in the following chapter.

Target Market

The field of application for the Friction Disc is heavy mechanical engineering. Initially, the wind industry was addressed as first target market. In 2006, the development was started for Senvion's 3.3 megawatt onshore turbine. SKF and its customer established a development contract and assured mutual exclusivity within the wind industry. Thus, SKF became single supplier (SKF, 2014c; Senvion, 2014, p. 1; Law, 2012, p. 5; SKF, 2014a).

Senvion is a global manufacturer of onshore and offshore wind turbines. Its product portfolio comprises wind turbines with nominal powers of 2.0 to 6.15 megawatts. The company's core expertise lies in the production and installation of wind turbines. SKF's customer develops, manufactures, sells and erects. With more than 3,700 employees it has installed more than 6,100 wind turbines globally. By 2014, the company has in Germany a market share of 9% in terms of installed wind turbines (Senvion, 2015a, p. 10, 2015b; Fraunhofer IWES, 2015, p. 40).

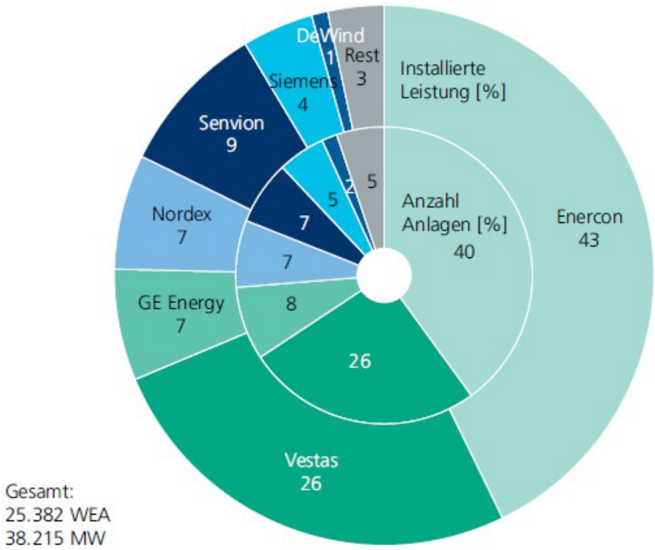

Figure 8: Market share regarding running onshore wind turbines in Germany by 2014 (Fraunhofer IWES, 2015, p. 40)

Industry Context

The industry of the Friction Disc technology has been mainly positive. Wind energy has been clearly on the rise. During 2014 more than 51 Gigawatt's installed capacity have created an unprecedented increase. In Germany, the share of electricity generated from wind energy made up nearly 10% of the gross electricity consumption. With 28%, overall the renewable energies delivered the highest share of the gross electricity consumption compared to any other energy source in 2014. Politically, these are important steps for the intended energy turnaround (Fraunhofer IWES, 2015, p. 5). Consequently, this resulted in a clear trend towards larger power plants and massively increased power ranges. The challenge of minimizing the individual component weights within the nacelle presents a huge opportunity for the SKF Friction Disc (Gläntz, 2011; SKF, 2014a).

However, there were also factors that hamper the acceptance of the Friction Disc in the industry. By 2008 and 2009, the global economic crisis reduced the confidence of the team and hence the speed of implementation (SKF, 2014c).

Competitive Situation

SKF is single supplier of the Friction Disc. Consequently, no other competitor is allowed to deliver a similar product for this specific application (Law, 2012, p. 5; SKF, 2014c). Thus, SKF has just to compete with its own technological alternatives which have been introduced and compared previously. However, SKF needs to be aware of emerging and established market rivals that potentially could offer alternatives to their innovation (Schilling, 1998, p. 277).

Market Barriers

A general prerequisite to entering the wind energy market is the certification process. Any technical product has to be certified by an accredited certification organization before being used in a wind turbine and this also applied to the Friction Disc. Together with the TU Chemnitz, SKF applied and tested the friction coating. Ultimately, the team managed to achieve the required certification and thereby the permission to enter the market (SKF, 2014c, 2014a). Further market barriers were the requirements of SKF's customer, but SKF was able to satisfy the customer needs (SKF, 2014a).

Opportunity

Due to the mutual exclusivity contract of SKF and its customer, the success of the Friction Disc was clearly linked to the success of SKF's customer. Their 3.3-MW wind turbine was characterized by competitive energy efficiency, weight distribution advantages, reliability, and size. In profitability assessments of potential investors the turbine was well ranked. This ultimately led and still leads to good sales figures for SKF's customer (SKF, 2014c, 2014a).

As mentioned previously, the wind energy industry is clearly on the rise. In the last few years, there is a clear trend to more powerful wind turbines. By 2014, the 3 to 4-MW class turbine size had considerably expanded and nearly reached the same installation rate as 2 to 3-MW class turbines. The latter category dominates the market (Fraunhofer IWES, 2015, p. 36, 2015, p. 38). By then, the achieved volumes supported the commercialization of the Friction Disc and pushed its success. However, as this trend further evolves the 3.3-MW turbine may be outdated in the near future (SKF, 2014c).

Beside the wind industry, there are additional opportunities for the Friction Disc particularly in applications where the requirement is to transmit high torques by rigid couplings, e.g. in industries like rolling mills, turbo-machines, marine and marine renewables, or power plant constructions (SKF, 2014c, 2014a).

Organization

The Friction Disc has been developed within SKF Germany. The SKF Group is a leading global supplier of products, solutions, seals, mechatronics, services associated with roller bearings, and lubrication systems (SKF, 2015, p. 1). By 2014, the company had more than 48,500 employees and generated net sales of 7.6 billion euro (SKF, 2015). In 2006, the project was initiated within the innovation department Flexi Force and was later transferred to the project management department New Business. Following on from this, it was carried out by a cross-functional/divisional team (SKF, 2014c).

Strategy

SKF's vision in the recent years is "[t]o equip the world with SKF knowledge. To take all the knowledge gained over more than 100 years to develop and deliver products, solutions and services which enable customers to be more successful and profitable in their business" (SKF, 2015, p. 29). Therefore, the company established the SKF Care strategy model with four dimensions: Business Care, Environmental Care, Employee Care and Community Care. These four categories are the guiding principles of SKF in terms of how they operate and do business (SKF, 2015, p. 11).

For the Friction Disc project, Business Care and Environmental Care were especially relevant. Within the project a dedicated customer focus when delivering sustainable value was realized (→ Business Care). Furthermore, SKF wanted to provide customers with innovative technologies, products, and services that reduced environmental impact (→ Environmental Care). Both dimensions were perfectly addressed by the Friction Disc. The product offers a great downsizing potential for the overall wind turbine drive train that ultimately leads to huge cost savings and reduces the environmental impact when serving a renewable energy device (SKF, 2015, p. 11).

The objectives of Flexi Force and New Business were complemented within the Friction Disc project. Thus, the Friction Disc project was actually in line with the SKF group goals as well as with the Flexi Force and New Business department goals (SKF, 2014c, 2014a).

Structure and Processes

Since the project started in 2006, there have been two reorganizations of SKF's structure. As of 1st January 2015, SKF merged its two industrial business areas, Strategic Industries and Regional Sales and Service to be more efficient in addressing industrial customer needs. Since then, SKF operates through three business areas: Industrial Market, Automotive Market, and Specialty Business. Although the Friction Disc project was included within the industrial market, finding a suitable product home was a challenge for the team (SKF, 2015, p. 35). The standard portfolio of SKF contains rolling bearings and units, seals, mechatronics, services, and lubrication systems. As the Friction Disc could not be allocated to one of these categories, the former tooling and prototyping machine shop was chosen to become product home (SKF, 2014c, 2014a).

The product innovation process of the Friction Disc was realized based on the SKF internal New Customer Offer (NCO) process. This development process is mainly based on the Stage-Gate process according to Cooper and is meant to develop and launch a product for one specific customer. This process worked well and allowed enough flexibility for the team. On the other hand, the transfer into series production turned out to be more difficult. The Friction Disc was meant to be a niche product. However, the SKF is well positioned to handle high volumes, but the handling of brand-new innovations is a different challenge due to initially low volumes (SKF, 2014c, 2014a).

Company Culture

The overall company culture within SKF was mainly shaped by a low level of failure acceptance and little appreciation for innovative initiatives. Accordingly, this situation presented real challenges for the Friction Disc project. In the beginning, the team had to face derision and needed to defend their project against tough internal criticism. This situation lasted until the first testing of the Friction Disc showed very good results (SKF, 2014c, 2014a).

Funding and Commitment

Initially, it was not easy to persuade project sponsors and stakeholders to support the Friction Disc project and invest in validation testing and analysis. It was important for the success of the project that the first test results turned out to be positive. Following this, senior management supported the project and sanctioned any project expenses without any major discussions having to take place. Due to the organizational structure of the SKF, project budgeting was not clear from the beginning. Especially for urgent cash requirements this situation was unfavorable. Thus, it was essential to maintain the high level of upper management commitment so that the team could overcome these hurdles. The support from upper management was not only for the funding aspect important, but also when it came to production priorities. This helped considerably when short-term availability of the manufacturing facilities was required for prototype production (SKF, 2014c, 2014a).

Entrepreneurial Team

During the innovation process, the core entrepreneurial team within SKF consisted of three people: an innovation manager, a project manager, and the key-account manager for SKF's customer. The people fulfilling these roles had a high level of experience and professional competence. The innovation manager had very specific knowledge regarding coatings that he gained throughout his career as an engineer in the production line. The project manager was very familiar with the technical aspects and requirements of power transmission applications due to his previous job as an application engineer, whilst the key-account manager provided insights into customer needs. Having these attributes meant that, the team saved a lot of time and costs during the innovation process of the Friction Disc (SKF, 2014a, 2014c).

Despite several setbacks during the project caused by internal and external skepticism and contradictions, the core team members showed great perseverance. They were highly motivated to bring the project to a successful conclusion and were convinced of its potential. Furthermore, they trusted each other and worked as a team (SKF, 2014a).

After the development contract with the customer was signed, the core team was joined by further representatives from production, design, and quality management. Having this broad and profound team network in place ensured an efficient innovation process. Due to contrary objectives of daily and innovation business, challenges emerged, e.g. in case of prototype versus high volume production on the machines of one manufacturing channel (SKF, 2014a, 2014c).

Innovation Process

Opportunity Identification

SKF's key account manager had to constantly have his finger on the pulse when it came to the customer and had to monitor the market closely. Therefore, in 2006 he realized that SKF's customer faced technical challenges during the conception phase of the 3.3-MW wind turbine, the largest onshore wind turbine at that point in time. A major challenge was to design the turbine in such a way that it was still transportable on the streets. Thus, the customer needed a solution that was compact, reliable, and feasible (Baumann, 2009, p. 1; SKF, 2014a, 2014c, 2014b).

Based on discussions with the customer and joint brainstorming sessions, the core project team worked on a possible solution. From this an idea emerged that a friction increasing intermediate disc for flange couplings could enhance the transmissible torque capacity. Until that point in time, the intended friction increasing coating procedure had just been applied for relatively small surfaces like drills and tools. Thus, the team followed an iterative process to align the application requirements to the product (SKF, 2014b, 2014a). In general, the timing was right as SKF's customer was just developing its new 3.3-MW wind turbine and needed an adequate technical solution (SKF, 2014a).

Product Development

After idea generation, the concept of the Friction Disc had been verified by conduction of several preliminary friction tests. The idea had been checked to determine if it had the potential to be utilized for bigger surfaces as well. Afterwards, during the validation phase, several tests had been conducted to optimize the material composition and the particle density of the coating. After prototype testing, the Friction Disc had reached application maturity and could be introduced to the market (SKF, 2014c, 2014a).

Lead User Integration

SKF's customer was similarly lead user of this product. According to von Hippel, lead users face needs that will be general in a marketplace, but face them earlier than those in the mainstream market. Furthermore, they benefit significantly by obtaining a solution to those needs (Hippel, 1986, p. 796). This was the case with SKF's customer, when the company developed one of the biggest onshore wind turbines at that point in time and needed a solution to transmit the high torques. SKF and its customer initially signed a non-disclosure agreement and subsequently concluded a development contract as a basis for their cooperation. Thus, SKF's customer was closely integrated in the product development and was updated frequently on a regular basis. A further benefit was that SKF had a reference case in the market with the Friction Disc was proving itself in a real life running environment. After two years in use, the first Friction Disc prototypes were dismantled and showed almost no traces of wear (SKF, 2014c, 2014a).

Development Partnerships

SKF involved two further strategic partners in the development process of the Friction Disc. One of these partners was the company that took responsibility for the coating process. SKF deliberately selected this company because of their previous experience in coating parts with comparable dimensions for industrial use. With optimized parameters high process reliability could be realized (SKF, 2014c, 2014a). Furthermore, SKF chose the technical university of Chemnitz as strategic partner for testing the ultimate friction coefficient of the Friction Disc. Previously, SKF had contacted several scientific institutes and universities that were unable to deal with these high values of the friction coefficient. The technical university of Chemnitz had the essential equipment and could prove their expertise by their participation in several comparable industrial projects (SKF, 2014c, 2014a).

Risk and Quality Management

During the process, SKF undertook a detailed risk assessment and followed a strict quality management process. As mentioned before, the product innovation process of the Friction Disc was based on a Stage-Gate process. Consequently, the progress of the process was constantly reviewed at certain milestones by a project committee. Furthermore, SKF has high quality standards for their own production and suppliers. This quality standard is realized by detailed specifications for production and the final product. The first requirements for the Friction Disc were formulated and subsequently validated by having adequate test procedures in place. However, formulating a reliable test procedure for the Friction Disc was one of the main challenges of the product development process. Together with the technical university of Chemnitz the team ultimately managed it to reliably test the friction coefficient. Based on the validated test results, the internal production and the supplier specifications were elaborated (SKF, 2014c, 2014a).

An essential part of quality management within the product innovation process is risk management. Potential risks from technical as well as from a market perspective were constantly analyzed in short intervals by the team. Every risk and its possible countermeasure was discussed and subsequently documented in detail (SKF, 2014a).

Platform Strategy

The basic result of the Friction Disc product development process that SKF finally achieved was an assured coating process. This process could be utilized not just for the Friction Disc, but for many other shapes of blanks. There is no geometric limit beside the fact that the parts need to be placed in the coating bath. According to the project manager of the Friction Disc project, the interest in the power transmission branch is quite high for such friction increasing coatings (SKF, 2014c).

In general, the Friction Disc is not a standard product that can be used for any application. The disc needs to be customized in close cooperation with the customer and depending on the specific requirements of the application. However, there is further potential for the Friction Disc within the power transmission industry (SKF, 2014b; Gläntz, 2011).

Intellectual Property

SKF's customer is patent owner and SKF received the license to produce the Friction Disc for their own purposes and in any other but not for applications within the wind industry. SKF subsequently protected the coating process, its associated measurement method, and the technical configuration of the Friction Disc (SKF, 2014c, 2014a).

Commercialization

Because of the mutual exclusivity regulated in the contractual agreement, commercialization of the Friction Disc in the wind industry is limited to this customer. In other industries, SKF is free to commercialize (SKF, 2014c, 2014a).

Value Proposition and Business Model

From customer perspective, the central value proposition of the Friction Disc is the possibility to downsize the main dimensions of the powertrain, its associated potential for weight reduction, and the simplified assembly process. Since 2009, the Friction Disc is a mature and certified product. Correspondingly, the customer can rely on the agreed performance (SKF, 2014c, 2014a).

Besides the actual Friction Disc, SKF consults extensively its customers regarding application engineering. In cooperation with the customer, each disc needs to be customized with respect to a given application. Based on this, the specific Friction Disc is designed. In general, the SKF value creation contains product development, application engineering, parts of the manufacturing process, and taking the overall responsibility for the final product. For any further value creating step, SKF involves partners (SKF, 2014c, 2014a).

Commercialization Partnerships

According to the structure of the company, SKF is dependent on suppliers. Within the Friction Disc project, SKF strategically cooperates with a supplier that produces the disc blanks and with another company that takes responsibility for the coating process. SKF and its partners developed an elaborate process for product tracking and documentation that was subsequently realized by them. The Friction Disc is sold directly to SKF's customers. Furthermore, customer service and logistics are SKF's responsibility and the company has full responsibility for distribution (SKF, 2014c).

Timing

The timing of market introduction was exactly right as SKF managed to synchronize the development process of the Friction Disc with that of the wind turbine powertrain of SKF's customer. While SKF's customer developed its wind turbine, SKF simultaneously worked on the Friction Disc. Ultimately, the Friction Disc was available on time as a mature and certified product when SKF's customer started series production of their 3.3-MW wind turbine. Regarding time to market, this represented a perfect fit for SKF (SKF, 2014c).

Marketing

As mentioned before, the former tooling and prototyping machine shop was chosen to be the product home. The product home is responsible for marketing according to SKF's strategy. They are required to produce promotional material and provide this to the sales unit for communication to their customers (SKF, 2014c).

A few trade fair exhibitions and some supporting promotional material attracted some customer attention. However, to increase customer awareness for the Friction Disc and its benefits, a greater focus on marketing should have taken place. In general, this is an essential part of the diffusion process of technical products. This is especially true when it comes to radical technological innovations. In these circumstances a clear explanation of the technical benefits is required if they are not intuitively obvious. Therefore, adequate promotional material and marketing helps to highlight the advantages of the solution (SKF, 2014c, 2014b).

Innovation Success

Performance

Product Performance

The product performance of the Friction Disc is very high and meets the exact requirements of the customer. Several field tests have proven its performance and the friction coefficient which is the main feature of the Friction Disc, has been certified by an accredited certification organization. Even after several years of use, the Friction Disc exhibits no loss of quality and by 2014 SKF had not a single return from the customer (SKF, 2014c).

Sales Performance

Today, every wind turbine of SKF’s customer in the 3.3-MW-class is equipped with the Friction Disc. Since its market introduction in 2009, the yearly sales figures have been constantly rising and by 2014, a medium three-digit sales number has been reached. The Friction Disc became a particularly profitable and sustainable business for SKF and overall it has provided a very good return on investment (SKF, 2014a, 2014c).

However, notwithstanding the great potential of the Friction Disc for further applications in other industries, there are just a few alternative applications that have been equipped with the Friction Disc. By now, the wind industry is by far the largest application field. As the Friction Disc is not a standard product and can only be applied to the specific customer application, resources are needed for reliable application engineering and design adaption. According to SKF’s strategy, this is the task and responsibility of the organizational product home (SKF, 2014c, 2014b).

Efficiency

The overall efficiency of the innovation process was considered quite high regarding both dimensions – costs and duration. The period between the first customer contact and series production of the Friction Disc amounted to a very short duration of 2.5 years. This is due to the fact that SKF and its customer synchronized their development processes till the point when series production of the 3.3-MW wind turbine began. Furthermore, the team took particular care to keep the development costs down. The tests of the Friction Disc at the technical university of Chemnitz have been relatively low (SKF, 2014a, 2014c).

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KIT Scientific Working Papers
ISSN 2194-1629
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