PROJEKT NO. 346-011

OPERATION OPTIMISATION WITH CERAMIC BALL BEARINGS

APPLICATION OF ENERGY-EFFICIENT BEARING SOLUTIONS IN THE INDUSTRY

ELFORSK
– RESEARCH & DEVELOPMENT IN ENERGY EFFICIENCY

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CERAMICSPEED BALL BEARINGS: FROM CYCLING TO INDUSTRY

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Back in 1998, when CeramicSpeed's founder and CEO Jacob Csizmadia became the first athlete to break the world record in 24-hours in-line skating, riding more than 500 km, the event marked the unplanned beginning of CeramicSpeed, which became reality six years later. The secret behind Jacob's world record was the use of ceramic bearings in his skates, an optimisation that has ever since been widely utilised among elite cyclists. CeramicSpeed sponsors today several of the world's best cycling teams and sells its ceramic bearings in more than 40 countries.

Nonetheless, the ceramic bearings are an advantage for more than just the in-line skating athletes and elite cyclists. The unique properties of ceramic bearings in terms of strength, lower friction and long lifetime, deliver benefits in all forms of rotating industrial equipment, and it is here that the great economic gains are most visible.

Even if the ceramic bearings are more expensive to purchase than traditional steel bearings, the price premium is earned back home quickly, because the CeramicSpeed bearings have 4-8 times longer bearing service life and can reduce the energy losses in the bearings by up to 70 %. Having to change the bearings in the production equipment is a difficult and highly expensive process, and this is because the company, not only it has to pay wages for the mechanics hired to carry out the task, but it also has to deal with an entire production utility halted. The CeramicSpeed bearings are thus a guarantee for higher efficiency and a more stable production.

After the huge success amongst the best cycling teams, CeramicSpeed has turned its attention on the large optimisation potential in the industry.

HIGH OPTIMISATION POTENTIAL WITH CERAMIC BEARINGS

Approx. 60 % of the electrical energy used by businesses and their buildings in Denmark is converted via electric motors. The energy losses calculated from these are estimated at 65 GWh per year. The results of the ELFORSK project 346-011 on the Application of energy-efficient bearing solutions in the industry show that for the electric motors only, there is a theoretical saving potential of 35 GWh a year, only by replacing steel bearings with ceramic bearings, which have up to 70 % lower bearing losses. In addition to this, are also taken into consideration the savings gained on bearing losses under transmission (belt and gear) and load components. The project team mentions that a cautious estimate of the energy-saving potential is more than 50 GWh a year.

The project has also conducted lifetime testing, amongst others, on the CeramicSpeed's own equipment EELPRAA.

The investment in ceramic bearings is so significant that it should primarily be implemented in the equipment, which has the largest bearing losses. The project team has monitored the energy losses in the industry and identified the motor losses within mixed motor operation and ventilation, as the most interesting applications. There are also large transmission losses within mixed motor operation, in particular, within machining equipment and within the loaded components of ventilation, compressed air, pumping and cooling. See the overview in table 1.

The project team has estimated the yearly Danish turnover by the procurement of bearings in industry and buildings up to a billion Danish Kroner. The achieved electrical savings alone provide a payback between 3 and 35 years, depending on the motor size, load and operating time. However, within energy-efficient equipment with variable speed drive and in the more congested operating environments, the longer bearing service life means that there is a significant economic advantage by switching to ceramic ball bearings.

Table 1 provides an overview of the bearing losses in the system components, motor, transmission, and load, distributed on use and system size.

	MOTOR			TRANSMISSION			LOAD		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Ventilation									
Pumping									
Compressed air									
Cooling									
Hydraulics									
Other motor operation									

CERAMIC BEARINGS CREATE VALUE IN ALL TYPES OF ROTATING EQUIPMENT

In the project 346-011, the promising results of the 2013 ELFORSK award-winning project on the electricity-saving ball bearings are converted into all common types of rotating equipment, e.g. fans, compressors, presses, crushers, grinding machines, and others. A number of tests have been conducted, which have proven the effects of ceramic bearings on electricity consumption and maintenance costs. A simple and user-friendly calculation tool has been developed to quantify the electricity savings by changing to ceramic bearings and, which industry maintenance workers, equipment suppliers and energy company's advisors amongst others can use.

By replacing the conventional steel ball bearings with CeramicSpeed bearings, which feature high-precision races and silicon nitride ceramic balls, the energy losses in the bearings of electric motors and other rotating equipment is reduced by up to 70 %, paving the way towards electricity savings. Additionally, benefits include a significantly longer bearing service life and lower maintenance costs. See figure 1.

The project team has calculated the electricity savings by replacing steel bearings with ceramic bearings in a variety of different motor sizes. They have also analysed the user economy by replacing existing electric motors with relatively low efficiency to more efficient electric motors with ceramic bearings.

In a subsequent analysis, the team measured the savings that end users can achieve from the ongoing costs of maintenance and bearing replacement. These non-energy benefits (NEB) are empirically greater than the electricity-savings, and within the analysis, these gains are sought quantified economically.

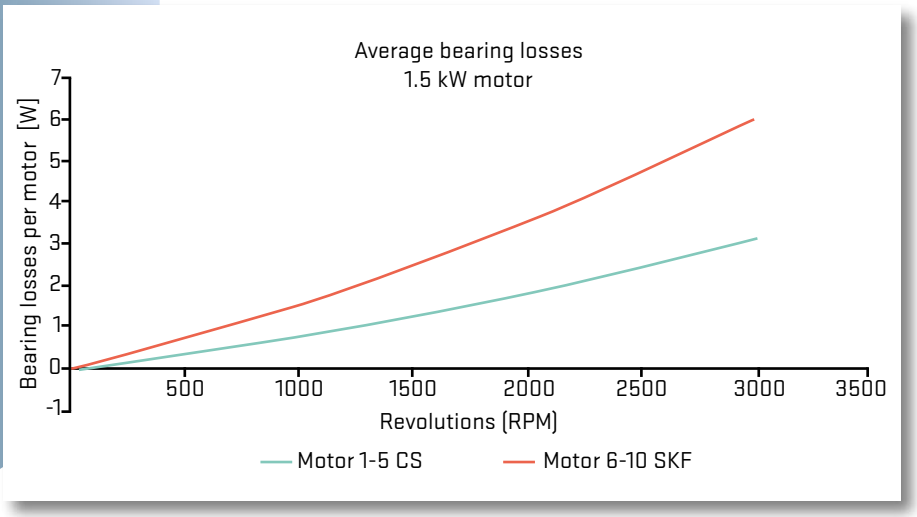


Figure 1 shows the average bearing losses for motors with steel bearings (SKF) and ceramic bearings (CeramicSpeed) respectively, at different rotational speeds (RPM).

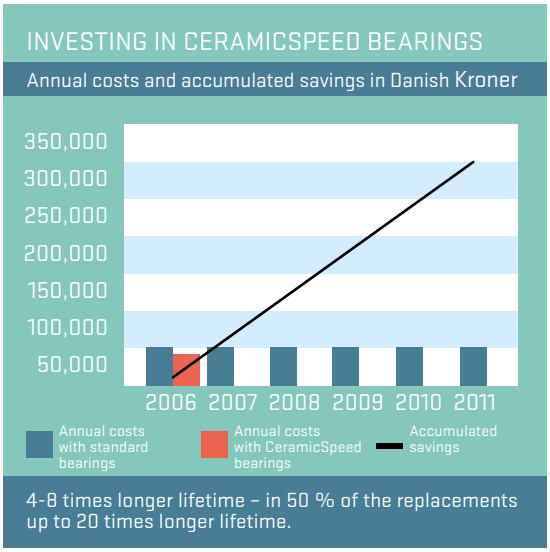


Figure 2 shows that an investment in 2006 of almost 50,000 Danish Kroner in CeramicSpeed Bearings that gave the customer Arovit accumulated savings of 300,000 Danish Kroner over the following six years .

REDUCED MAINTENANCE WITH CERAMIC BEARINGS

The project team has conducted a variety of tests on CeramicSpeed's own 6205 test rig, a newly installed service life test machine (EELPRAA). Coast down tests and consumption testing have been conducted at the Danish Institute of Technology in order to verify the estimated bearing losses.

In a customer case study from Premier Is - Mejerigaarden A/S, payback times were calculated down to 1.1 years for the largest engines. In this case, the project team also calculated the gains achieved by replacing older, inefficient motors with energy-efficient IE3 motors equipped with ceramic bearings. In this case, the payback period varied between 1.8 years for the smallest engines, to 6.5 years for the largest ones.

The non-energy related savings achieved by using ceramic bearings instead of the conventional standard bearings with steel balls are substantially greater than the value of the energy saved. In the project, the annual costs of servicing applied to the bearings in the Danish industry is calculated to be respectively 4,550 million Danish Kroner for standard bearings (750 million Danish Kroner spent on bearing purchase, 3,800 million Danish Kroner spent on the staff that undergoes the replacement). For ceramic bearings, the numbers reach only 1,950 million Danish Kroner (1,252 million Danish Kroner on bearing purchase and 700 million Danish Kroner spent on the staff employed to carry the replacement). In addition to this, the total includes the benefits from fewer production halts.

	SPEED	CURRENT EARLY LOSS	ENERGY SAVINGS		PAYBACK TIME	
Motor size			Only bearings	Bearings and motor	Only bearings	Bearings and motor
[kW]	[RPM]	[kW/år]	[kW/år]	[kW/år]	[år]	[år]
37	1500	34,558	1,693	17,981	9.2	1.8
75	1500	50,142	3,009	24,891	11.6	2.4
110	1500	68,831	4,818	29,921	7.3	4.0
160	3000	102,440	10,756	56,307	3.0	2.1
250	3000	118,367	12,429	48,541	2.6	3.6
355	3000	130,370	9,126	42,560	1.1	6.5

Table 2 shows the energy savings and payback time when upgrading from steel bearings to ceramic bearings and to electric motors with higher efficiency for different motor sizes.

AVOID BEARING CURRENT DAMAGES WHEN USING FREQUENCY CONVERTER AND CERAMIC BEARINGS

During recent years, many companies have invested in equipment, which is operated, with a frequency converter, in order to achieve a more energy-efficient operation. However, in the systems with a frequency converter, there has been registered an increasing number of bearing damage on standard bearings fitted with steel balls. These damages occur when the induced current in the system flows through the balls and results in a micro welding between the balls and bearing races. The surfaces become increasingly torn, and the lubricant becomes both contaminated and damaged by the high temperatures. Such bearing current can reduce the steel bearing's service life from several years to only a few months.

Especially under such operating conditions, the ceramic bearings are more attractive, because the balls in a ceramic bearing are not electrically conductive. Thus, bearing current damages will not occur in ceramic bearings. Companies with systems that are operated through a frequency converter, will achieve both electricity savings because of lower bearing losses, as well as a much greater economic gain, when choosing the replacement to ceramic bearings. These benefits are possible because the ceramic bearings prevent bearing current damages and lead to a more stable system operation, with no downtime and less costs caused by bearing replacement.

New research also suggests that even modest electrical currents across bearings can drive an electrolytic process, which releases hydrogen ions from the lubricant, and which is believed to accelerate hydrogen embrittlement in the steel. This usually leads to costly bearing damages, but can be eliminated by the use of non-conductive rolling elements like those found in ceramic bearings.

Damages on a steel bearing caused by bearing currents.

CERAMIC BEARINGS HAVE 4-8 TIMES LONGER SERVICE LIFE

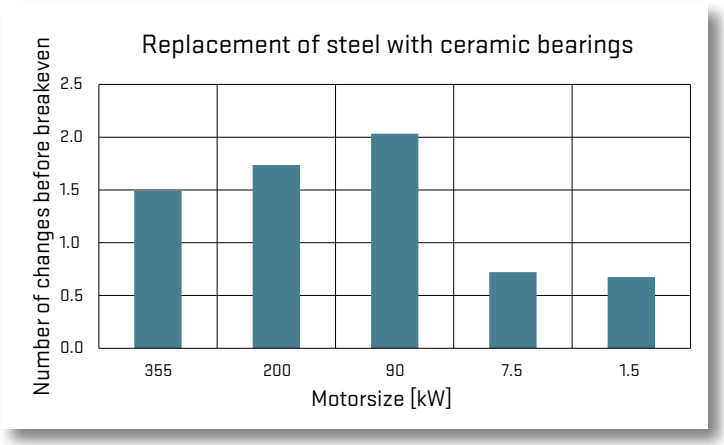
Almost all CeramicSpeed bearings proves a service life, which is between 4 and 8 times longer than standard bearings. The reason for this lays in a number of properties of the ceramic bearings, which balance the higher purchase cost. In the 2013 ELFORSK award-winning project, the operating temperatures of the ceramic bearings were measured, and the results have shown a temperature 14-17 °C lower than standard bearings. This is directly connected with the lower friction found in ceramic bearings, and the resulting lower losses. A further benefit from this fact is, that a lowering of the operating temperature by 15 °C empirically doubles the lubricant's lifetime. See the overview in figure 4.

Ceramic bearings are more robust and thus, can handle a more contaminated operating environment than a standard bearing. The hard balls found in the ceramic bearings crush the contaminating factors that enter the bearing, avoiding any damage transfer to the races. In addition, the hard ceramic balls can also polish the bearing races and thus, polish any small damages, which can always occur on the races. Further the ceramic balls do not corrode like those of steel.

The ceramic balls are manufactured with greater precision and are therefore rounder than steel balls, making the diameter to vary much less from ball to ball. The balls' resistance means that even under high loads they retain their round shape, whereas the steel balls are more easily deformed. The bottom line result is less vibrations in rotating equipment with the ceramic bearing.

Finally, it has been proven that ceramic bearings have less need for lubrication because of their low friction. Therefore, the risk for damages in case of poor or lack of lubrication is not as high as for steel bearings. This proves specifically important during start up of rotation and in applications with many accelerations and/or speed variations during operation.

Figure 3 shows the calculations of savings thanks to the longer service life for a range of ABB motor sizes. The columns show how many bearing replacements must be carried out before the investment in a ceramic bearing is earned back. The savings can vary based on the energy class and manufacturer.



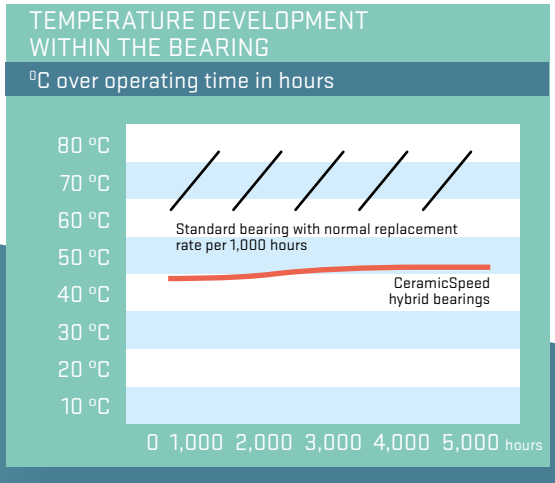


Figure 4 shows the difference in temperature development within the bearing on the grinding mills in Holstebro. While a standard bearing features a need of replacement after every 1,000 hours of operation, a ceramic bearing after 5,000 hours of operation still keeps a fairly low temperature.

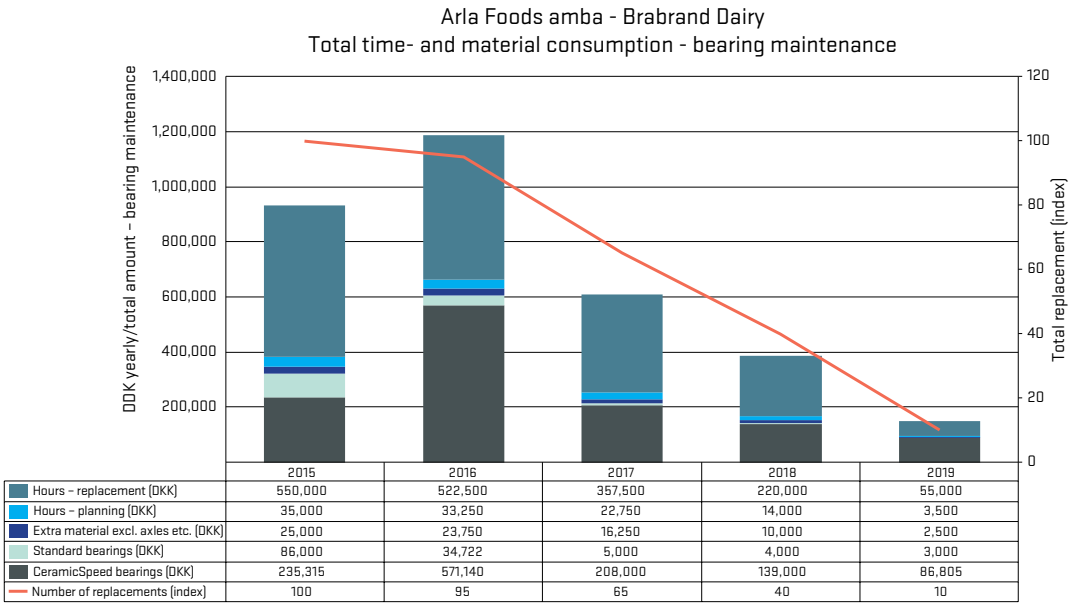
ARLA FOODS OPTIMISES WITH CERAMIC BEARINGS

Brabrand Dairy is one of the food companies, which benefit from the advantages from replacing steel bearings with ceramic bearings.

The dairy giant is one of the companies that have truly had their eyes opened to the many benefits of an upfront major investment made into ceramic bearings, in order to achieve a more stable operation performance and better food safety. The investment has been implemented on several of the company's production sites.

At the Brabrand Dairy, a half-year scheduled service was the standard procedure in place to prevent costly breakdowns at the decanter. The cost of such scheduled services amounted between 600,000 and a million Danish Kroner per year. By replacing the bearings in the decanter with ceramic bearings, the transition to condition-based maintenance was possible, in which the service and repairs are scheduled only after the results of condition analysis and not after following specific time schedules.

Operating manager Michael Helm from Arla Foods in front of the goods lift.



	2015	2016	2017	2018	2019
Hours – replacement (DKK)	550,000	522,500	357,500	220,000	55,000
Hours – planning (DKK)	35,000	33,250	22,750	14,000	3,500
Extra material excl. axles etc. (DKK)	25,000	23,750	16,250	10,000	2,500
Standard bearings (DKK)	86,000	34,722	5,000	4,000	3,000
CeramicSpeed bearings (DKK)	235,315	571,140	208,000	139,000	86,805
Number of replacements (index)	100	95	65	40	10

Figure 5 shows the results from the last two years of operation in rotating equipment in Brabrand and a forecast for the upcoming year, where steel bearings will no longer be used. In the period between 2017 and 2019 an annual reduction of 1.2 million Danish kroner is expected on maintenance and bearing replacement, as the existing steel bearings have been upgraded to CeramicSpeed bearings.

The result is that the need for main overhauls has been reduced to 1 during the same period where earlier three were needed, and that the only components replaced now are the ones actually damaged and in need of replacing. In the past two years, the dairy has carried out vibration analysis on their bearings and have been able to schedule service and repairs based on this. Brabrand Dairy has invested nearly 350,000 Danish Kroner in the CeramicSpeed LongLife Xtreme Bearings and vibration analysis equipment, and in return has saved more than 1,500,000 Danish Kroner In reduced maintenance need.

In Holstebro, maintenance manager Ove Raabjerg Nielsen contacted CeramicSpeed already in 2008, as he repeatedly experienced operational issues with a grinding mill, which ran 5,000 revolutions per minute (RPM). In his case, it was necessary to implement bearing replacements for every 1,000 hours of operation, and he had set up permanent monitoring on the motor so it could automatically switch off when the temperature reached above the critical limit of 80 °C.

The solution in Holstebro was a replacement with CeramicSpeed Bearings, at the same time upgraded with food-approved lubricant. Today, the electric motor is running at a constant temperature of approximately 35 °C below the critical limit, and the bearing service life is extended by more than a factor of five. See figure 4 page 7.

From the production at Arla Foods.

43.817 KWH SAVED ON VENTILATOR WITH CERAMIC BEARINGS

Since the ventilator operating performance is one of the application areas, where relatively the largest energy losses from bearings is found, in the project 346-011 has been implemented the simulation of a ventilator, which is mounted with horizontally overhang. Therefore, one bearing is put under a high radial load (8,5 kN) and the second bearing primary under axial load (5 kN). A ventilator's efficiency is usually determined by measuring the total pressure rise over the ventilator, the airflow through the ventilator and the engine power input. However, the uncertainty of this type of measurements is so high that it was more suitable to implement a simulation of the bearing losses by standard bearings and ceramic bearings respectively.

The result showed significantly lower bearing losses by axial load and somewhat lower bearing losses by the radial load. Overall, the ceramic bearings in the ventilator lead to a reduction in bearing losses of 43 % - from 215 W to 123 W.

The simulation from project 346-011 is supported by the experience with the company H. J. Hansen, which was interested in the energy optimisation of the operation performance of a ventilator, powered by an electric motor via a belt drive. It was calculated on the effect of supplementing the new ventilator with a new motor with ceramic bearings and at the same time, allow the engine to pull the fan directly without the belt drive. Amongst others, the experiment led to the engine's capacity to lower the engine speed from 1,400 RPM to 1,000 RPM.

The ceramic bearings will reduce the bearing losses in a typical fan with approx. 43 %. Under certain operation modes, the savings could reach as high as almost 50 %.

According to the analysis, the new ventilation system would have a yearly electrical consumption that is 43,817 kWh lower than the previous system. The total payback for the investment is 8 years, however, H. J. Hansen has achieved, at the same time, a more stable operational performance.

EASY TO CALCULATE THE SAVINGS WITH CERAMIC BEARINGS

The Danish Institute of Technology has collected the results from the project calculations and practical tests in a simple and user-friendly calculation tool, which can be downloaded from the project page (346-011) on www.elforsk.dk. This tool makes it easier for decision-makers in the industry and building operation to get an overview of the profitability gained from the replacement with ceramic bearings depending on the motor size, runtime, load and so on.

CeramicSpeed has marketed the project's results during seminars for potential industrial customers and has achieved a constructive collaboration with several major companies. Thus, Grundfos has started to use ceramic bearings in some of its energy-efficient centrifugal pumps, and CeramicSpeed expects that, with the expanded and improved documentation on the advantages of ceramic ball bearings advantages, a market expansion with various motor and machine manufacturers can be achieved.

CeramicSpeed is working systematically to exploit the project's test results to improve its ceramic bearings' competitiveness in relation to conventional steel bearings; the increased sales to the industry will play an important role in reducing the manufacturing cost of ceramic bearings.

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