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Technical
- Design Parameters for Gearbox Bearing Service Life
- High-Efficiency—Reduced Cost—PM Motors

Power Play
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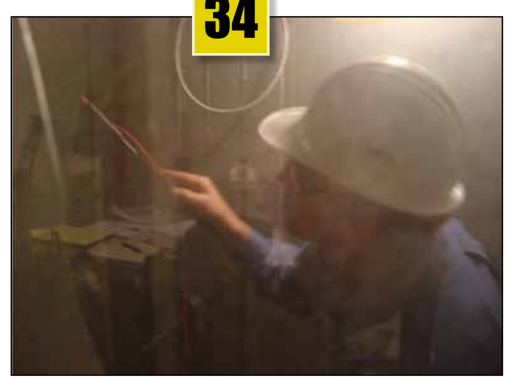

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How to Become an *Expert* in Your Field

Danish physicist Niels Bohr once said an expert is a person who has made all the mistakes that can be made in a very narrow field.

So I figure all I have to do is be myself in order to become an expert at just about anything, right?

Well, no—expertise is not so easily acquired. Neils Bohr was on the right track, of course, but in addition to making the mistakes, you have to understand them, learn from them—and not repeat them.

Someone who has demonstrated that ability is Aarnout Kant, the business unit manager for Siemens Mechanical Drives in Elgin, Illinois. I had the opportunity to meet him at a recent tour of the Elgin operations. During the tour, Kant gave a presentation about the company's history, philosophy and the significant changes and investments they've made in the Elgin facility over the past several years.

During Kant's presentation, he recounted how, as a young engineer, he had designed a gearbox that was to be installed at the world's largest copper mine in Chile. When the gearbox was completed, Kant traveled to Chile to oversee its installation. Unfortunately, when the power was turned on, they heard a horrendous pinging noise. As it turned out, someone left a screwdriver inside the housing. It got caught in the unit's fan, breaking off two of the fan's blades. Of course, it wasn't Kant's fault that someone left a screwdriver inside the gearbox. But in order to get at the fan to replace it, the motor and coupling had to be removed. Basically, the entire unit had to be disassembled in order to replace one of its least expensive components. As Kant described it, it was a design lesson he had to learn the hard way.

But he wasn't embarrassed by it; in fact, he embraced and learned from it. And more importantly, he incorporated that learning into new gearbox designs for his company. Today, Siemens offers gearboxes with a removable shroud over the fan section, as well as fans with replaceable blades.

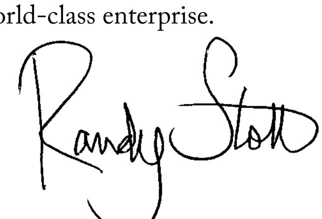
But even rarer than an individual who learns from his mistakes is an organization that does so. And organizational learning seems to be a major point of emphasis at Siemens.

Manufacturing gears in the United States is new for Siemens. At the old facility, there was a small gear manufacturing cell for repair and service work; but beginning in 2009, the company completely remodeled and retooled its facility to accommodate local gear manufacturing for all their gear drives, including a brand-new heat treating facility that came fully on-line in 2011. Plant manager Peter Herzhoff described how the company built this facility based on the knowledge gained at other plants around the world, using the exact same processes, machines and technologies as at other facilities, right down to the plant layout.

"We want the gear to be the same whether it was manufactured in Germany, the U.S., India or China," Herzhoff said.

The emphasis on organizational knowledge was also evident at Siemens' new assembly facility, which was completed in 2009. There, I saw continuous improvement boards stationed around the plant highlighting not only the company's successes, but, more importantly, its failure to meet specific goals. The boards include places for employees to make suggestions, as well as before-and-after photos demonstrating incremental improvements in plant layout and operations. Jacob Schiff, plant manager for the assembly facility, described how management walks the plant floor every morning to review the boards and make adjustments, anticipate problems, incorporate changes and improve the operation. Every day, they look at their mistakes and use them to improve their operation.

Anyone can make a mistake. We've all had our "Where did I leave that screwdriver?" moments. But the ability to transform mistakes into expertise may very well be the difference between the average company and a world-class enterprise.



Randy Stott,
Managing Editor

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Structural Change and Growth—Coming to a Global Economy Near You

Brian K. Langenberg

(*Welcome to the first installment of* Market Update*—a by-the-numbers, in-the-now snapshot of industrial markets worldwide, along with some prognostication to assist in planning your next moves—when to hold 'em, when to fold 'em, etc. Look for* Market Update *in future issues of* Power Transmission Engineering.)

Rising emerging market income growth and industrialization, increased resource demand and a gradually improving U.S. economy are driving global growth. Recent data points are mixed. Emerson's February order data showed improvement in process automation and "less bad" comparisons in HVAC. Employment continues to slowly improve. Conversely, the shift in energy patch activity to oil from gas is reducing profits for some companies (Baker Hughes—3/21/12).

Europe matters—to Europeans. Surprises concern us, not rehash. The noise from Europe is a loud negotiation about who pays and how much. If policy error did not lead to Armageddon in 2008, 2009, 2010 and 2011, we are hard-pressed to see why 2012 is different. When history books are written, the combined political leadership of most of Europe (with money), China, the U.K. the U.S. and parts of the Middle East are going to look pretty good. I am serious. Currently, European auto production and consumer-related activity is down—likely through the first half—and has impacted demand for drives and industrial capital spending—particularly at Siemens, ABB and Schneider.

Improving price/cost. Raw materials are down (15–25 percent) from six months ago—aluminum, copper, nickel, tin, platinum and palladium—just as price actions are working their way through. Several companies called out materials as a 4Q headwind, but that reverses in the next couple of quarters.

Energy and materials demand. Strong upstream activity for oil, gas and commodities is driving 70–80 percent of incremental industrial demand—from oil and gas (moving to oil) through pipe, welding, machinery and general industrial activity. Growth will be positive; mix and margin questionable. Close to home, shale plays have provided better price and margin than oil. The energy-equivalent price ratio between oil and gas should be 12:1. With Brent Crude at $125 and natural gas at $2.40 the ratio is 54:1, so investment is rushing toward oil.

Self-generated growth/urge to merge. Private equity and geography have structurally changed the growth game—sustainably higher prices for corporate assets and the inability to buy assets that do not exist. Corporates are designing products for emerging market price points, building out sales, manufacturing and local management and, where possible, buying a manufacturing asset. Deals generally bring a customer base or distribution at "healthy" prices that often nearly preclude earning an adequate return. Call it the "new disciplined."

Global power cycle. Rising demand for electricity is a given—the profitability of supplying the market is under stress and pricing in current backlogs is poor. The broad theme from every participant—U.S., European, Japanese—is one of strong demand and intense price as everybody fights for the same emerging market pie.

Home markets will offer little respite—Siemens, Alstom and Mitsubishi Heavy have all expanded North American gas turbine capacity and General Electric in turn has voiced a desire to spend more time focusing on the German market. Six months ago GE was looking for 15–20 percent margin in its total energy segment, but the high end is not currently on the radar screen.

Renewables are down. In China 35 percent of installs are not even connected to the grid. Could bounce back in the second half of 2012, but there is no guarantee and it no longer matters to multinationals who were shoved out of the market three years ago. Offshore wind and larger units are the trend, but gas below $3 makes it a difficult sell. Forget tax credits in '12—it is an election year and President Obama was recently photographed at a pipeline project.

Transmission & Distribution. Again, more competition—but fundamentals are improving. Distribution remains solid, owing to replacement demand; new construction will help—but not this year. New transmission project activity ramped up months ago; the transformers will follow by year-end. Increased competition—Hyundai in particular—may depress peak margins in this cycle.

Asia/technology complex accelerates by mid-year. Indirectly, this end market affected your life in the 4Q as flooding in Thailand impacted key players in process and HVAC—particularly Emerson and Unite

ResidentialHVAC. Low inventory, better price and no expectations can only help. Trane cut price at least five percent in the 4Q to clear inventory and was not

Brian K. Langenberg, CFA, *has been recognized as a member of the Institutional Investor All-America Research Team, a Wall Street Journal All-Star, and Forbes/Starmine (#1 earnings estimator for industrials). Langenberg speaks and meets regularly with CEOs and senior executives of companies with over $1 trillion in global revenue. His team publishes the Quarterly Earnings Monitor/Survey—gathering intelligence and global insight to support decision-making. You can reach him at Brian@Langenberg-llc.com or his website at* www.Langenberg-LLC.com.

alone. Empty distributor channels and warm weather should drive a restock and residential refurbishing activity has improved.

It's not all about China. While headlines are headlines, facts are facts. Resource-rich economies are spending cash on resource extraction, industrialization and rising consumption. We've said all along "BRIC" should be split into BR—countries with resources—and IC—countries which must purchase resources.

With respect to China, the bad news is the slowdown is real. The good news: a) it already happened; b) it has mashed mostly construction equipment (ex CAT which took share)—i.e., rail, wind and small Chinese manufacturers whom big process companies do not really sell to yet; and c) it is likely to turn with a stimulus program in the works.

China's current slowdown started last year, and though recent data (growth, targets and lower iron ore price) are negative, we see a trough. One year ago we estimated 45 percent of China's export economy had margins of 10 percent or less; today, rising wages and higher capital costs have worsened the situation. This is a political transition year and China will need to accelerate substitution of capital for labor. They have no choice. This will be good for capital investment and anybody playing in automation. And a precision economy will need precision manufacturing. The issue will be intellectual property protection.

Russia is now a European growth driver; think energy, non-residential construction and agriculture. Brazil struggles with a strong currency but is spending on infrastructure and foreign direct investment remains high. Expect it to continue as Caterpillar, PACCAR, Hitachi and many others are putting in manufacturing capacity. Japanese and Korean engineering and construction companies are citing high quotation and negotiation activity in process, chemicals and power generation from emerging markets ex-China.

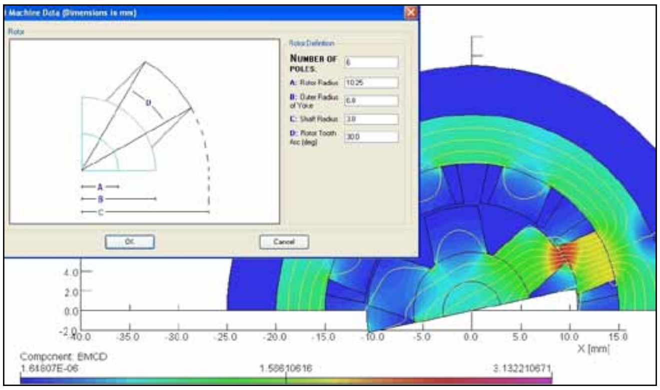
U.S. is becoming structurally more attractive—despite itself! The outlook for U.S. manufacturing is its brightest in 30 years, driven by energy costs (lower here) and labor (rising there).

Offshore markets are no panacea. Intense price competition (energy), industrial policy (when China decides to take over a sector, it does so), and rising labor rates have cut into share, profit and increased business risk. These shifts were always in the sooner- or-later category. Natural gas has changed the dynamic, and plans to build multi-billion refineries in places like Pennsylvania (Royal Dutch Shell) generate 5–8 jobs for every person directly employed. Resource-driven economies will continue capturing growth spend, but more growth will be closer to home. We think the outlook for heavy industry is bright.

Identifying Motor Design Characteristics

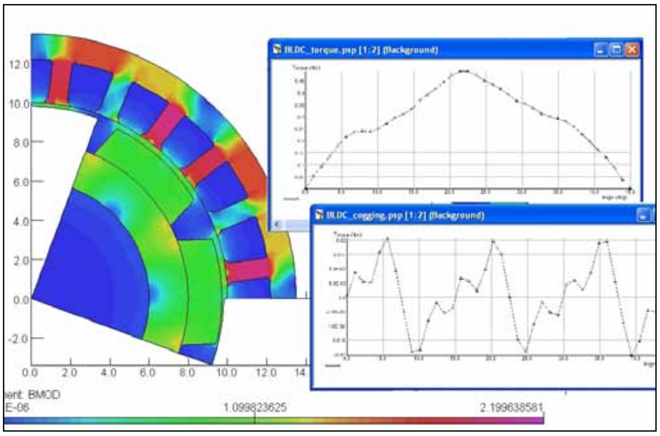
COBHAM OFFERS AUTOMATION SOFTWARE SOLUTIONS

Optimal design solutions to rotating electrical machine requirements can now be created in hours, by non-specialists, using a new version of design automation software from Cobham Technical Services. Cobham's *Machines Environment* introduced a new level of user friendliness when it was launched by providing a design entry system that allows precision finite element analysis (FEA) models of motors



and generators to be created and solved in minutes. The two-dimensional (2-D) version of the software has now been integrated with Cobham's unique optimization tool which automatically finds the solution within a design space—even for multiple or competing design objectives.

Cobham's *Machines Environment* is an application-specific extension to the well known *Opera* electromagnetic simulation package. It provides a front-end to the simulator that speeds design entry by means of Wizard-style dialog boxes. Users select



the style of motor or generator they want to design from a library of all common types, including induction, brushless permanent magnet and switched reluctance motors, and synchronous motors or generators. Then, dialog boxes allow the user to enter parameters to define mechanical geometry, material properties and electrical data, and the FEA model is automatically created.

The use of parameterized models and the ability to quickly load and modify previous designs has always made it possible for users to perform 'what-if?' design investigations. Now, to extend these possibilities to the maximum, Cobham has integrated a unique optimization tool that makes it simple for users to find the best solution across the design space. While auto-optimization tools are not new, they usually require manual intervention if the globally optimal solution is to be found, and the simulation times involved often make this impractical. Cobham's Optimizer 'intelligently' selects and manages multiple goal-seeking algorithms including stochastic, descent, particle swarm and Kriging to eliminate the need for manual intervention.

Setting up an Optimizer run from the *Machines Environment* has now been made as easy as the design entry process. Because most FEA simulations can take as little as a few seconds, the integrated software makes it feasible to thoroughly explore the design space. Thousands of simulations can typically be executed within hours.

"This software makes the high accuracy of finite element analysis available to all engineers, not just the expert with years of experience," says Cobham's Jeremy Howard-Knight. "Even a novice engineer can now create a precision finite element model and find the best solution in a design space, without needing to know much more than what he or she wants to achieve."

The 2-D *Machines Environment* is now in its fourth generation, and Cobham has developed an extensive library of rotating machine design styles, and design components. However, if there are still any unusual features that need to be incorporated in designs, users also have open access to the scripts that generate the models, and can modify them at will to automate proprietary motor and generator design concepts. A library of common material properties is also included in the design software. Again, if users employ any special materials, such as an unusual grade of steel for laminations, then a new menu item can be created within minutes. Cobham will also generate custom scripts for users on request.

Cobham's *Machines Environment* appeals to the many users of analytic motor design programs, giving a means of performing much more accurate analysis rapidly and without the engineering overhead usually required for accurate FEA. The tool can deliver significant advantages in today's market environment. Currently, there's enormous pressure to improve energy efficiency for instance. The combination of highly accurate simulation and sophisticated optimization provides the means to identify the design characteristics of the perfect machine in very short timescales. A three-dimensional version of *Machines Environment* is optionally available.

New Website Offers Different Approaches to Motor Design. Cobham Technical Services has launched a new website to help engineers understand the contribution that FEA software can make to motor design cycle efficiency and design optimization. The new site (*www.motor-design-software.com*), gives engineers a multi-faceted view of the ways electromagnetic FEA software can be used to design motors. Users can explore the underlying tools, looking at aspects such as the creation of design models or analysis of simulation results. They can also investigate the automated design approach for different types of design, by selecting a specific form of motor or related electromagnetic design topics such as magnetic gearing and linear motion. A range of interesting research material is available on the site including technical papers and details of training courses. Users may also register for a webinar on rotating machine design.

For more information:

Cobham plc.
Brook Road, Wimborne,
Dorset, BH21 2BJ,
United Kingdom
Phone: +(44) 1202-882020
www.cobham.com

Pittman

TACKLES TORQUE DENSITY AND DURABILITY

Pittman G30A planetary gearboxes are designed with maximum torque density and durability in mind. These small gearboxes are engineered to complement five different series of Pittman motors, allowing a wide range of output torques and speeds. The mounting profile is 30.5 mm (1.20 in) in diameter, or 38.0 mm (1.50 in) square when the optional mounting flange is used. Gearbox lengths vary depending on the gear

continued

reduction and range from 33.7 mm (1.33 in) to 51.2 mm (2.02 in). Fourteen standard reduction ratios are available ranging from 4:1 to 1,296:1 and allow a maximum output load of 2.47 N-m (350 oz-in) to 8.83 N-m (1,250 oz-in). Custom gear ratios can also be configured to meet just about any application need.

Carefully engineered for challenging applications, the G30A planetary gearbox incorporates sintered steel planet gears to promote high torque capacity and low audible noise while maintaining a compact design. Single piece carrier plates with integral gear posts and sun gear can be arranged to achieve many different reduction ratios. The gearbox output is through a 416 stainless steel shaft and a sintered metal output bearing. Optional ball bearings are available for high radial loads.

The G30A gearbox complements the Pittman 8220, 8690, 8540, 9230, and 1300 Series brush and brushless DC motors. When the G30A is combined with the latest motor materials and manufacturing technology such as high energy neodymium magnets, silicon lamination steel, and advanced winding techniques to maximize slot fill, a high-efficiency system is created for high-tech motion applications.

For more information:

Ametek
627 Lake Street
Kent, OH 44240
Phone: (215) 256-6601
www.ametektip.com

RSF Linear Encoder

ELIMINATES WEAR AND PROVIDES EVEN PRESSURE

RSF Elektronic, represented by Heidenhain Corporation, has released the new slim profile linear encoder series MSA 700 and 800 tailor-made for metrology applications which require protection from contamination. Typical applications for these encoders are optical comparators, and video and vision systems. The main advantages offered by these encoders are generous mounting tolerances, low level backlash and optimized thermal behavior. Central to the design of these new encoders is the reading carriage and reading head con-

nected by a wear-free and maintenance-free magnetic coupling. The carriage is also constrained by a magnet guide that affects the ferromagnetic tapes on the extrusion. Hence, there are no forces that could stress guide parts and no contact points that could prematurely wear. Improving upon old roller bearing or spring coupled encoders, the new magnetic coupling and guide eliminates wear and provides even pressure along the measuring length. This combination allows for generous mounting tolerances without any negative influence on accuracy. An additional benefit of this magnetic coupling is the extremely low backlash, reducing one of the main weaknesses of sealed encoders.

The fiber-reinforced sealing lips made of fluororubber (Viton) are wear and coolant resistant, allowing the encoder to operate in harsh environments. High velocities are also possible due to the high degree of rigidity and ideally formed blade area of the reading head. The scale itself is fastened via a flexible adhesive film in the profile, which compensates for the differing linear expansion between the glass and the aluminum. Thus a reproducible thermal growth is ensured by symmetrical expansion or shortening of the scale to the profile. Expansion differences between the aluminum profile and machine slide are accommodated by flexible fastening elements.

This new MSA 700 and 800 series is defined as sealed incremental linear encoders that have grating pitches of 20, 10, and eight microns, and come in accuracies of two, three and five microns. This makes them suitable for customer applications requiring precision and protection. They have the same mechanical footprint and electrical properties of the MSA 600 series, and can be customized to suit customer specifications.

For more information:

RSF Elektronic
Represented by Heidenhain
333 East State Parkway
Schaumburg, IL 60173
Phone: (847) 490-1191
www.heidenhain.com

TB Wood's

OFFERS BELT DRIVE SOLUTIONS

The TB Wood's Engineering Belt Drives Group is a value added resource to its customers. Engineering support activities include evaluation of customer applications to determine if standard or made-to-order components can be applied, review of customer component drawings for manufacturability, and confirmation of design adherence to industry standards like MPTA, ARPM and ISO. "Our engineers quickly and accurately translate customer information into a delivered belt drive solu-

continued

tion," said Alex Vevasis, engineering manager, TB Wood's Belt Drives Group. "By applying our extensive knowledge and understanding of belt drive systems, we effectively shorten our customer's design cycle."

TB Wood's engineers can also provide drive selection assistance by recommending the appropriate product family and the specific drive components for each customer application. A drive detail report is generated which includes performance ratings, installation parameters and a part list. Drives are routinely evaluated and redesigned to provide increased efficiency, enhanced performance and reduced total life costs. To help improve the effectiveness of maintenance teams, TB Wood's engineering support can also provide product training, including proper installation techniques and problem indicators which can lead to improved system uptime and drive life.

For more information:

TB Wood's Incorporated
440 North Fifth Avenue
Chambersburg, PA 17201
Phone: (717) 264-7161
Fax: (717) 264-6420
www.tbwoods.com

Tolomatic

RELEASES HIGH FORCE LINEAR ACTUATOR

Tolomatic's unique IMA55 high-force servo linear actuator is now available with an optional roller screw that boosts its thrust capability to 6,875 pounds force (30,470 N). In addition, a new compact IMA22 integrated-motor actuator has been added to the line. The IMA22 features a ball screw and can deliver up to 325 pounds force (1,446 N). Available in four sizes, the IMA line of integrated-motor rod actuators features stroke lengths from three to 18 inches (76.2 to 457.2 mm) at speeds up to 24 inches per second (610 mm/sec). The addition of these two actuators significantly expands the range of applications for these actuators to include pressing, clamping, valve control, spot welding and volumetric filling. "With the addition of the roller-screw option on the IMA55, the service life of the actuator increases by nearly 10 times in high-force applications," said Aaron Dietrich, marketing manager, Tolomatic. "The standard ball screw on the IMA22 offers efficiency and economy in lower-force applications that require accuracy, repeatability and durability in a compact package."

All of the IMA actuators integrate a servomotor and a ball or roller screw for long service life that is designed to fit a multitude of budgets. With its integrated servomotor, the IMA actuator is shorter for a given stroke length than other types of rod actuators. Its patent-pending design allows for easy re-lubrication of the screw without disassembly, reducing maintenance and increasing service life compared to other rod actuators without this feature.

For more information:

Tolomatic, Inc.
3800 County Road 116
Hamel, MN 55340
Phone: (800) 328-2174
Fax: (763) 478-8080
www.tolomatic.com

Renold Couplings

PREVENT COSTLY EXCAVATIONS

When a large equipment manufacturer needed a long-term solution to protect against costly coupling failure on their excavators, they turned to Renold Hi-Tec Couplings. The company previously used rubber-in-shear couplings which were failing after 4,000 hours of operation. Each time a coupling failed, the excavator had to be stripped down and the coupling replaced. This was proving costly as the excavator runs 24 hours a day, seven days a week and any unplanned downtime means that the cost increases per tonnage of material excavated. The coupling is fitted between the diesel engine and the gearbox, which has three outputs. These outputs drive three hydraulic pumps, which in turn drive all the motions on the excavator. As these excavators are used on very demanding applications, good coupling life is very important. Renold therefore

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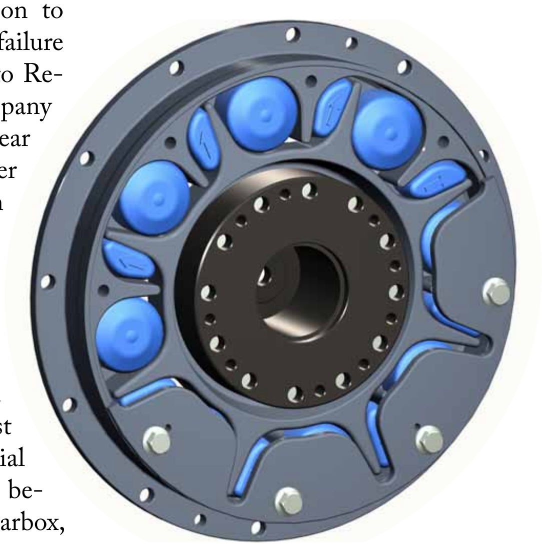


recommended the HTB-GS rubber-in-compression coupling. The HTB-GS has already far exceeded the 4,000 hours life of the rubber-in-shear coupling and is still going strong, according to Renold.

For more information:
Renold Hi-Tec Couplings
112 Parkinson Lane
Halifax
West Yorkshire
England
Phone: +(44) 1422 255 000
www.renold.com

Haydon Kerk

UPDATES LINEAR ACTUATOR

Haydon Kerk Motion Solutions, a manufacturer of linear motion products, has released a new version of the popular 36 mm G4 linear actuator. This configuration includes a special adapter plate that allows the smaller 36 mm OD unit to replace existing size 17 hybrid stepper motor linear actuators. The 36 mm G4 linear actuator meets the performance of the larger hybrid size 17 single-stack

actuators. The 36 mm unit with the integrated size 17 adapter plate easily replaces existing hybrid units by using the same bolt pattern and pilot surface. Force output range of the G4 36 mm can stack is from 70 N to 260 N (16 lb to 58 lb). Output resolution ranges from 0.013 mm (0.0005") to 0.102 mm (0.004") per step command.

The G4 linear actuator architecture employs the latest technologies to extend reliability and meet higher performance requirements. The design utilizes optimized teeth geometry along with high-energy neodymium magnets that result in a higher continuous force output in a small package. With 20 percent higher output force across the entire speed range, compared with other designs of similar size, the G4 also contains the latest custom-engineered plastics and larger bearings for greater rotor support and higher axial load capability.

The 36 mm linear actuator is suitable for applications that include medical equipment, bar code scanning devices, printing equipment, laboratory instrumentation and other mechanisms requiring high force in a small package. As with other Haydon stepper motor linear actuators, there are three configurations available: captive, non-captive, and external linear.

For more information:
Haydon Kerk Motion Solutions
1500 Meriden Road
Waterbury, CT 06705
Phone: (203) 756-7441
www.haydonkerk.com

Low Inertia Disc Couplings

SUITABLE FOR BACKLASH SYSTEMS

Ruland offers both single- and double-disc style couplings for highly accurate systems found in industries such as test and measurement, medical, semiconductor, solar and liquid handling. Disc couplings have low inertia and are torsionally stiff, making them suitable for precise zero-backlash systems with speeds up to 10,000 rpm. Disc couplings are comprised of two black anodized aluminum hubs and multiple flat stainless steel disc springs. Single disc styles are suitable for systems where compact installation is required. Double disc styles add a center spacer to increase the misalignment capabilities. The center spacer is available in a choice of anodized aluminum or insulating acetal for electrical isolation. The thin disc springs allow for a substantial amount of misalignment between shafts, while remaining rigid under torque loads. Par-

continued

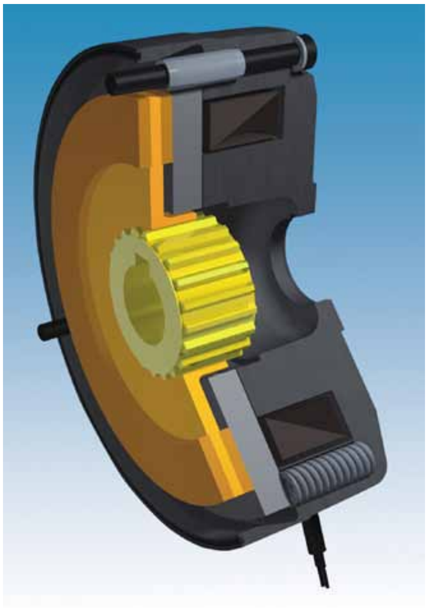
allel misalignment is accommodated by the double-disc style or by two single-disc couplings used in tandem. Ruland single- and double-disc couplings are available in both clamp style and set screw style with bore sizes ranging from 3 mm to 30 mm (⅛" to 1¼"). Disc couplings are part of Ruland's complete product line, which also includes shaft collars, rigid couplings with precision honed bores and five types of zero-backlash motion control couplings: beam couplings, bellows couplings, oldham couplings, curved jaw couplings and miniature disc couplings.

For more information:
Ruland Manufacturing Co., Inc.
6 Hayes Memorial Drive
Marlborough, MA 01752
Phone: (800) 225-4234
www.ruland.com

Mayr

PROVIDES MAINTENANCE FREE BRAKES FOR TURBINES

The application of safety brakes in wind turbine pitch drives requires extremely conscientious dimensioning and precise knowledge of braking torque tolerances. If these prerequisites are fulfilled, high-quality brakes will



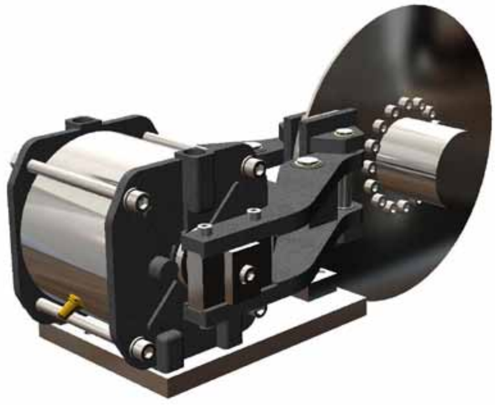
work without requiring any maintenance across their entire service lifetime. The pitch drive brakes have the task of securing the rotor blades against twisting once they have been angularly positioned by the gear motors. This rotor adjustment must always function, even if, for example, the power supply has failed. In this case, the motor can be supplied by a battery or capacitor. If no such emergency supply is available for the brake, the motor is designed so that it is capable of turning the rotor blades against the braking force to bring them into a safe position (out of the wind) even when the brakes are applied. Well-founded knowledge of the braking torque tolerances for the brakes used is particularly important in such cases. On the one hand, a sufficient braking torque must be provided to hold the rotors; on the other hand, the maximum motor torque must not be exceeded, so that it remains possible to turn the blades to a safe position against the applied brakes. Of course, this must be ensured in any ambient conditions occurring during normal operation, such as for example at a relative air humidity of > 90 percent or at temperatures well below freezing point. Offshore, mechanical components are subjected to additional strain due to the aggressive, salty air. Mayr Power Transmission has equipped its maintenance-free wind power brake, based on the tried and tested ROBA-stop-M brake, for these tough conditions. Metal surfaces, in particular, had to be protected against corrosion. In addition to rustproof components such as in thrust springs, friction linings especially developed for these applications combined with special non-corrosive counter friction surfaces have proven their worth.

For more information:
Mayr Corporation
4 North Street
Waldwick, NJ 07463
Phone: (201) 445-7210
www.mayrcorp.com

Ogura

RELEASES PNEUMATIC-STYLE, SPRING-ENGAGED CALIPER BRAKE

Ogura has developed two series of spring-applied, pneumatically released caliper disc brakes. These are the ANB-1100-CP and ANB-2300-CP. The 1100-CP has 11,000 newtons of



clamping force and the 2300 has 23,000 newtons of clamping force. The actual torque applied to a given application is a function of the diameter of the disc. The disc for either brake would be customer supplied.

The new brakes from Ogura have stationary cylinders that make them highly reliable and very resistant to vibration. Even though the brakes can produce a tremendous force, they are relatively lightweight for their size and take up significantly less space than an equivalent single-face brake. They are suitable for wind turbines and railcar shuttle equipment because any time pneumatic pressure is lost, the brakes can come on and hold in an emergency.

For more information:
Ogura Industrial Corp.
PO Box 5790
Somerset, NJ 08875
Phone: (732) 271-7371
www.ogura-clutch.com

Darali Cycloidal Drive

OFFERS HIGH EFFICIENCY, COMPACTNESS AND SIMPLE MAINTENANCE

Backed by ISO-9002 certified manufacturing, Darali Cycloidal Drive has the unique advantage of high efficiency, compactness, simple maintenance, 500 percent shock load capacity, and is stocked in Piscataway, New Jersey for quick delivery. Unlike a conventional gear mechanism that has shearing contact between gear teeth, the torque transmission components of cycloidal reducer undergo compression contact. In addition, 2/3 of ring gear pins/rollers (size B10 ~ B27) are engaged with cycloidal discs at all times to reduce speed and transmit torque. Furthermore, the Darali Drive torque transmitting components are made of bearing grade steel alloy, heat treated and hardened to Rockwell hardness of HRC 61 ~ 63.

With the unique speed reduction mechanism, single-stage ratios range from 6:1 ~ 87:1. The physical size of the Darali Cycloidal Drive remains the same from 6:1 ~ 87:1, and there is no additional item to be maintained. Double-reduction ratios range from 102:1 ~ 7,569:1. Darali Cycloidal Drives come with various mounting (foot, flange, face) and input configurations (shaft-in, C-face, top mount). Sizes are available to handle applications from fractional input hp to more than ½ million (500,000) in-lbs of output torque. Smaller units from size B08 to B12 are packed with maintenance-free grease lubrication. Larger sizes are oil lubricated with provisions of breather, easy drain and sight glass. Spare parts are readily available. Certain spare parts, such as eccentric bearings, can also be used to repair other brands' cycloidal reducers.

For more information:
BCC (USA) Inc.
143 Ethel Road West,
Piscataway, NJ 08854
Phone: (800) 272-1361
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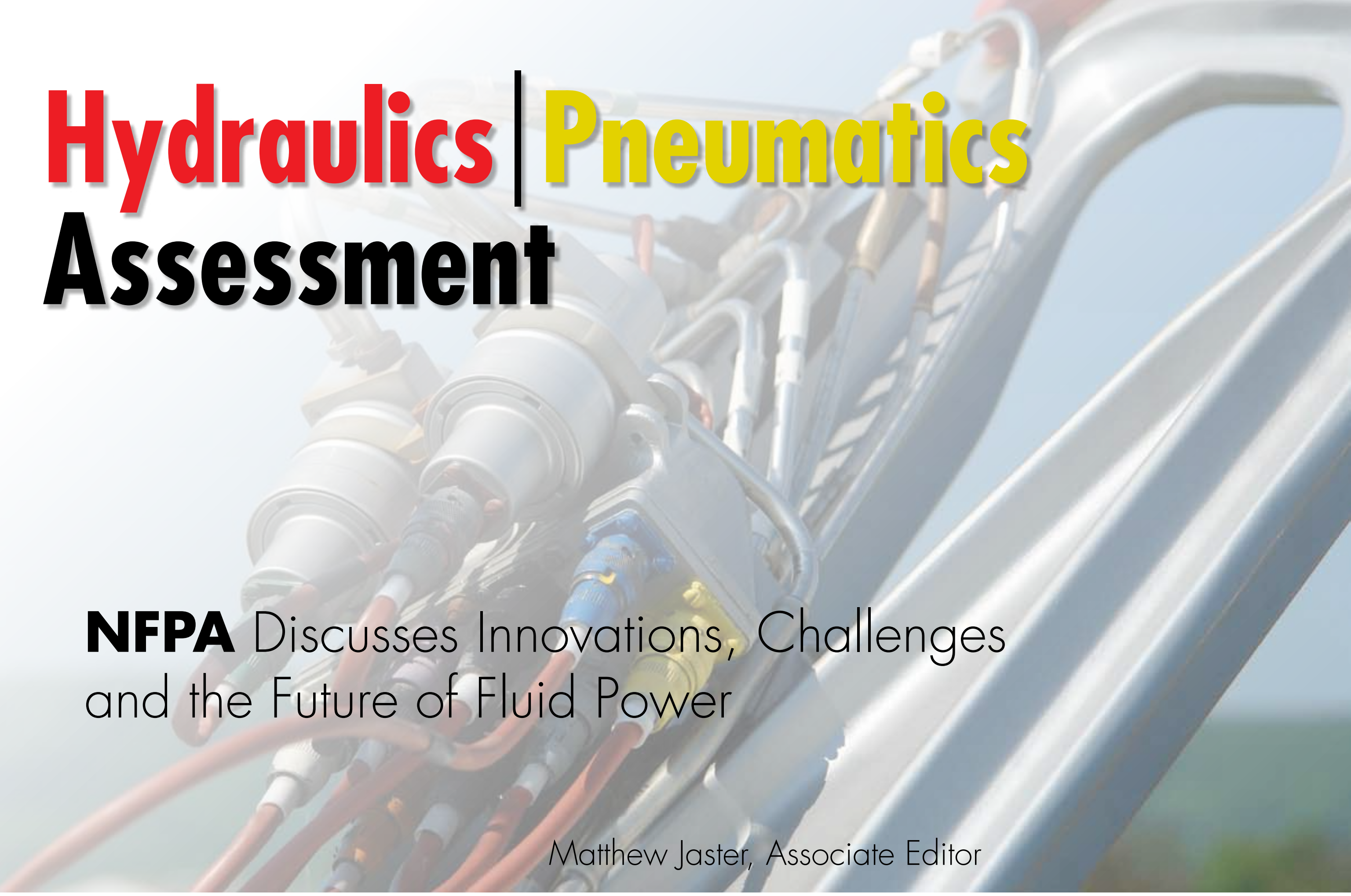


Hydraulics | Pneumatics Assessment

NFPA Discusses Innovations, Challenges and the Future of Fluid Power

Matthew Jaster, Associate Editor

The National Fluid Power Association (NFPA) is an organization consisting of manufacturers, distributors, suppliers and educators working together to strengthen the fluid power market. Its mission is to serve as a forum where all fluid power channel partners can advance fluid power technology and successfully compete in the global industrial market. The organization just held its 2012 Annual Conference in Hawaii from March 6–10. *PTE* recently caught up with Eric Lanke, CEO of the NFPA, to discuss the conference, the state of fluid power in 2012 and the latest technologies that are changing the industry.

Eric Lanke, CEO, NFPA.

Q: What role does the NFPA play in sharing the latest fluid power technology with the industry?

NFPA doesn't develop technology directly. NFPA does, however, bring members together to support efforts that lead to technological developments beneficial to our industry. For example, NFPA was a key player in bringing members and academic research institutions together to secure a multi-year National Science Foundation grant that supported creation of the Center for Compact and Efficient Fluid Power (CCEFP). The Center is a group of universities working with industry to advance such areas as energy efficiency and storage, reduction in size of fluid power systems, and portable sources of power to drive these smaller and more efficient systems. At the same time, a core benefit of the CCEFP is that young engineering students are now being attracted to study fluid power. This is creating a broader pipeline of engineers trained in fluid power for our manufacturers and their customers.

Q: How are the latest fluid technologies changing the industry today?

There are many examples of technology breakthroughs, from both industry and from the CCEFP, that hold the potential to transform the fluid power industry by strengthening its position in existing markets and opening new ones. Hydraulic hybrid technology is being used on delivery trucks and garbage trucks to deliver major energy savings, and research is advancing to make these systems more compact for use on passenger vehicles. Variable speed drives are being used in industrial settings to achieve energy savings on many applications. Hydraulics promises energy savings and reduction in downtime and maintenance when used to transmit power in wind turbines. Pneumatics is making strong and innovative progress in fast growing medical markets, where it is being used to power anything from artificial hearts to oxygen concentrators. Innovations like these are expanding the reach into our industry. They speak well of our member companies and create a new image for our technology. That spurs more interest among customers, generates new customer markets, and attracts talented people to this industry.

In 2011 NFPA launched our Innovation Award program to recognize the innovative use of fluid power technology by engineers and technicians working in our end-use markets. We recently recognized two engineers at GenTech Global for a hydraulic application that reduces energy consumption and emissions on commercial fishing boats. Their innovation eliminated an additional engine typically used to power the boat's electrical systems, reducing overall fuel consumption by up to 25 percent. Applications are now being accepted for the 2012 NFPA Innovation Award. If your readers have an innovative fluid power application that increases energy efficiency, system reliability or reduces environmental impact, I would encourage them to submit an application for consideration at *http://www.nfpa.com/ourindustry/nfpa_innovation_award.asp.*

Q: Describe the greatest challenges to those involved in fluid power in 2012

The last few years have certainly been interesting ones for the fluid power industry. The global economy has been reshaped in the wake of the Great Recession, and many businesses are rethinking their approach to global markets and global competitors to stay profitable. A historic downturn, followed by a vigorous rebound has pushed the fluid power industry—unlike many other sectors—to heights in excess of the industry's pre-downturn highs. Many fluid power companies have experienced growth and a return to profitability; but many challenges remain. Globalization has accelerated, the supply chain struggles to meet demand, and although the country is experiencing a period of high unemployment, many fluid power companies are having trouble finding the talent they need to drive success in their organizations.

Q: What are the big stories coming out of the NFPA Annual Conference?

NFPA's 2012 Annual Conference was themed around Global Product Development and Differentiation—providing members with innovative resources and tools to better prepare them for taking advantage of opportunities associated with doing business in today's global economy.

One of the speakers at this conference focused on the changing macroeconomic landscape, with the idea that our fundamental business cycle is becoming more volatile. This makes NFPA's efforts to provide predictive data and tools for members more important in helping them anticipate and manage the ups and downs of the industry and key customer markets.

One of NFPA's key strategic priorities is helping our members thrive in this environment by expanding and diversifying their global operations. New programs have and are being launched that focus on three key objectives: (1) Helping NFPA members connect with needed international partners; (2) Providing education and resources on topics related to international business; and (3) Augmenting our existing market information reports with information necessary to make smart decisions about international business opportunities.

Q: How are the educational portions of the NFPA doing today, particularly engaging young students in the career opportunities in fluid power?

The NFPA Education and Technology Foundation is very focused on this issue, and has successfully developed several programs that will improve fluid power's attractiveness to students and enhance our ability to make further inroads in the future. One of our key programs in this regard is project grants offered to universities and technical schools to add or augment the fluid power educational materials used by their students. A total of 24 such grants—all valued at a maximum of $5,000—have now been awarded to the 17 different schools. This past year saw five new awards, including two to new schools, further broadening the reach of fluid power instruction. We also focus on exposing young students to fluid power and the benefits of working in our industry. Our marquee program here is the NFPA Fluid Power Challenge—a design competition for eighth graders that teaches both engineering and fluid power. In its fourth successful year, more than 1,500 students have participated in this program.

continued

NFPA members discuss new marketing technology at the 2012 Annual Conference recently held in Hawaii (courtesy of the NFPA).

Q: Many associations don't offer the levels of market research and industry data that the NFPA gives to its members. Why is this information so important and how does the NFPA provide the best (and most recent) statistics to its members?

NFPA's information services are important because they help members plan ahead for changes in the industry and customer markets. To the extent that fluid power companies can anticipate changes, they can make adjustments that create competitive advantage. This is beneficial to individual companies, and also to the competitive position of the industry as a whole.

For example, if you can look at our data sources and use our tools to see a downturn coming, you may be able to make adjustments early that make it possible to retain more employees through the downturn. This is key to success and profitability because companies that are able to do this are better prepared to take advantage of upward movements in customer markets than their competitors. And retaining trained staff is vitally important in an era of growing workforce scarcity. It's going to be harder to hire when everyone else is hiring…after the economy has obviously begun to improve.

Q: Is membership up or down in 2012? What steps is the NFPA taking to increase membership in 2012?

Membership has been ticking upward in 2011 and 2012, reflecting the recovery of the industry. And, participation in association activities, such as conferences and our statistical programs, is on the uptick as well. Our membership focus is to develop services that support our members directly in their daily jobs. For example, we are making it easier to use our industry statistics programs by creating an interactive and customizable web-based dashboard so they get the information they need, how they need it, and when they need it. And we're developing more global sources of information to support member efforts to develop business overseas.

Eric Lanke, CEO of the NFPA, discusses the agenda at NFPA's 2012 Annual Conference (courtesy of the NFPA).

Q: Some people become members of associations by name only. What advice can you offer NFPA members to play a larger role in the association? What tools are available to help them become more involved?

Members who become more involved in the association have the opportunity to shape the services and benefits they receive, and can help generate greater value for their companies and themselves personally. NFPA members can participate on committees that create programs they benefit from, and many also benefit just from being able to work as a team with industry peers. We make it easy as possible to participate and balance respect for the time pressures they face with the value they need to generate. Committee participation is often a stepping stone to subsequent levels of involvement in NFPA governance, up to and including service on the NFPA board of directors.

Q: What does the future hold for the NFPA and for fluid power in general?

Fluid power will continue to be a major force in motion control. Our members have a track record of developing innovative products and uses for fluid power, and we're helping support development at the industry level. We look to see our technology compete strongly in traditional markets, and see new markets open up. 2009 was a tough year for this industry; but we are back standing tall in 2012. Many manufacturing industries can't say that, and it's a testament to our members and their leadership. We like to think it says something about the relevance of the services NFPA provides as well. There will almost certainly be another downcycle in this five year time period, but with NFPA's help, our members will be ready. We encourage you to learn more about NFPA's initiatives and other programs being launched over the upcoming months by visiting our website.

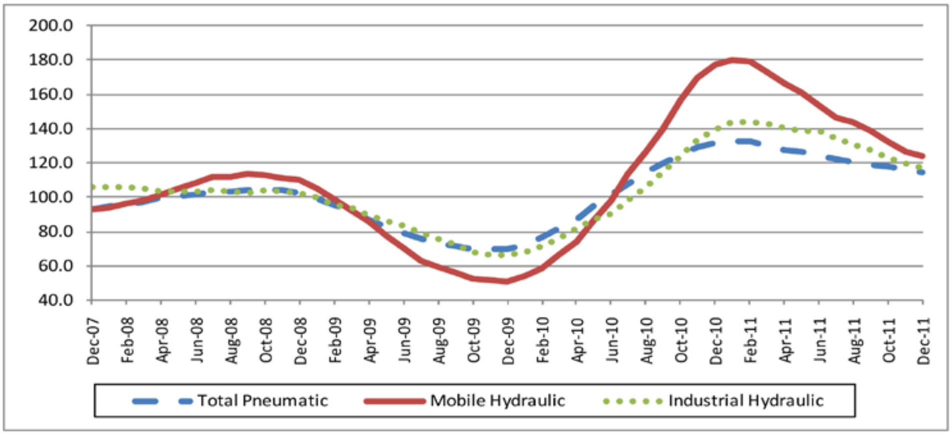
For more information:

National Fluid Power Association
3333 N. Mayfair Rd., Ste. 211
Milwaukee, WI 53111
Phone: (414) 778-3351
www.nfpa.com

Fluid Power Industry Growth Trend

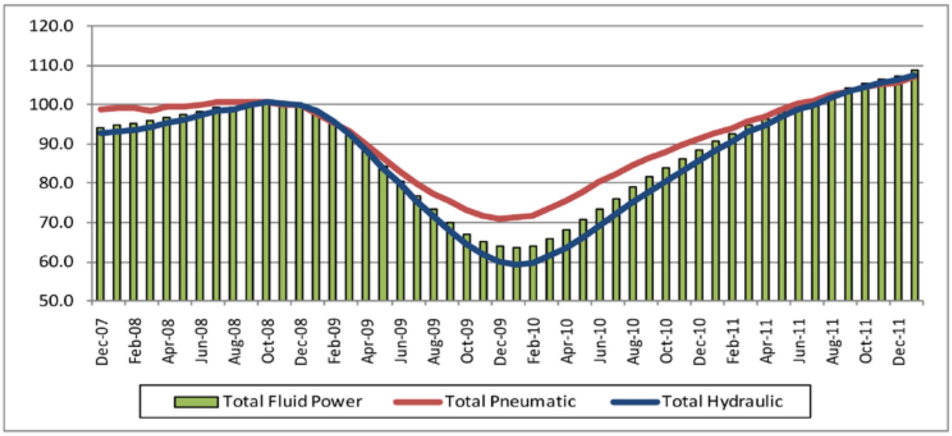
The latest data published by the National Fluid Power Association shows industry shipments of fluid power products for January 2012 increased 17.3 percent compared to January 2011, and increased 13 percent compared to last month. Mobile hydraulics, industrial hydraulics and pneumatics all showed growth in January 2012 when compared to January 2011, and also increased when compared to last month. The charts and table are drawn from data collected from more than 80 manufacturers of fluid power products by NFPA's Confidential Shipment Statistics (CSS) program. For more information, contact Eric Armstrong at (414) 778-3372, or email at *earmstrong@nfpa.com*.

Pneumatic, Mobile and Industrial Hydraulic Orders Index



Each point on this graph represents the most recent 12 months of orders compared to the previous 12 months of orders. Each point can be read as a percentage. For example, 117.3 (the December 2011 level of the industrial hydraulic series) indicates that industrial hydraulic orders received from January 2011 to December 2011 were 117.3% of the orders received from January 2010 to December 2010. (Base Year 2008 = 100)

Total - Hydraulic and Pneumatic Shipments



This graph of 12-month moving averages shows that in January 2012, both pneumatic shipments and hydraulic shipments increased. (Base Year 2008 = 100)

Shipments - Cumulative year-to-date % change (2011 vs. 2010)

	Total Fluid Power	Total Hydraulic	Total Pneumatic
	Shipments	Shipments	Shipments
Oct. 2011	22.8	26.5	17.2
Nov. 2011	22.1	25.4	16.6
Dec. 2011	21.2	24.2	15.8

The table above is expressed in terms of cumulative percent changes. These changes refer to the percent difference between the relevant cumulative total for 2011 and the total for the same months in 2010. For example, the December pneumatic shipments figure of 15.8 means that for the calendar year through December 2011, pneumatic shipments were up 15.8% compared to the same time period in 2010. (Base Year 2008 = 100)

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Sky Science

S.S. White Provides Twisting, Turning Power Transmission with Flexible Shafts

Matthew Jaster, Associate Editor

The flexible shaft is a power transmission device that provides rotary motion around bends and corners. It can be routed over, under and around obstacles that would make using a solid shaft impractical. Flexible shaft assemblies can be used in everything from 747s to children's toys. They have incredibly long lives and are not affected by continuous operation at speeds up to 50,000 rpm and temperatures as high as 1,000 degrees F and as low as -300. Though they are often confused with tension cables—both look the same from the outside—the dynamics of the wires inside flexible shafts are very different.

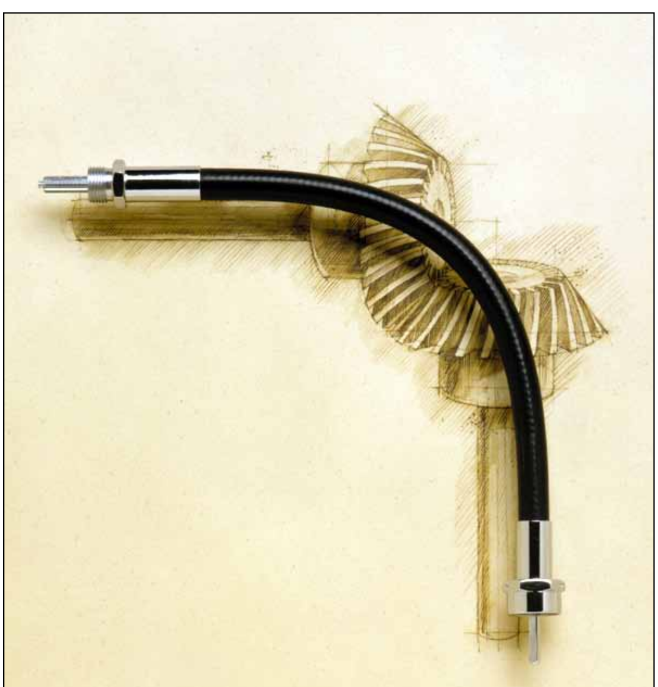
Photo courtesy of Airbus

The Anatomy of the Flexible Shaft

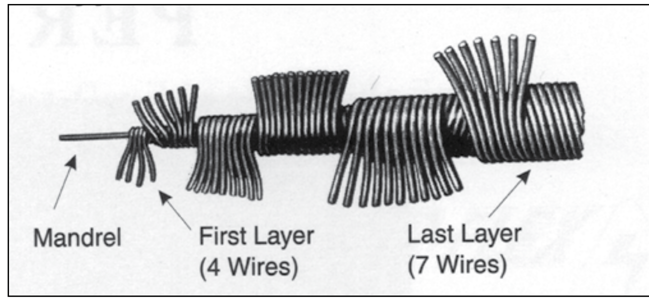
"Essentially, the flexible shaft consists of layers of wires with opposing pitch angles. You're basically applying a twisting motion to the shaft that would make the outer layer tighten down on itself while the layer underneath will be opening up, creating interference and high torsional stiffness," says Brian Parlato, vice president, sales and marketing at S.S. White Technologies. "It's the dynamics of these opposing forces that creates the magic behind flexible shafts."

The ability to twist and turn through obstacles like a pretzel is really what makes the flexible shaft unique. "This is a key consideration in designing and developing these for aerospace applications. It is never straight or just a simple radius; there's always a series of bends," Parlato says. "The flexible shaft takes a snakelike route through the aircraft in order to link actuators together, for example. The path is critical. It's important we're involved at the earliest stage of the system design to try to get the most beneficial path for the flex shafts. Just changing the bend radius by a couple of inches can increase the endurance life significantly."

S.S. White's engineers can maximize the shaft's torque carrying capability while retaining optimum performance characteristics of other key parameters. This is achieved with a proprietary computer modeling software program, called *Perflexion*, that can optimize the performance of any flexible shaft. *Perflexion* allows the design engineer to statistically capture and balance all of the properties of torsional strength, bending flexibility, torsional deflection, point of helix and others without compromising performance. *Perflexion* was conceived by taking S.S. White's own Dr. Adam Black's thesis on flexible shafts and essentially transforming it into a computer program.



This is a typical flexible shaft overlaid on a drawing of right angle spiral bevel gears. It shows how a flexible shaft can achieve the same outcome, but less expensively and more simply.



The construction of a typical flexible shaft starts with a single mandrel and then builds up layers of multiple wires wound at opposing pitch angles. S.S. White varies the size of the wires, the number of wires per layer, and the number of layers per overall diameter to achieve the specific performance requirements.

"Every application has its own unique routing path so no two applications are the same as a result," Parlato says. "Through the application of *Perflexion,* torsional strength can be increased by as much as 25 percent."

Another key innovation for flexible shafts in aerospace applications is a lubrication system known as Flexcellent. Developed exclusively by S.S. White, this system reduces the time-consuming and labor intensive removal and re-greasing of wire wound flexible cores at regular "C-check" intervals. Flexcellent reduces maintenance time, contamination and overall service costs. "Many of our flexible shafts run within hydraulic lines, but in other applications outside of hydraulics, they run inside a casing. Without proper lubrication, the shaft can overheat, wear, or fatigue. We've come up with a couple of interesting ways to lubricate the shaft," Parlato says.

Opportunities in Aerospace

The aerospace industry utilizes flexible shafts in thrust reversers, flaps and slats, cargo doors, rudder controls, etc. "A flexible shaft is responsible for providing power or synchronizing actuators on the aircraft," Parlato says. "Every application is custom. Essentially, you want the shaft to provide maximum torsional strength along with maximum bending flexibility. Then other factors like torsional deflection and point of helix come into play. Today, you'll find flexible shaft on almost every fixed and rotary aircraft on the market."

Two key applications for S.S. White in the aerospace industry are found in thrust reverser actuation systems (TRAS) and flaps and slats.

Thrust Reverser. The thrust reverser is used in aircraft engines to slow down the plane after landing. Flexible shafts provide power and also synchronize and connect the actuators that open and close both halves of the thrust reverser. "On smaller jet engines the thrust reverser basically consists of two large deflector plates coming together at the back of the engine to form a wedge. When the thrust hits the deflector plates it is redirected forward, slowing the aircraft down," Parlato says. "These two plates have actuators that move them back and forth. There's a motor and it drives the flexible shaft which drives the ball screw actuator." Larger, turbo fan engines use nacelle bypass ducts which are also actuated in a similar way by flexible shafts.

S.S. White provides flexible shafts for several thrust reverser systems. These flexible shafts can be ten feet long in some cases. Flexible shafts from S.S. White were utilized in the Rolls-Royce Trent XWB for a recent engine test flight of the soon to be launched newest member of the Airbus fleet, the A350. They have also been used in Airbus' A320 and A380 as well as Boeing's 787, 747, and 737.

When a major aerospace manufacturing firm needed flexible shafts for a thrust reverser system, they turned to S.S. White. The A380 Airbus was the first jet to include an electronic thrust reverser actuation system instead of a hydraulic or pneumatic powered system . "S.S. White has been extremely responsive to our needs," says a senior product support manager with 32 years experience in the aerospace industry. "They've been the main supplier of our flexible shafts for many years. They're willing to work with us and provide the quality support that's necessary in these high precision engineering applications."

Flaps and Slats. Flaps are hinged surfaces mounted on the trailing edges of an aircraft wing that help reduce the speed of an aircraft while landing. Slats are the surfaces on the front edge of the aircraft wing that improve airflow at high angles and also for landing. A leading motion and control technology firm provides the hydraulic motors (standard and custom) for flap and slat drive systems. S.S. White, in turn, provides a series of flexible shafts along the wing that drive the actuators that enable the flaps and slats to extend and retract. "A typical system would include five flexible shafts for a flap and five for a slat per plane, 10 flex shafts total," Parlato says. "These are found on regional jets like the Embraer ERJ 145 and Bombardier RJ200, typically seating not more than 50 passengers."

This is the center of an actuator which feeds power to the two adjacent actuators. So one shaft comes in and powers the center actuator and two shafts leave to power the adjacent actuators.

Engineering Challenges

One of the greatest challenges for S.S. White is being brought in late during the design stage. "Many companies that work with us for the first time think we can just come in and route the flexible shaft around everything else. While this is absolutely true, it becomes a much longer process if we're not

continued

involved at the beginning of the project. We can address all the variables that come into play if we're involved early in the design and development of the system. The shaft development can be very challenging otherwise," Parlato says.

While many industries have to deal with strict lead times for components, this is not a typical problem where commercial aircrafts are concerned. "Aircraft design and engineering is deliberate and time consuming, as it should be," Parlato says. "Every aerospace engineer is incredibly careful about what they're putting into the aircraft and they take their time to make sure it is right."

It could typically take more than two years to bring an aerospace system to market and this includes testing. For smaller planes, most of the development work can be accomplished in a year. Still, when dealing with components for aircraft applications, safety is a top priority and one that no one wants to put a timetable on.

"If the thrust reversers, for example, don't work properly, the plane won't stop at the end of the runway and things could get ugly," Parlato says.

Another challenge is quality control. S.S. White has put in an enormous amount of time and effort to ensure the company keeps up with the stringent requirements. "Quality is part of our culture. We are quality certified to both ISO 9001 and AS 9100 revC," Parlato says. "We can trace a wire back to the raw material we used to draw that wire. This is your ticket to entry in both the aerospace and medical environments."

Beyond Flexible Shafts

In order to gain new business in other industries, S.S. White purchased the surgical orthopedic division of Snap-On Inc. in 1999. S.S. White engineers now create state-of-the-art hand-held surgical instrumentation for the removal of orthopedic implants. "We took this business and grew it significantly," Parlato says. "In fact, the high quality demands of aerospace applications are just as significant in medical applications. You have to document everything you've discussed or even thought about in this industry. The regulations are very strict when it comes to surgical components and procedures. Our emphasis

The right hand side of this photo shows the flexible shafts ringing the nacelle and attaching to the actuators.

on quality in aerospace applications has certainly helped."

Parlato says that S.S. White also provides CNC components for various aerospace applications including valves and manifolds. "We plan to turn our attention to systems work in the future. It just makes sense to start getting involved in the design and development of the actual actuation systems." The company currently is focused on four areas including aerospace, medical, automotive, and CNC machining.

"We have 30+ CNC machines in our facilities and we've been providing all the machining for aerospace parts since 2005. This is an area we're looking to expand. There's currently a huge push in the Asia market and we think we can become a major player in that market in the future."

Still, the bread and butter at S.S. White can be found 30,000 feet above ground where each and every aircraft utilizes flexible shafts.

"Our claim to fame is that we understand the science behind flexible shafts," Parlato says. "We've defined the terminology and we've built the test equipment. It helps that we really speak the language of aerospace and have essentially become an aircraft company."

The Bombardier RJ200 plane with GERJ34 engines. The flexible shaft is visible going into one of the actuators which make up the Thrust Reverser Actuation System (TRAS).

For more information:

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www.sswt.com

From Teeth to Air Fleets

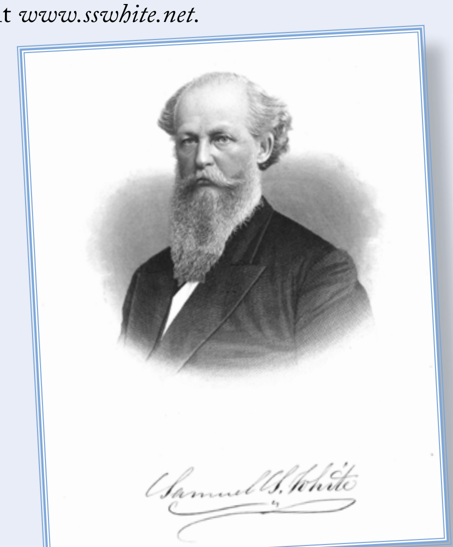
The history of the flexible shaft is a fascinating one that began in 1844. After setting up his own tooth factory in an attic in Philadelphia, Samuel Stockton White would spend decades building the largest dental manufacturing company in the world with sales offices in New York, Boston and Chicago. One of his employees, Dr. Eli Starr was an inventor with more than ten patents and the man responsible for introducing high speed flexible shafts in S.S. White dental engines.

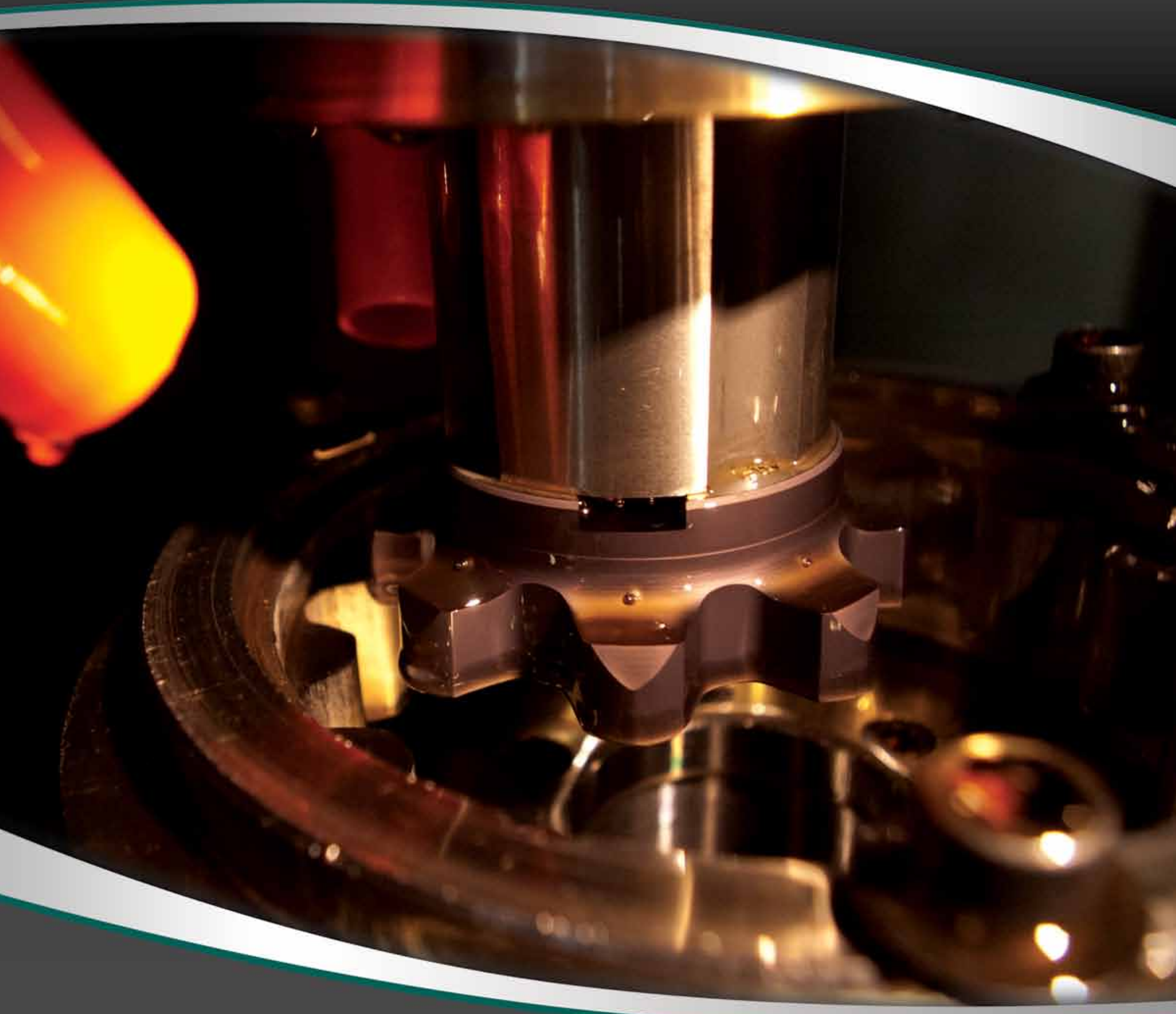
By 1881, the company took its flexible shaft into the industrial market. It replaced the drive links in speedometers found in automobiles like the Ford Model T (1915) and ended up in aircraft assemblies for the U.S. military (1941). "By World War II, engineers had come up with all sorts of interesting applications for the flexible shaft in the aerospace industry," says Brian Parlato, vice president, sales and marketing at S.S. White Technologies.

In 1972, the S.S. White Industrial Division relocated to its present day location in Piscataway, New Jersey and severed its ties with its sister company S.S. White Dental Manufacturing. The following year a young engineer named Rahul Shukla joined the company. Even though Shukla held three engineering degrees he had never heard of the term "flexible shaft". He spent the rest of the 1970s on tireless calculations, countless experiments, and lengthy research studies on the flexible shaft.

In 1984, senior research engineer Adam Black III joined S.S. White. After five years of field work on flexible shaft mechanics, Black submitted a doctoral thesis to The Stevens Institute of Technology. In 1987, a doctoral degree was awarded to Black for his research. Shukla purchased the company and became CEO in 1988. He changed the name from S.S. White Industrial Division to S.S. White Technologies, Inc.

Today, the company focuses on aerospace, medical, automotive and CNC machining with facilities in the United States, United Kingdom and India. For more information, visit *www.sswhite.net*.





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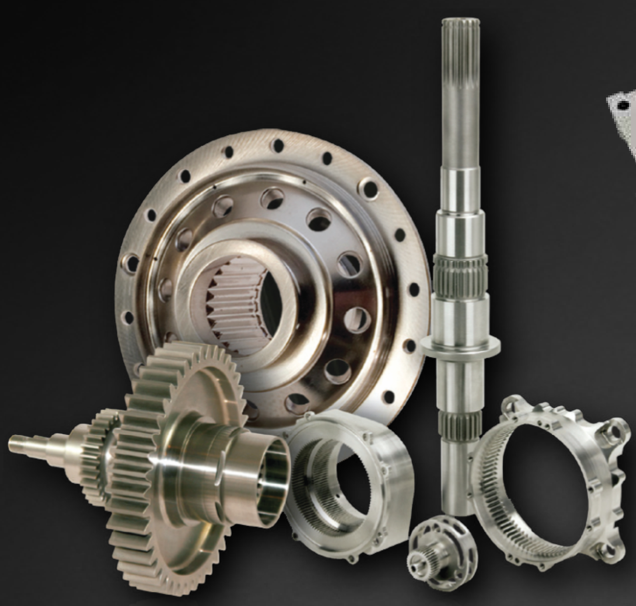

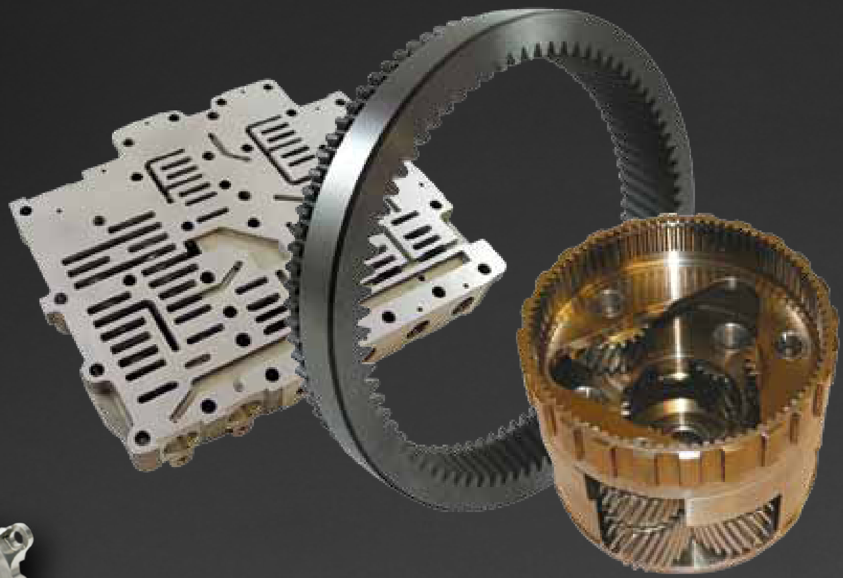

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University Improves Sustainability of HVAC Motors in Platinum LEED Building

Adam Willwerth

Introduction

A new preventive maintenance program at a leading New England Ivy League university demonstrates how the push for more sustainable "green" building management has led to a growing awareness of a chronic, widespread problem with HVAC motors—electrical bearing damage and failure.

Variable frequency drives (VFDs), also known as inverters, adjustable speed drives, etc., are widely used because they save energy—especially in applications with varying loads. Because many centrifugal fans and pumps run continuously, their motors use less power if the input is modulated by VFDs. For example, a 20 percent reduction in fan speed can reduce energy consumption by nearly 50 percent.

But if efficiency increases are not sustainable, their savings vanish. Shaft currents induced by VFDs can wreak havoc with bearings, dramatically shortening motor life and causing costly repairs. To mitigate these currents and realize the full potential of VFDs, a reliable method of shaft grounding is essential.

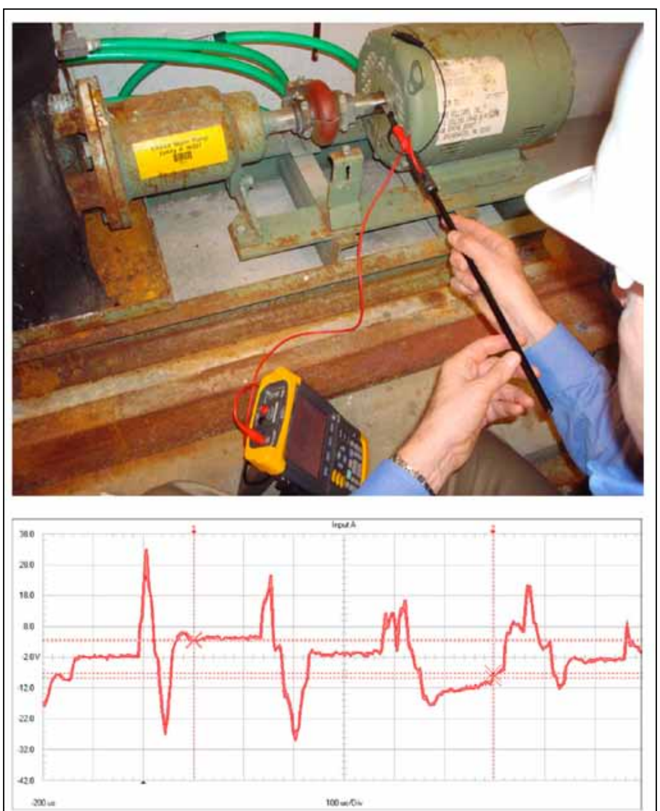

Figure 1—Motor #1 powers a chilled water pump with the VFD set at 60 Hz and motor running at 1,776 rpm (7.2 amperes).

And the problem is all too common. According to a recent survey of 1,323 construction projects valued at $5 million to $50 million each, the number of such projects specifying VFD-driven motors rose by 21 percent between June 2009 and November 2010. But only a fraction (about one out of six) of those sites installing new VFDs will protect their motors' bearings through shaft grounding. Consequently, there is a ticking time bomb out there—many of the motors recently fitted with VFDs are headed for trouble.

The referenced university's maintenance department has spearheaded a push for sustainability campus-wide through the renovation of its own headquarters. When completed in 2006, this complex received a Platinum Leadership in Energy and Environmental Design (LEED) rating—the highest rating awarded by the United States Green Building Council. More recently, the university also had the highest score on the College Sustainability Report Card, an annual grading of the "green credentials" of 300 colleges and universities.

One of the maintenance department's most significant efforts to foster sustainability at the more than 300 buildings it services is a testing program for HVAC motors controlled by VFDs. Many of the buildings have their own maintenance managers; whenever such a manager requests testing on a motor in his/her building, technicians from maintenance headquarters use portable oscilloscopes and voltage-measuring probes to determine whether or not shaft voltages are present—voltages that cause electrical discharges through the motor's bearings.

If harmful discharge levels are detected, the maintenance department may recommend the installation of a proven bearing-protection device that bleeds off the damaging currents—for example, the Aegis SGR Bearing Protection Ring. This shaft grounding ring safely redirects VFD-induced shaft voltages by providing a very low impedance path from shaft to frame and bypassing the motor bearings entirely. Key to the ring's success are conductive microfibers that line the entire inner circumference of the ring in two rows, completely surrounding the motor shaft. A protective channel in the ring allows the fibers to flex without breaking and keeps out debris.

The university maintenance department has already used the Aegis ring successfully for fan and pump motors in several new buildings on campus. Manufactured and sold by Electro Static Technology, the ring is available in two versions—a continuous ring or a split. Designed for installation with either brackets or conductive epoxy, the split ring (used in the university's retrofit program) simplifies and speeds field installations because it can be installed without uncoupling attached equipment.

The Importance of Shaft Grounding

The need to ground motor frames has long been recognized, but the need to ground motor shafts has only recently become clear. Along with proper tuning of a drive's frequency range output, an effective shaft grounding device is needed to prevent premature bearing failure. Ironically, some products designed to protect bearings—such as conventional grounding brushes—require extensive maintenance themselves. Others—such as insulation—can shift damage to connected equipment.

As a demonstration of the university maintenance department's new program, Aegis rings were installed in December 2009 by the ring's manufacturer on two VFD-controlled HVAC motors in the basement of the maintenance headquarters, which is cooled in the summer by ground-source heat pumps. Motor No. 1 powers a chilled water pump; Motor No. 2 is an identical motor that runs an air supply fan. Both were 3-year-old Baldor 7.5 hp motors (NEMA frame size 213T, shaft diameter 1.389"). Unfortunately, both motors made a high-pitched whining sound, indicating that "fluting"—i.e., bearing damage caused by electrical discharges—had already occurred. Obviously, shaft grounding provides the best protection when installed on a new motor or a motor with recently replaced bearings.

Motor No. 1. Before the grounding ring was installed on Motor No. 1, the shaft guard was removed. With the VFD set at 60 Hz, the motor was running at 1,776 rpm (7.2 amperes). When a voltage probe was held against the motor shaft, the oscilloscope (set at 10 volts and 100 microseconds-per-division) indicated peak-to-peak discharges of 61 volts. The oscilloscope display showed rapid voltage collapses at the trailing edge of the waveform—typical of the electrical discharges that damage bearings.

After the readings, the shaft was cleaned with fine-grit sandpaper and wiped with an alcohol-dampened rag. Paint was removed from the motor end bracket with a Dremel rotary tool and a small wire-brush bit to expose a bare metal surface against which the grounding ring would be mounted with conductive epoxy. In addition to the split-ring Aegis SGR, the manufacturer's kit contained tubes of conductive epoxy and activator. The tape was then removed from one joint of the ring, allowing it to be opened, to fit over the motor's shaft without the need to de-couple and realign the motor to the pump.

Equal proportions of epoxy and activator were then mixed, and small amounts were applied to the back of the ring.

Prior to installing the ring, a narrow band of Aegis colloidal silver coating was applied around the shaft where the fibers contact it, to improve the surface conductivity. The ring was then installed on the shaft and re-taped.

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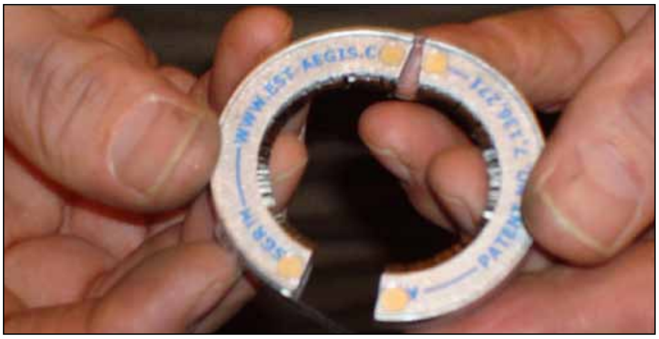

Figure 2—Equal proportions of epoxy and activator are mixed and small amounts are applied to the back of the ring.

Figure 3—Narrow band of Aegis colloidal silver coating is then applied around the shaft to improve surface conductivity. Ring is then installed on the shaft and re-taped.

Figure 4—Ring is pushed back against bare metal of end-bracket, maximizing electrical contact via conductive epoxy. To ensure ring is correctly centered on shaft, metal spacers (included in the kit) are inserted into gaps between two halves of ring. Post adhesive cure, spacers are removed. Installation time: about 10 minutes.

Next, the ring was pushed back against the bare metal of the end bracket, maximizing electrical contact via the conductive epoxy. To ensure that the ring was correctly centered on the shaft, small metal spacers (included in the kit) were inserted into the gaps between the two halves of the ring. Once the adhesive cured, the spacers were removed. The entire installation took about 10 minutes.

Approximately an hour after installation the epoxy had cured sufficiently to allow testing of the motor again with the oscilloscope and probe. This time, with the VFD set at 60 Hz, the motor running at 1,775 rpm (7.4 amperes), and the oscilloscope set at 10 millivolts and 100 microseconds-per-division, the discharge plot displayed on the scope was essentially a straight line—indicating that shaft voltage discharges were being diverted by the Aegis ring to ground.

Motor No. 2. Motor No. 2 was more difficult to reach because it was located in a tiny room sealed with bulkhead doors to contain noise and rushing air. Pre-installation shaft discharges were measured at 50.8 volts (peak-to-peak).

Figure 5—One hour after installation, epoxy has cured and motor again tested with oscilloscope and probe. Now—with VFD set at 60 Hz; motor running at 1,775 rpm (7.4 amperes); and oscilloscope set at 10 millivolts and 100 microseconds-per-division—discharge plot displayed on scope is essentially a straight line, indicating shaft voltage discharges were diverted by Aegis ring to ground.

Figure 6—Unlike Motor #1, the Motor #2 shaft is difficult to reach, with only a couple of inches between the end-bell and a sheave exposed; the versatility of the split-ring Aegis SGR and ease of installation using conductive epoxy become even more apparent.

The shaft was cleaned and prepared in the same manner as that used for Motor No. 1, but because the motor shaft was difficult to reach and only a couple of inches of it between the end-bell and a sheave were exposed, the versatility of the split-ring Aegis SGR and the ease of installation using conductive epoxy became even more apparent—and necessary.

A hand-held heater was used to speed the epoxy's cure, and about a half-hour after installation, the shaft voltage was measured again. This time the reading was only 380 millivolts, peak-to-peak.

A Closer Look at Bearing Damage

The cumulative bearing damage caused by VFD-induced shaft voltages and resulting bearing currents is often overlooked until it is too late to save the motor. The high peak voltages and extremely fast voltage rise times (dv/dt) associated with the insulated gate bipolar transistors (IGBTs) found in today's typical pulse-width-modulated VFD cause non-sinusoidal currents that can overcome standard motor insulation. Hard to predict but easier to prevent, this damage can occur even in motors marketed as "inverter-ready." Without some form of mitigation, shaft currents can discharge to ground through bearings, causing unwanted electrical discharge machining (EDM) that erodes the bearing race walls and leads to excessive bearing noise, premature bearing failure and subsequent motor failure.

When a VFD-controlled motor fails, warranty claims against motor and VFD manufacturers may be invalidated. Because systems that use VFDs are so varied and the potential causes of failure so numerous, even when the VFD and motor are properly rated and perfectly matched to each other and neither is inherently defective, the liability question usually amounts to a circle of pointing fingers. For many years, the problem of VFD-induced bearing damage was often misdiagnosed, until repair shops and testing consultants proved the connection.

Inadequate grounding significantly increases the possibility of electrical bearing damage in VFD-driven motors. Viewed under a scanning electron microscope, a new bearing race wall is a relatively smooth surface (Fig. 10). As the motor runs, tracks eventually form where ball bearings contact the wall. With no electrical discharge, the wall is marked by nothing but this mechanical wear. Bearings are designed to operate with a very thin layer of oil between the rotating ball and the bearing race, but if shaft voltages build up to a level sufficient to overcome the dielectric properties of the lubricant, they discharge in short bursts along the path of least resistance—typically the bearings—to the motor's frame. Without proper grounding, VFD-induced electrical discharges can quickly scar the race wall.

During virtually every VFD cycle, these induced currents discharge from the motor shaft to the frame via the bearings, leaving small fusion craters in ball bearings and the bearing race wall that eventually lead to noisy bearings and bearing failure. In a phenomenon called fluting, the operational frequency of the VFD causes concentrated pitting at regular intervals along the bearing race wall, forming washboard-like ridges. Fluting can cause excessive noise and vibration. In an

HVAC system, the noise may be magnified and transmitted by ductwork throughout the entire building.

Sustainable Shaft Grounding Technology

To guard against such damage and thus extend motor life, the VFD-induced current must be diverted from the bearings by means of mitigation technologies such as bearing insulation and/or an alternate path to ground. But bearing insulation and ceramic bearings do not protect attached equipment and conventional shaft-grounding brushes often create more maintenance problems than they solve.

Because the problem is best addressed in the design stage of a system, the best solution arguably would be a motor with built-in bearing protection, available at a reasonable cost. Although both Baldor Electric and General Electric now offer the Aegis ring on certain models, most standard motors do not provide bearing protection and only specify Class F, G or H insulation for the windings.

Fortunately, bearing damage can be mitigated by retrofitting previously installed motors with a shaft grounding ring such as the Aegis ring.

The versatile ring is available for any NEMA or IEC motor, regardless of shaft size, horsepower or end-bell protrusion. These rings have been successfully applied to fan motors, pump motors, compressors, generators, turbines, AC traction and break motors, and a long list of other industrial and commercial applications.

For VFD-equipped motors of less than 100 hp (75 kW), a single Aegis ring on the drive-end or non-drive-end of the motor shaft is typically sufficient to divert harmful shaft currents. For most motors above 100 hp (75 kW), or motors with roller bearings, a combination of insulation on the non-drive-end with an Aegis ring on the drive-end provides the best protection in order to break a potential circulating current in the bearings while discharging the shaft voltage to ground.

Once installed, the Aegis grounding ring requires no maintenance and lasts for the life of the motor—regardless of rpm. Test results show surface wear of less than 0.001" per-10,000-hours of continuous operation and no fiber breakage after two million direction reversals.

Conclusion

Operations and maintenance costs are often 60–80 percent of the total lifecycle costs of a building. With equipment that does not have to be repaired or replaced as often, that percentage will drop. Energy-saving technology must be sustainable to help reduce these costs. In the case of VFDs, to "bank" cost savings from their reduced-energy usage, users must protect the bearings of motors controlled by the VFDs with proven long-term, maintenance-free shaft grounding such as that provided by the Aegis SGR Bearing Protection Ring.

The university's maintenance department estimates that several hundred motors campus-wide could benefit from this technology, and they are hoping the test results will entice individual building managers to contact the department for an evaluation. In keeping with its green mandate, the department is aggressively promoting the Aegis ring as a way of realizing the full energy and cost-saving potential of VFDs.

Figure 7—Hand-held heater is used to speed epoxy's cure; post-curing, shaft voltage is measured again, showing a reading of only 380 millivolts, peak-to-peak.

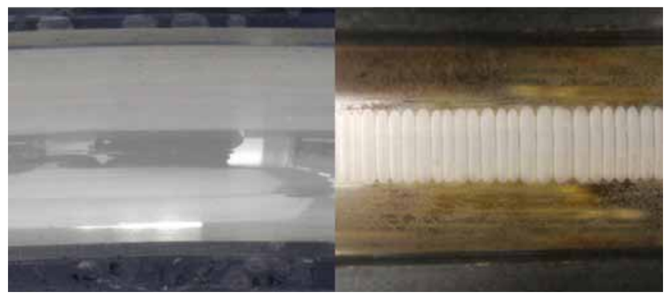

Figure 8—New bearing (left); fluted bearing (right).

Figure 9—Aegis grounding ring requires no maintenance and lasts for life of motor, regardless of rpm.

Adam Willwerth *has extensive experience in industrial product development and commercialization. He is named on four patent applications pertaining to conductive microfiber shaft grounding ring technology and has presented seminars on the subject of bearing current mitigation at professional conferences in the U.S. and Europe. He holds a Master of Business Administration degree from Southern New Hampshire University and a Bachelor of Science degree in management from the University of Maryland.*

Gearbox Bearing Service Life: A Matter of Mastering Many Design Parameters

Hans Wendeberg

Management Summary

The availability of high-strength shaft materials, in combination with bearings with high carrying capacity, allows use of slimmer shafts. However, the modulus of elasticity remains the same, so seat design for bearings and gears must be given close attention.

Introduction

The service life of a gearbox is determined by many factors. Bearings, for example, play a major role since they contribute an important function while also interacting with the shafts, casing and oil. Without a doubt, the sizing of the bearings is of great importance in gearbox reliability. For over 50 years, bearing dynamic carrying capacity has been used to determine a suitable size needed to deliver a sufficient fatigue life. But despite the existence today of advanced calculation methods, they do not fully predict service life. Producers of high-quality bearings have introduced better ways to express (quantify) improved performance, but only in terms of increased dynamic carrying capacity.

This article will cover the following:

- Sizing of bearings based on dynamic carrying capacity and how this relates to service life
- How the design of the interface between bearing and shafts should be adapted to modern shaft materials
- How the design of the interface between bearing and gearbox casing influences service life of the gearbox
- Influence of modern electric motor speed controls on bearing-type selection

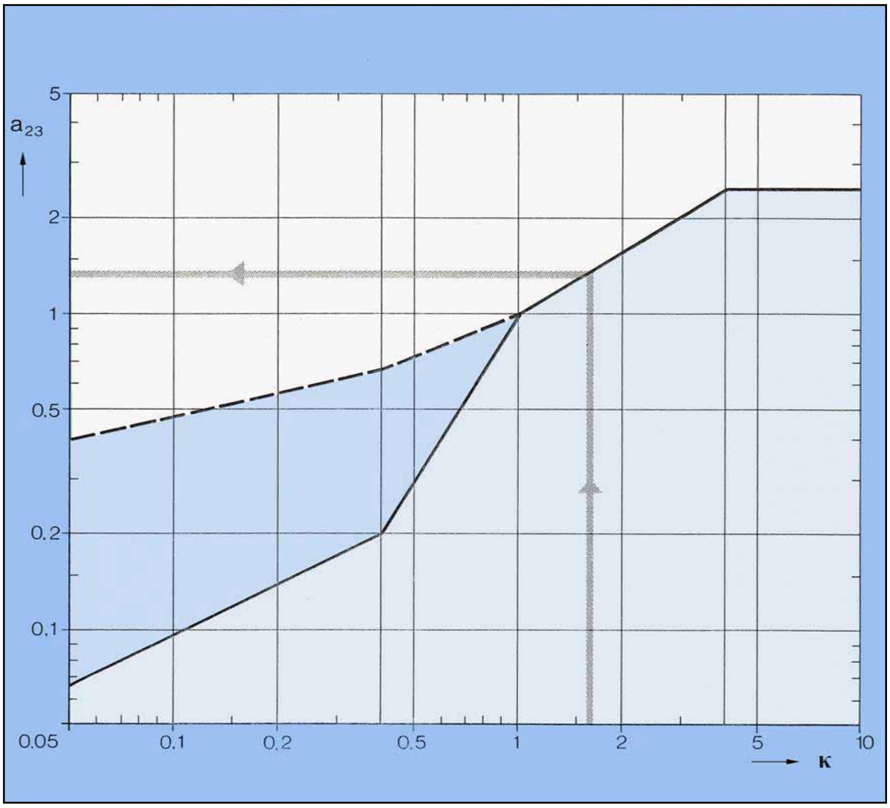

Figure 1—Life adjustment factor a_{23} for oil film influence.

Sizing of rolling element bearings based on dynamic carrying capacity. For modern high-quality bearings, the classic basic rating life can deviate significantly from the actual service life in a given application. Generally speaking, service life in a particular application depends not only on load in relation to bearing size, but also on a variety of influencing factors, including lubrication, the degree of contamination, misalignment, proper installation and environmental conditions.

The first method accepted by ISO for determining a suitable bearing size is the classic Lundberg and Palmgren equation $L_{10} = (C/P)^p$, making it possible to determine a suitable dynamic C-value (which in turn defines the bearing size) needed to satisfy a need for a fatigue life L_{10}.

The influence of material properties and lubricant film thickness was introduced in the 1960s, represented by the a_{23} factor (Fig. 1).

$$L_{10} = a_{23}\,(C/P)^{P}\;[a_{23} \text{ is a function of } \kappa \text{ and the material}] \quad (1)$$

As an attempt to take some of those factors into account when determining a suitable bearing size, the DIN ISO281:1990/AMD2:2000 contains a modification factor a_{SLF} to the basic rating life $L_{10} = (C/P)^{P}$. The method makes provision for bearing manufacturers to recommend a calculation methodology for this life modification factor to be applied to a bearing based on operating conditions. Some life modification factors apply the concept of a fatigue load limit P_u analogous to that used when dimensioning other machine components. Furthermore, the life modification factor makes use of the lubrication conditions and a factor η_c for contamination level to reflect the application's operating conditions.

Basic Conditions

The life modification factor considers bearing load level, oil film thickness and the stress-inducing influence of indentations in raceways and rollers from oil contaminants.

The influence of the oil film thickness is strong, and is represented by the κ–value. κ is the ratio of the actual operating viscosity to the rated viscosity for adequate lubrication (Ref. 1).

The influence of indentations from oil contaminants is very important, and complex to model. The η_c–value (contamination factor) acts as an inverted stress concentration factor defined as a value between 0 and 1, where 0 represents "severe contamination" and 1 represents "extreme cleanliness." The DIN ISO 281 Addendum 4:2003 describes a method to obtain an η_c–factor for a given application. SKF has developed a standardized method to estimate the η_c–value using load level; oil film thickness; size and type of contamination particles; mounting practice; filter effectiveness; and seal effectiveness into account (Refs. 2–3).

$$L_{10m} = a_{SKF}\,(C/P)^{P}\;[a_{SKF} \sim \kappa, \eta_c, P_u, P] \quad (2)$$

SKF and other bearing producers over the last decade have introduced high-performance-class bearings that are given higher dynamic carrying capacity figures and, in SKF's case, another scale for the life modification factor a_{SKF} to adapt L_{10m} calculations to the new technological developments in material and manufacturing (Fig. 2).

Therefore, the development from the purely sub-surface fatigue theory—"Acta Polytechnica" from Lundberg & Palmgren (Ref. 4) equation $L_{10} = (C/P)^{P}$—to a more realistic bearing application model, has introduced some adjustment factors to account for other, influencing phenomena in the sizing of rolling bearings. Observe that by choosing how to define the different factors in relation to the operating conditions—such as lubrication quality and oil cleanliness—it is possible to consider more effects than load, exclusively; this makes it trickier to evaluate bearings from different manufacturers based only on published dynamic carrying capacity figures.

Limitations of the classical and modified sizing models. The different issues of the L_{10} models for determining bearing

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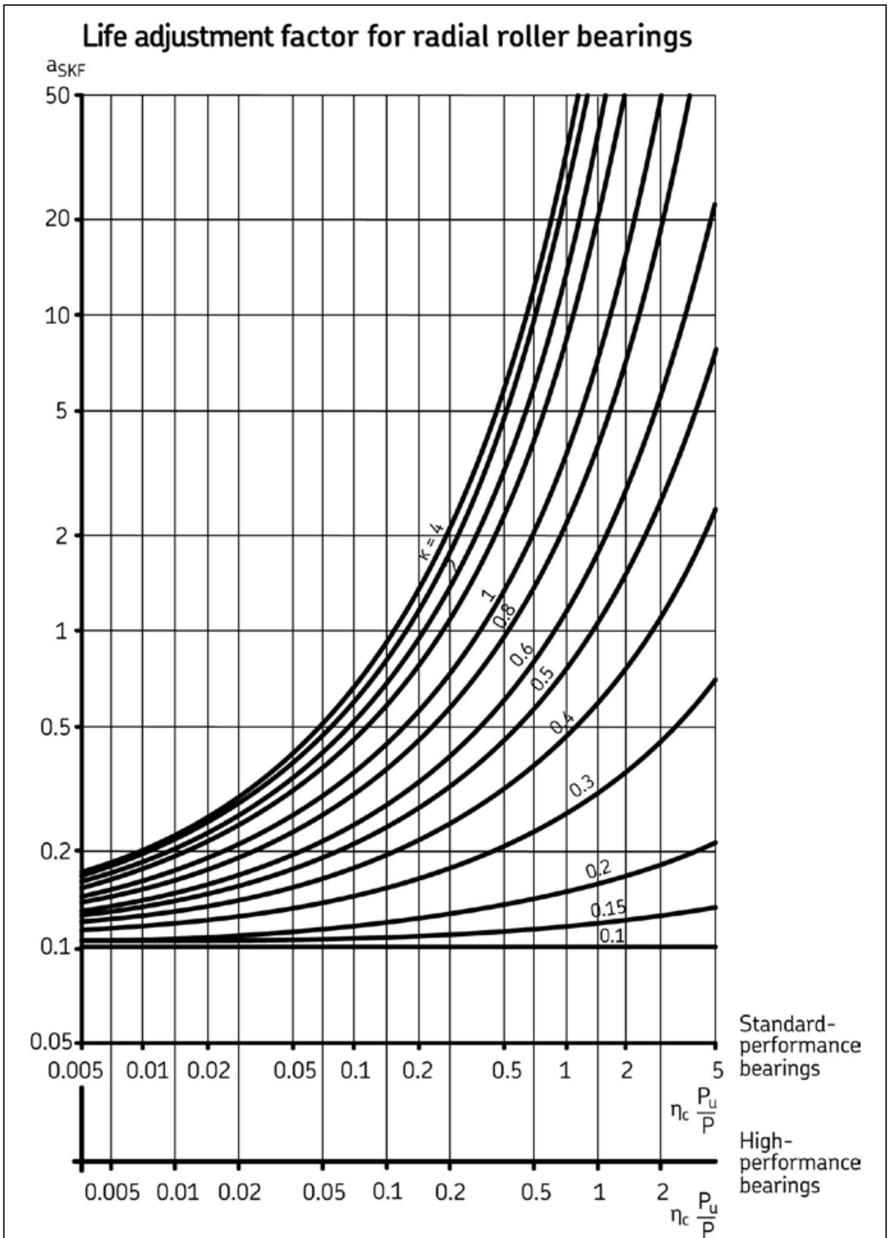

Figure 2—Life adjustment factor a_{SKF} for oil film quality, load level and indentation influence; separate "high-performance scale."

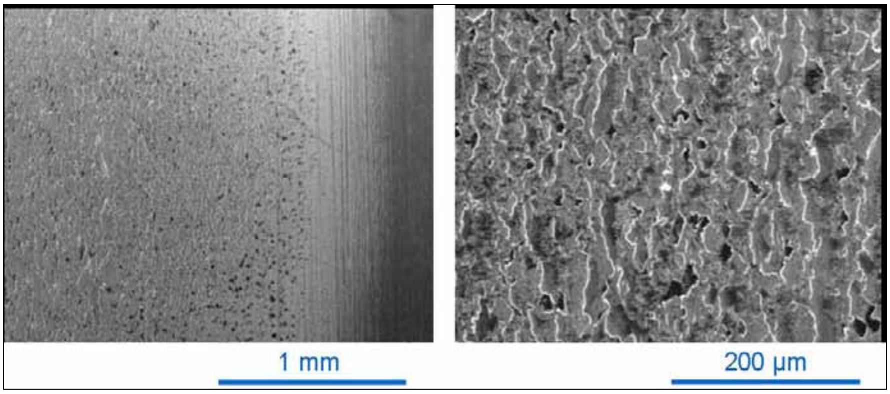

Figure 3—Surface distress.

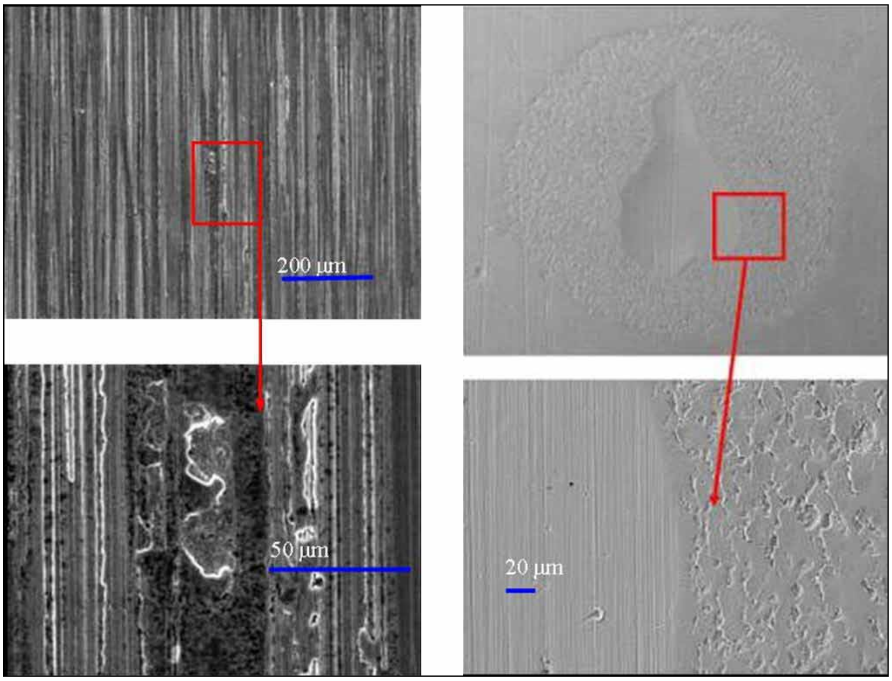

Figure 4—Surface distress on asperity summits (left) and in the area around an indent (right).

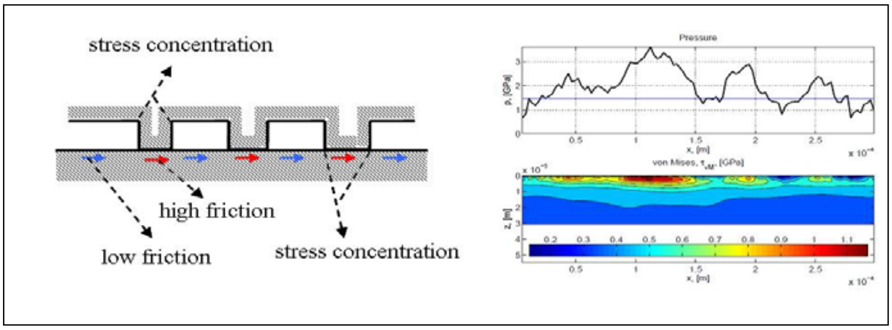

Figure 5—Schematic representation of the traction discontinuities and stress concentration areas in boundary or mixed-lubrication regime of rough surfaces.

size are well-grounded in mathematical models and practical testing, but limited in the use of only one failure mechanism—i.e., fatigue of the raceways or the rolling elements to deliver a suitable service life when determining a suitable bearing size. In the a_{SKF} diagram, very thin oil film (e.g., κ equal to 0.1) is associated with a life modification factor of 0.1—independent of load level—which is to be understood as predominant, surface-induced fatigue. In the bearing (and in the adjustment factor model), surface-induced fatigue gains importance at low values of κ and η_c.

Wear from abrasive particles in the oil film is a complex phenomenon. It will, for instance, surely change the contact geometry—which in turn will change the wear progress—so its progress is difficult to predict. Work on predictive models is in progress but will not be discussed here in detail. Recent findings in the field of surface distress in the thin-film regime—applicable to bearings in the lower-speed part of gearboxes and on gears—are, however, bringing new insights that are finding practical applications in bearing design and manufacturing (Ref. 1).

Surface Distress

In many industrial applications having lubricated rolling/sliding contacts (rolling bearings, gears, cam-followers) the power density has increased accordingly, due to the need for higher efficiency, reduction of weight and costs (i.e., downsizing). However, with the increasing severity of the working condition—that is, by heavier loads in combination with higher temperatures, thinner oil films and/or boundary lubrication conditions—machine components can sometimes suffer from surface distress (Ref. 5). This phenomenon manifests itself initially with a change of coloration/dull appearance of the surface, and grows as the damage progresses. Under the microscope, the affected surface areas show the presence of tiny microspalls, microcracks or micropits (Fig. 3).

Today it is recognized that surface distress is a surface damage phenomenon associated with poor lubrication conditions, thus high, local friction and pressures at asperity level. This phenomenon has been the subject of many recent experimental and numerical studies (Refs. 7–12).

Surface Friction

Real contacts, even when running under "nominal pure rolling" conditions, always have a small amount of slip; this results in some sliding friction and, consequently, in the possibility of surface distress risk. Testing has shown that nominal, pure rolling conditions can also exhibit surface distress. Under equal conditions and number of cycles, it has also been found that as the boundary friction coefficient is increased, surface distress is more severe. One easily concludes that boundary friction is a very important factor in promoting surface microcracks when the contact operates under boundary or mixed lubrication.

Importance of Lubrication and Roughness

Lubrication plays a major role in the life performance of rolling bearings, which is why life models account for the effect of the lubrication parameter κ (Ref. 1). The importance of lubrication and roughness in surface damage is very much related to the effect of local friction forces and stress concentrations (at asperity level). In boundary or mixed-lubrication, having irregularities (roughness or indentations, Fig. 4) on the surface will influence the way the dry and lubricated spots are distributed within the contact. Furthermore, discontinuities on surface traction and possible stress concentrations (Fig. 5) must also be considered. High roughness or high roughness slopes might promote local film collapse, high contact pressures and tractions. This will enhance stress concentrations in the critical areas of traction discontinuities.

Indeed, from the test results and theoretical modeling, surface distress appears first in areas of pressure discontinuities (high-pressure gradients) associated with increased roughness. It becomes apparent on the borders of grooves or in the summits of asperities or surface rises from indentations (Fig. 4). Rather unexpectedly, it is, in general, the smoother of the two mating surfaces that will first start the distress process. Some observations that may help to explain this discussed in the next section.

The Contact of Two Rough Surfaces

In industrial applications the contact always takes place between two real surfaces having a certain roughness. This is also the case in tests carried out using a surface distress test rig (SDTR), which has a rotating rod in contact with three discs (hardened bearing steel). As observed, when the test rod was rougher than the load-applying discs, surface distress did not appear for a reasonable time—even under the harshest conditions (Fig. 6a). However, when the discs were rougher than the rod (Fig. 6b) the surface distress easily appeared on the rod surface. This is also a common observation elsewhere (Ref. 11). As discussed (Ref. 13), the most likely explanation for this is the load history from the fatigue microcycles imposed by the roughness.

When the conditions in the contact are, in general, more towards boundary or mixed-lubrication, the stress history is then imposed by the dominant, rougher surface upon the smoother one, as long as there is some sliding. In real contacts, both surfaces will be rough and in movement (with some sliding); but if they have different roughness, the rougher surface will prevail over the smoother when imposing load microcycles. Therefore, the smoother surface is more susceptible to surface distress in the presence of some sliding, provided that the mechanical properties of both surfaces are the same.

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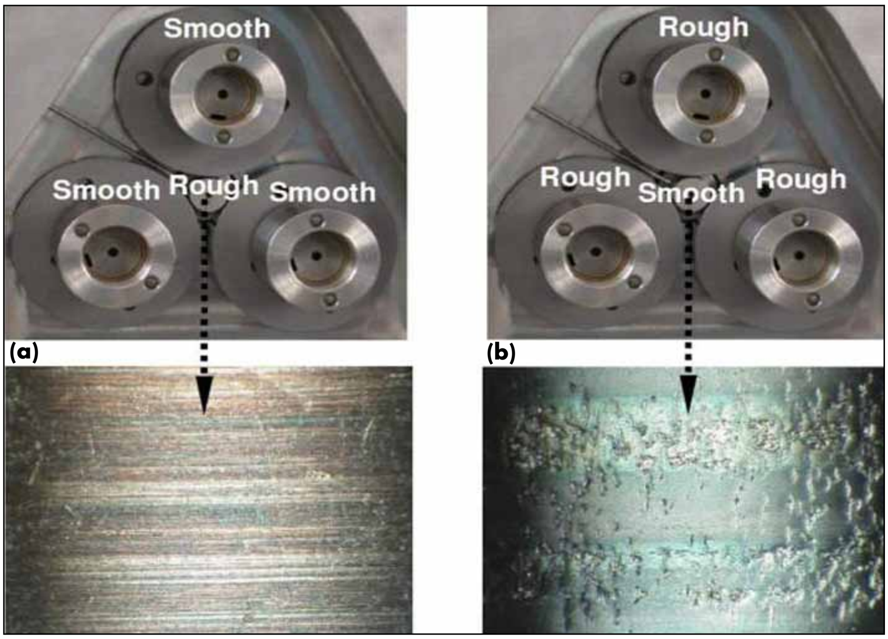

Figure 6—Effect of roughness location: (a) smooth discs on rough rod, and (b) rough discs on smooth rod.

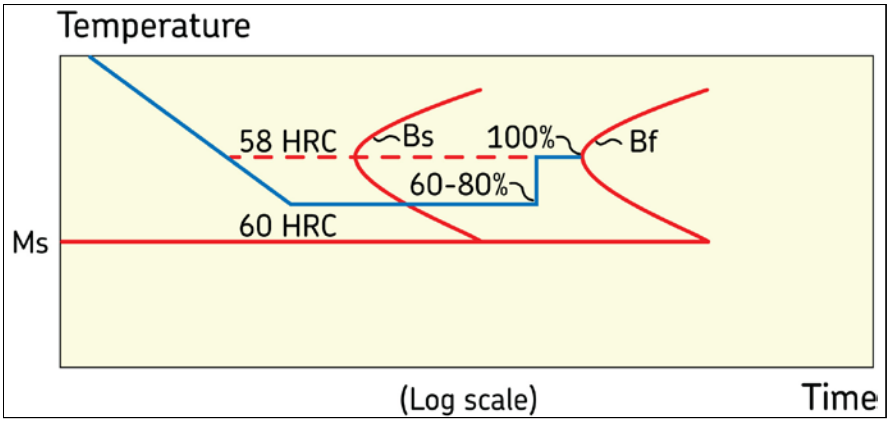

Figure 7—Bainite transformations with conventional and new process.

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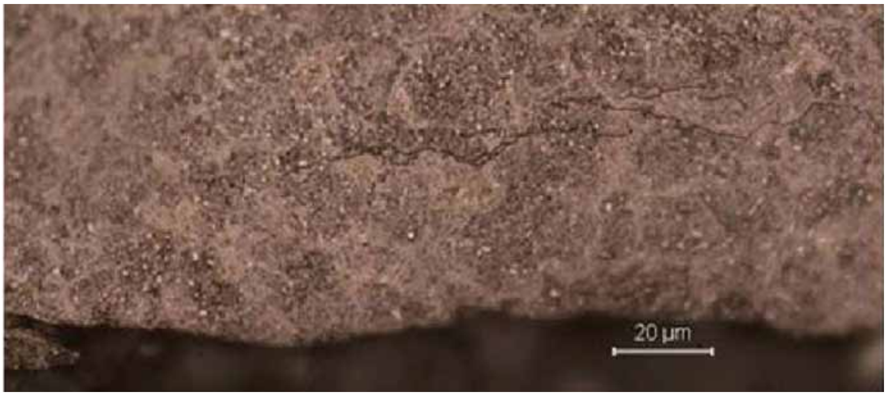

Figure 8—Severe wear damage phase under contaminated conditions.

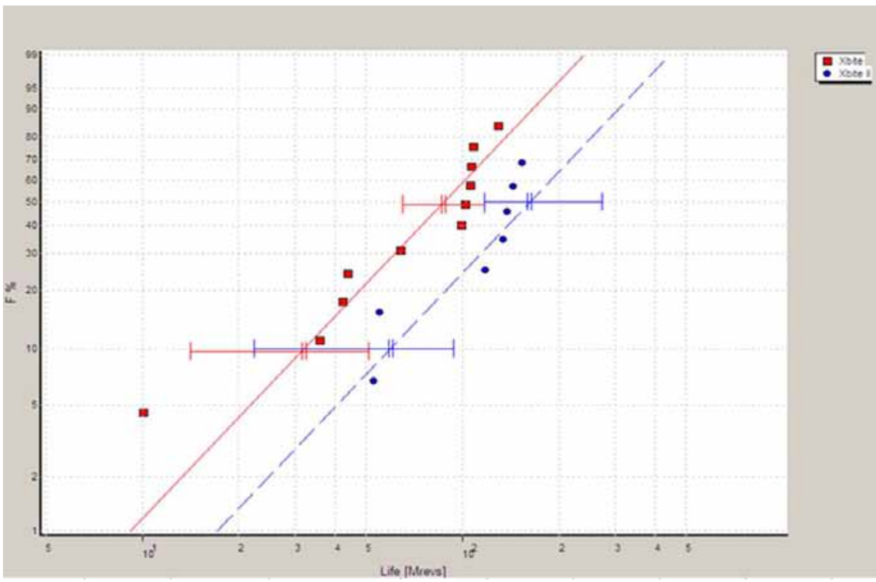

Figure 9—Weibull estimates for bearings tested under severe contaminated conditions.

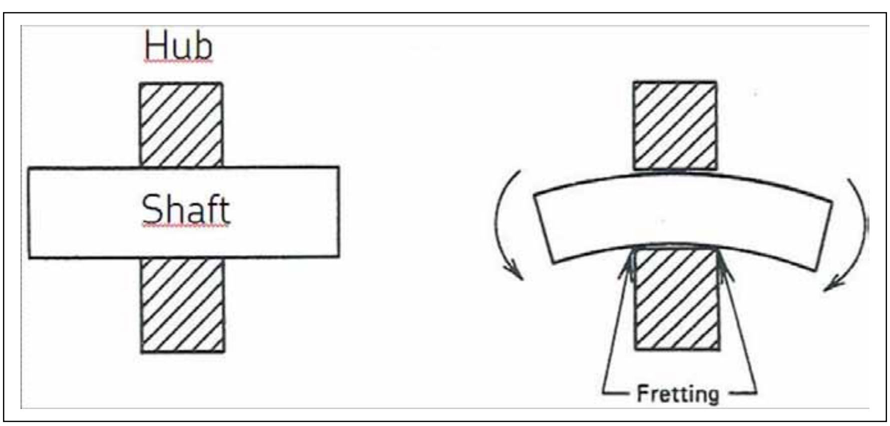

Figure 10—Straight shaft seat critical fretting points (Ref. 14).

Improving Wear and Metallic-Surface Contact Resistance

One way to enhance wear resistance is to increase the hardness of the components in contact. But this has consequences. If hardness increases, toughness is reduced, as well as a safe failure mode; spalling occurs instead of cracking, leading to catastrophic failure.

Development work was performed to find a way to improve the resistance to surface-initiated damage without losing the fundamental advantages of current processes. The bainite hardening used today can be manipulated to retain toughness, compressive residual stresses and—at the same time—increase wear and debris-contaminated condition life without loss of productivity. The process (patent-protected; Fig. 7) provides products with prolonged life under harsh running conditions while retaining all the benefits of existing long-term, successful hardening processes.

Wear tests conducted using significant amounts of debris in the form of chilled cast iron particles significantly delay the onset of heavy wear (Fig. 8).

Tests run under marginal lubrication conditions confirm the advantages of the new heat treatment method—about twice the life is attained under very low kappa conditions (Fig. 9).

This enhanced heat treatment will become the future standard and enhance the ability of bearing components to withstand environmental threats posed by application conditions encompassing debris contamination and marginal lubrication.

How the design of the interface between bearing and shafts should be adapted to modern shaft materials. Another surface failure-related mechanism that may limit the performance of a gearbox is fretting. Modern, high-strength steels offer great possibilities for transmitting high torque and load in gearbox shafts and gears, despite limited dimensions. However, modern high-strength steel still has the same modulus of elasticity as older, lesser steel material. Hence the deflection for a given condition is the same; conversely, if the increased stress resistance of a better shaft material is utilized, the shaft will deflect and/or twist more than if a less-stress-resistant material (resulting in a larger diameter shaft) was used.

To avoid damage to the joints between shafts, rings, hubs or gears, any increased shaft deflection/twisting due to downsizing requires close attention to the design of the shaft seats.

On Fretting Developing to Shaft Cracking

In a mechanical context, fretting is commonly used to describe wear and/or corrosion caused by small movements in interfacing, metallic surfaces. Also, surfaces that bind to each other via friction, e.g., interference fit joints, will, when the frictional binding force is overcome, move in relation to each other. This motion will also cause exposure of the metallic surfaces with oxidation as result. Typically, the oxidation results in discoloring. If the relative motion is large and the contact pressure high, the relative motion may, however, develop fretting. And if the fretting occurs in a critical place on a shaft surface, it may initiate surface damage that propagates to shaft breakage (Fig. 10.)

In a rolling bearing context, bearing suppliers work with fitting practices aimed at eliminating fretting caused by bearing rings subjected to rolling element loads. In the vast majority of rolling bearing applications, this is sufficient because the bearings are mounted in shaft positions where the bending/torsional stress is very low. In this situation, contact pressure between ring and shaft is only needed to eliminate motion/fretting—mainly from the shear stress between seat and ring bore resulting from the rolling elements.

In positions where shaft bending/twisting is more pronounced, the seats for shrunk components must be designed in a way that permits local motion and development of a limited surface damage without risk that the surface damage propagates. Using uncomplicated calculations, it is easy to show that interference between an inner ring and a shaft cannot eliminate motion caused by bending and or torsion. A solution to limit and "disarm" fretting due to shaft bending/torsion has to be sought outside the interference-dependent contact pressure domain.

Example: More Interference is Not Always a Solution

The contact pressure between a rectangular cross-section ring and a massive shaft when the ring is shrunk onto the shaft is expressed as a function of the ring hoop stress:

$$p = \frac{(d_e - d_i)}{d_i} \sigma_{hoop} \quad (3)$$

where:
d_e is ring inner diameter, mm
d_i is ring outer diameter, mm

For bainitic-hardened rings, a maximum hoop stress of 100 MPa is allowed from a fatigue life influence point of view; maximum contact pressure expected between a bainitic-hardened inner ring and a shaft is estimated at $100 \times (d_e - d_i)/d_i$ (MPa).

The inner ring dimensions of a bearing depend on the cross-section. For a typical ISO diameter series 0 roller bearing, the radial thickness of the inner ring is roughly 5.5–7.5 percent of the bore diameter. Smaller bearings have relatively thicker rings, and vice versa. For a 500 mm bore ISO series 0 bearing, the above gives that the maximum practical contact pressure in the bore at approximately $100 \times (1.055 - 1)/1 = 5.5$ MPa.

A heavier ring cross-section would result in a larger contact pressure, but within the ISO dimension system it is virtually impossible to find large inner rings with a radial thickness larger than 15 percent of the bore diameter. And so a ring-to-shaft contact pressure of 15 MPa is considered a practical, maximum pressure to achieve.

If such a ring is sitting on a shaft seat subjected to bending and/or torsion, the bending and/or torsional strain in the surface of the shaft results in a motion between shaft and ring—unless the ring is forced to develop the same strain as the shaft. If there is motion in the mating surface, fretting is likely to follow. The only way to eliminate all motion between ring and shaft is to ensure that the surfaces "bind" to each other. In normal machines, the only binding mechanism available is friction. If friction somehow results in a ring binding sufficiently to a shaft surface subjected to bending and/or torsion, the contact pressure X coefficient of friction must be larger than the shaft surface bending and/or torsion stress.

A commonly used maximum coefficient of friction given (for degreased and heated steel components) is 0.2. Using the above-estimated 15 MPa maximum level of contact pressure and the 0.2 coefficient of friction, the maximum shaft surface bending and/or torsion stress allowable to avoid motion between shaft and ring is estimated as $15 \times 0.2 = 3$ MPa.

Since maximum-allowable shaft bending and/or torsion stress values in modern shaft materials can amount to 100 MPa, it is obvious that interference between inner rings and shafts cannot

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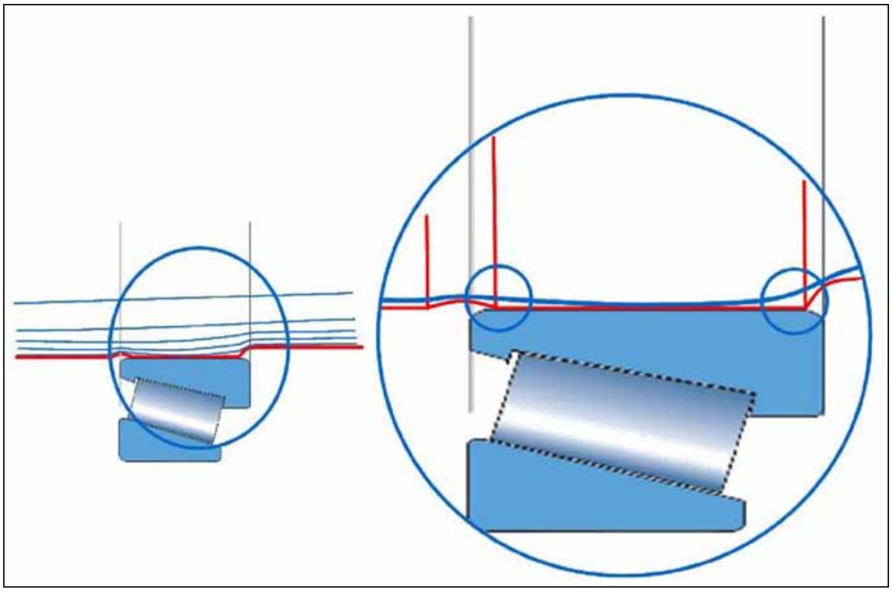

Figure 11—Shaft seats designed to create low stress areas at the borders of interference joints.

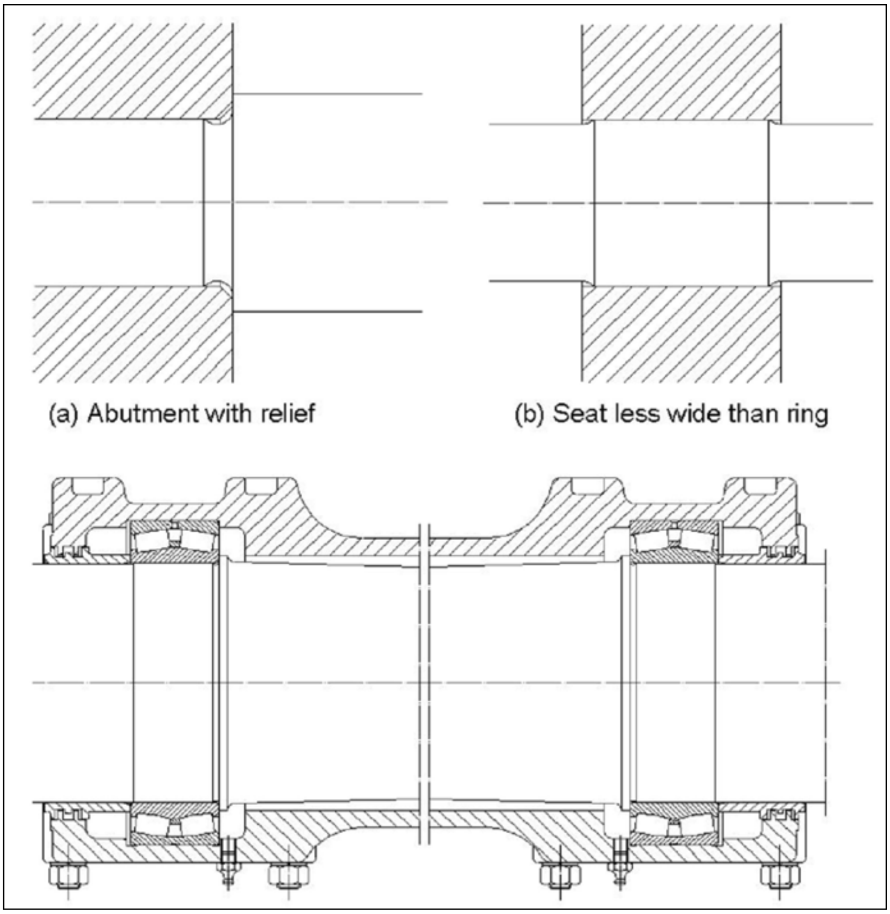

Figure 12—Design examples of components shrunk on shafts subjected to rotating, bending and/or torsion.

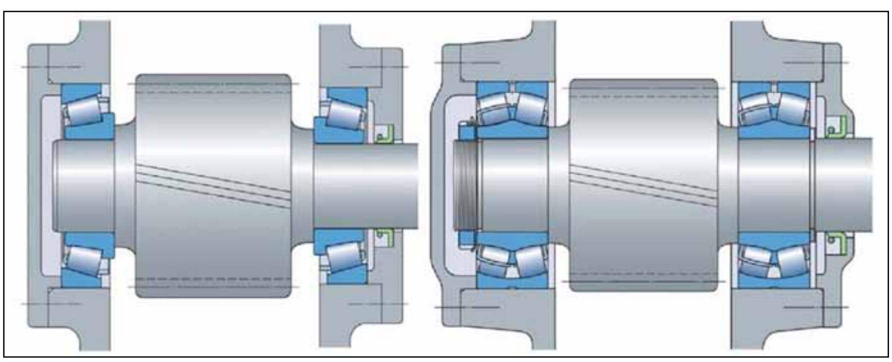

Figure 13—"Cross-locating" arrangements.

eliminate bending/torsion motion and, consequently, the fretting that may escalate into damage. Since the contact pressure available from a rolling bearing inner ring interference is not even close to eliminating the relative motion between inner ring bore and shaft seat resulting from shaft bending or shaft torsion, the task of eliminating, minimizing or disarming such motion/fretting is left to seat design.

One commonly used solution is to make the shaft stiffer under the ring, gear or hub to minimize strain (and consequently stress) in the interface surface, and to work with relieves or undercuts and make the hub part of the interference joint wider than the shaft part to relocate the fretting to the least-dangerous place (Fig. 11) in the interference joint. In Figure 11 examples "a" and "b" the softer shaft will rub against the hard inner ring or gear bore, which is far less dangerous from a shaft fatigue perspective than the opposite situation where (on a straight shaft) the inner ring or gear would rub into the softer shaft and then create a stress-raiser.

Small, sharp surface damages are stress concentrations that can develop into global fatigue cracks. In the shown examples, the rubbing part of the shaft is not subjected to bending stress and, as a consequence, not sensitive to the stress-raising effect of rubbing leading to fretting corrosion.

Figure 12 shows some design examples from machines where components (e.g., bearing inner rings) are shrunk on shafts subjected to rotation, bending and/or torsion.

Notice in the shown examples that the shaft seating is narrower than the cylindrical part of the inner ring bore; i.e., the transition between the ground bore and the machined chamfer is not contacting the shaft. This design eliminates the effect that the hard transition area between bore and chamfer of the inner ring is fretting or "coining" a groove into the soft shaft. Rather, the soft shaft is mildly deformed (crowned) at the ends of the seating.

How the design of the interface between bearing and gearbox casing influences gearbox service life. From the examples, it follows that the interface between shafts and components shrunk on shafts deserves attention—particularly if large deflections present. The interface between bearing outer rings and gearbox casing may in this respect seem less demanding, since there is no rotational load that generates motion. That perhaps is too optimistic, considering the potential effects of variable frequency drives.

For industrial transmissions, a very common bearing-to-casing design is to use a loose fit. The loose fit is often used—and needed—to make axial motion of the bearing outer rings possible; e.g., when adjusting clearance or preload in taper roller bearings, or to make two spherical roller bearings axially floating in a "cross-locating" arrangement (Fig. 13). The loose outer ring fit design is robust as long as the fit is loose enough to allow axial motion when needed, yet tight enough to distribute bearing load favorably—a sometimes-challenging compromise when involving, for example, large temperature gradients and/or varying torque.

If the casing bore tolerance is chosen correctly, the bearing outer ring is free to adjust axially; and as long as the load direction and magnitude on the bearing are constant, there will be no motion and thus no wear between outer ring and casing. Should for any reason the load direction frequently change, the outer ring contact will move in the casing bore, and wear may develop. Wear generates particles and increases looseness—typically, a self-generating mechanism.

Influence of modern electric motor speed controls in bearing type selection. In the previous section we dwelled on the outer ring to casing contact and the influence of the fit chosen.

Constant gearbox torque gives constant bearing load magnitude and direction; the loose outer ring fit works perfectly well. Should the torque change in magnitude and/or direction, bearing load magnitude and direction will change.

Variable frequency drives (VFDs) allow conventional, alternating current motors to be run at any speed, not just the nominal 900, 1,800 or 3,600 rpm associated with 60 Hz frequency.

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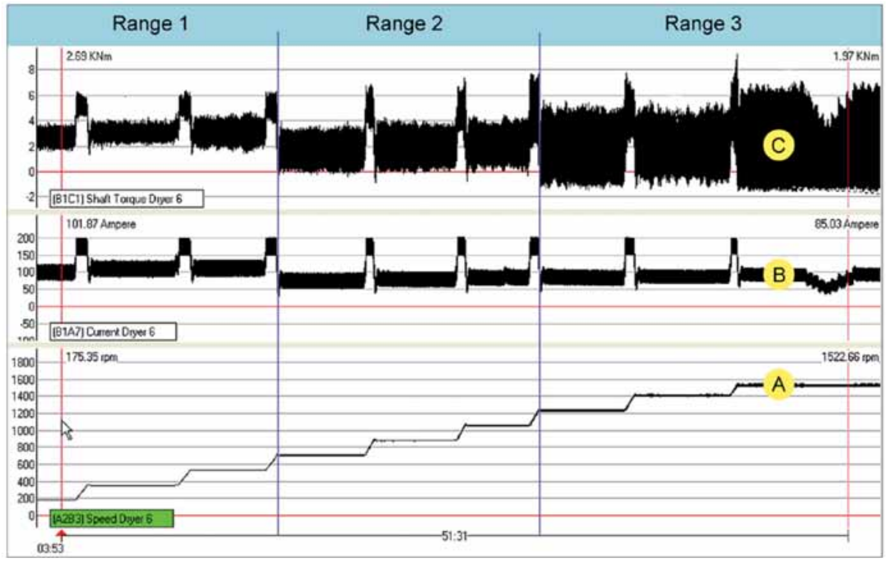

Figure 14—Measurements from paper machine drivetrain (courtesy Contec Control Technology AB, Sweden).

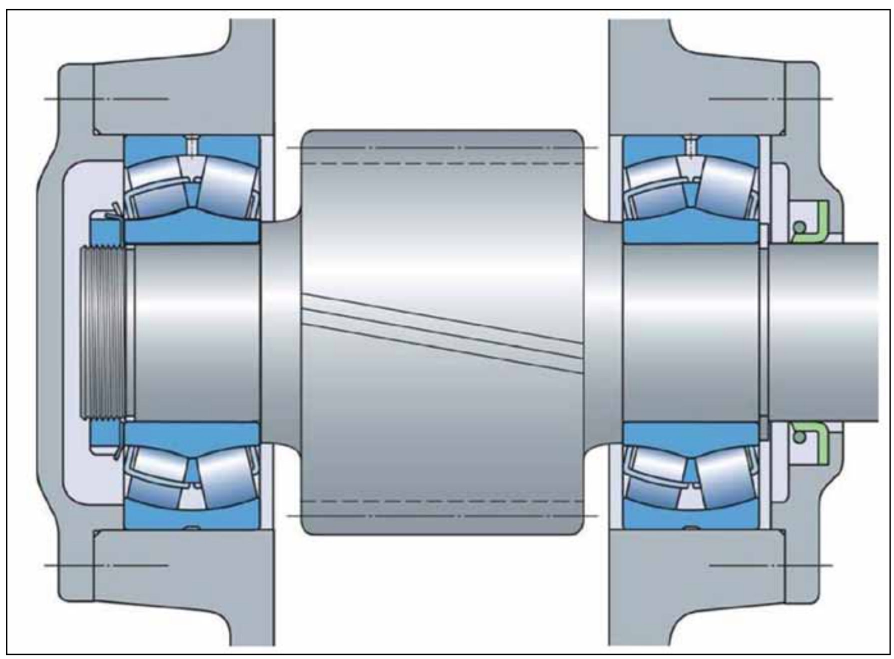

Figure 15—Two spherical roller bearings in "cross-locating" arrangement.

Many reports on subjects like pulsating torque, torque ripple and short-time torque peaks resulting from VFDs have been written, with the main focus on electric effects like bearing common-mode voltage, currents, voltage spikes, etc. (Ref. 15). To some extent concerns such as broken couplings and twisted shafts have also been reported (Ref. 16). Such extreme examples are fortunately rare. From a transmission bearing perspective, however, torque variations far less than what are needed to destroy couplings or shafts may generate motion and, consequently, wear between the bearing outer ring and casing.

VFDs are used to drive a machine with a constant and variable speed, typically including a feedback loop to keep the machine speed constant even if the load changes. VFDs are also normally programmable to smoothly ramp the speed of the drive motor up from, say, standstill to the desired operating machine speed. Depending on how the complete drivetrain—motor/coupling/gearbox/drive/shaft/driven machine—behaves in the torsional resonance domain with relation to how the VFD speed control or speed ramp-up behaves, the drivetrain may or may not excite any of its natural (torsional) frequencies. If the speed control loop or the speed ramp-up parameters are set with, e.g., unfortunate gain, a torsional resonance excitation may be sustained. Typically, one can easily monitor a drivetrain's performance; on the other hand, the gearbox in the middle may incur damage that goes unnoticed. A pulsating torque may (in a system with low damping) develop into reversing torque, in turn reversing shaft, gear and bearing loads.

In such a situation a gearbox designed with loose outer-ring fit seat tolerances will suffer from wear. The wear will generate iron oxide—a mild but powerful abrasive agent also contributing to wear—as well as harder components such as gears and bearings. Eventually the gearbox ceases to function due to bad gear mesh and/or worn out bearings.

The measurements in Figure 14 made on a drivetrain for a dryer section of a paper machine illustrate the above behavior. The measurements were made in an attempt to find the reasons for gearbox noise and limited drive shaft card and joint service life. Three physical parameters were monitored: driving motor speed (1), driving motor current (2) and driven machine torque (3).

The speed was increased following a programmed ramp-up; the motor current appeared as a range around 100 amps with the expected peaks, when the speed made an increment (i.e., when the machine was accelerated, the current was higher) and the torque delivered to the driven machine behaved similarly to the current—at least within Range 1. After that the torque showed an increasing variation (Range 2) and after that (Range 3) the torque progressed from varying to reversing. Naturally, the complete drivetrain rotated continuously; it was only the torque that was reversing—not the rotational direction.

Unless the gear and shaft masses are very large, operation under conditions such as those in Range 3 will, for most bearing positions in the gearbox, result in large changes in load magnitude and load direction. Naturally, bearing fatigue life is reduced due to increased mean loads. But the wear associated with a loose outer ring to casing design subjected to frequently changing load direction will very likely be noticed much sooner than fatigue of a bearing raceway.

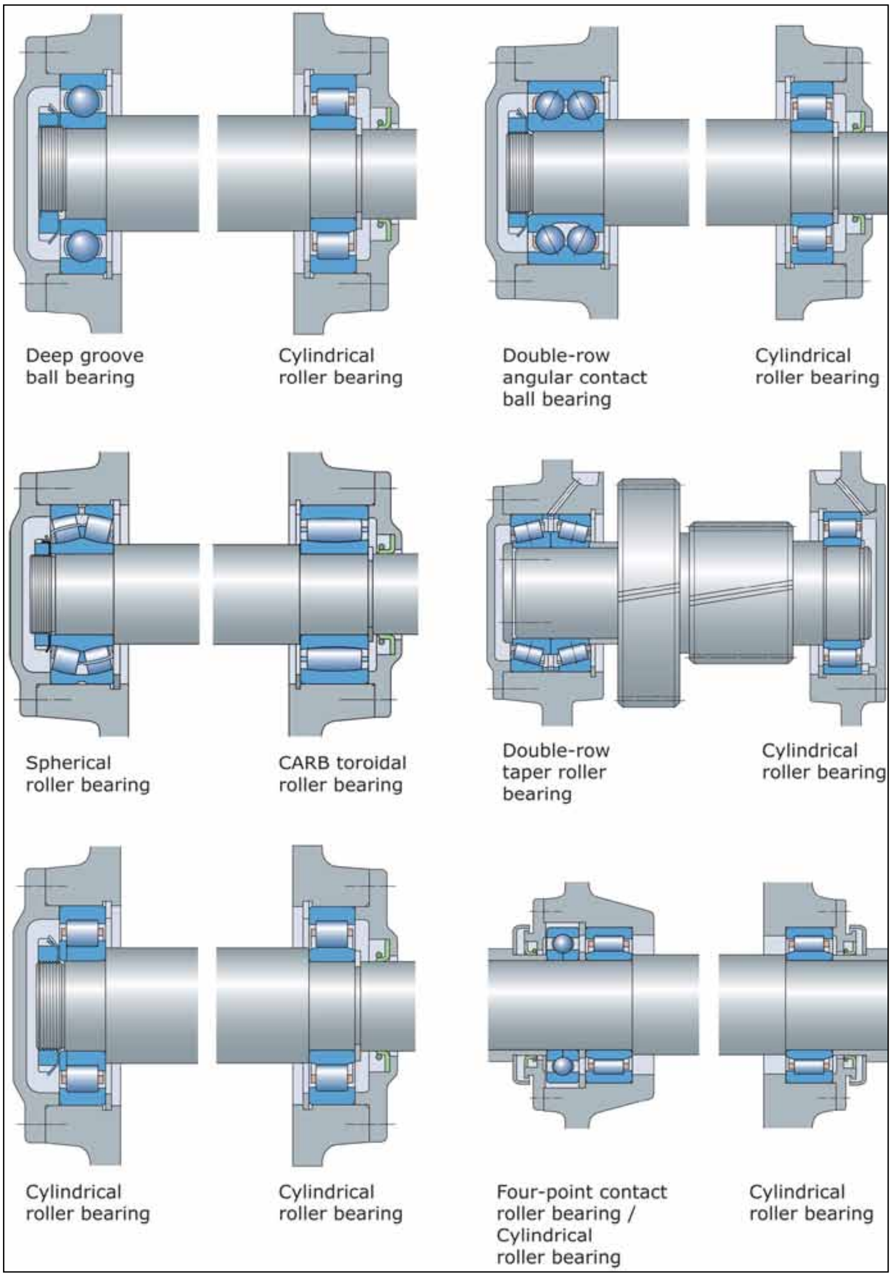

Figure 16—Different fixed–floating bearing arrangements.

The solution to gearbox service life limitations such as worn bearing seats in the casing and the resulting consequences is to *design for changing load direction*—i.e., leave the classic loose outer ring to casing fit "cross-location" designs (Fig. 15) in favor of tighter outer ring to casing fitting tolerances. *This means that axial expansion of shafts in relation to casing no longer can be managed via axial movement of one or both outer rings, so other solutions are necessary.*

Bearing arrangements such as two cylindrical roller bearings (for taper roller bearings, a tight outer ring fit makes axial clearance/preload adjustment more challenging) or arrangements of the fixed–floating type are then the right choice.

Fixed–floating arrangements (Fig. 16) can be made in a number of ways. For the examples shown the common factor is that the axial shaft expansion occurs inside one of the radial bearings, not between the outer ring and the housing. In the past, fixed–floating bearing arrangements were limited to so-called "stiff" bearings (i.e., not self-aligning). But with the introduction of the toroidal roller bearing design, self-aligning bearing arrangements are suited to tight outer ring to casing fit fixed–floating bearing arrangements.

Discussion and Conclusions

Despite the existence of advanced fatigue models for the sizing of bearings, the service life of bearings in gearboxes (and the service life of gearboxes themselves) is a more extensive matter than simply finding a sufficiently large bearing dynamic carrying capacity. Phenomena such as poor lubrication and contaminant-initiated surface fatigue are at least as important. New developments in the understanding of surface-initiated damage and how to treat material and surfaces to better-resist motion under high contact pressure offer significant improvement, but only as they relate to a larger dynamic carrying capacity in the bearings.

Finally, modern material and modern electric drive systems offer new opportunities for industrial gearboxes. But in order to benefit—not suffer—from some of the effects of strong shaft materials and multi-megawatt VFDs, bearing interface designs, tolerances and bearing arrangements must be adapted to the new operating conditions.

References

1. Morales-Espejel, G.E., A. Gabelli and E. Ioannides. "Microgeometry Lubrication and Life Ratings of Rolling Bearings," *Proceedings of the Institution of Mechanical Engineers*, Part C, Vol. 224, pp. 2610–2626, 2010.
2. Ioannides, E., G. Bergling and A. Gabelli. "An Analytical Formulation for the Life of Rolling Bearings," Acta Polytechnica Scandinavia, *Mechanical Engineering Series*, 1999, 137.
3. Gabelli, A., G.E. Morales-Espejel and E. Ioannides. "Particle Damage in Hertzian Contacts and Life Ratings in Rolling Bearings," *Tribolology, Transactions*., 2008, 51, pp. 428–445.
4. Lundberg, G. and A. Palmgren. "Dynamic Capacity of Rolling Bearings," Acta Polytechnica Scandinavia, *Mechanical Engineering Series*, Royal Swedish Academy of Engineering Sciences, 1947, 1(3).
5. ISO 15243:2004: Rolling Bearings—Damage and Failures: Terms, Characteristics and Causes.
6. SKF. a) General Catalogue: 6000/I EN, 2008; b) Brochure: SKF Oil Injection Method, 2930E; c) Book: *SKF Bearings in Electrical Machines*, 2124E; d) TI Leaflet: Axle Boxes for Wheel Shafts in Railway Vehicles, TI 6810.
7. Oila, A. and S.J. Bull. "Assessment of the Factors Influencing Micropitting in Rolling/Sliding Contacts," *Wear*, Vol. 258, pp. 1510–1524, 2005.
8. Brandão, J.A., J.H.O. Seabra and J. Castro. "Surface-Initiated Tooth Flank Damage–Part I: Numerical Model," *Wear*, Vol. 268, pp. 1–12, 2010.
9. Brandão, J.A., J.H.O Seabra and J. Castro. "Surface-Initiated Tooth Flank Damage–Part II: Prediction of Micropitting Initiation and Mass Loss," *Wear*, Vol. 268, pp. 13–22, 2010.
10. Lainé, E. and A.V. Olver. "The Effect of Anti-Wear Additives on Fatigue Damage," Extended Abstract, *62nd STLE Annual Meeting*, 2007.
11. Lainé, E., A.V. Olver and T.A. Beveridge. "Effect of Lubricants on Micropitting and Wear," *Tribology International*, 41, pp. 1049–1055, 2008.
12. Lainé, E., A.V. Olver, M.F. Lekstrom, A. Shollock, T.A. Beveridge and D.Y. Hua. "The Effect of a Friction Modifier Additive on Micropitting," *Tribology, Transactions*, 52, pp. 526–533, 2009.
13. Kim, T.H. and A.V. Olver. "Stress History in Rolling–Sliding Contact of Rough Surfaces," *Tribology International*, 12, pp. 727–736, 1998.
14. Stephens, R.I., A. Fatemi and R.R. Stephens. *Metal Fatigue in Engineering*, Second Edition, John Wiley and Sons Ltd, 2000.
15. Song-Manguelle, J., S. Schröder, T. Geyer, G. Ekemb and J.M. Nyobe-Yome. "Prediction of Mechanical Shaft Failures Due to Pulsating Torques of Variable Frequency Drives," *IEEE Transactions on Industry Applications*, Sept.– Oct. 2010, Volume 46 Issue 5, pp. 1979–1988.
16. Meckel, C. "Mechanical Damage of a Sub-Synchronous Cascade Drive Due to Torsional Resonance," *Cement Industry Technical Conf., IEEE IAS/PCA*, pp. 133–150, 2001.

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ACHIEVING High Electric Motor EFFICIENCY

John Petro

Management Summary

Permanent magnet (PM) motors made with ferrite magnets can significantly exceed the current NEMA Premium and IE3 efficiency standards and even the proposed future IE4 motor efficiency standards while still being highly cost-effective in the marketplace. This is made possible by using motor geometries that allow for flux concentration from the ferrite magnet components. The use of motor structures which can concentrate magnetic flux allows ferrite PM motors to achieve performance and power densities that approach those of PM motors using rare earth magnets, but without the cost penalties and supply source concerns of rare earth magnets.

Currently, ferrite PM motors with a 2.2 kW rating are operating at 93 percent efficiency, as compared to the IE3 standard of 89.5 percent. In addition, these motors maintain high efficiency over a broad range of speed and torque values. It is estimated that these motors can be further improved to have efficiencies of above 94 percent in the near future. The development path and design approaches to achieve such efficiencies will be discussed. This paper will present design projections of performance results from a range of motors and, in addition, provide measured results when they become available. The outstanding efficiency improvement provided by these motors will be compared to existing motor solutions that are currently available on the market, and the overall energy savings will be illustrated.

(This paper was first presented at the 2011 EEMODS—Energy Efficiency in Motor-Driven Systems—Conference sponsors' and is reprinted here with its sponsors kind permission.)

Background

The need to increase overall motor system efficiency has never been greater. With the rising costs of energy and the substantial concerns about global CO_2 emissions, achieving the highest possible motor system efficiency has become a critical priority.

In almost all cases, the addition of a variable-speed drive to an electric motor system leads to substantial energy savings by allowing motor speed and load to be optimized to the system requirements. The efficiency of the variable-speed electronic drive portion of a modern motor system is very high: almost always above 95 percent, often 97 percent, and recent improvements are pushing drive efficiencies to 98 percent and higher. These high efficiencies for variable-speed drives can be achieved over a wide range of motor speeds and loads.

However, even at these high efficiencies, the addition of a drive to a line-operated motor still reduces the peak efficiency of the motor system. In addition, induction motor efficiency is specified under sine wave line operation and, when operated using an electronic drive, the induction motor efficiency is usually degraded, further reducing the overall system efficiency. If an induction motor is only used at its rated speed and torque, then adding a drive will actually reduce the overall system efficiency. However, in real world applications, operation at only this one speed and load is rarely the case, which is why adding a variable-speed drive usually results in increased system efficiency.

Given how high drive efficiencies already are, there is very little room for improvement to overall motor system efficiency with additional drive improvements. Therefore, it is essential to improve the efficiency of the motors used with variable-speed drives. Indeed, motor efficiency improvements are critical if overall motor system efficiency is to be increased in any substantial manner.

Of course, any increase in motor efficiency must be balanced with the cost of the motor. For example, while high-efficiency motors can be made using exotic materials (rare earth magnets) and manufacturing processes, the high price of such motors greatly limit the applications that can adopt such a motor. It would clearly be far better to achieve high motor efficiency while using lower-cost materials and manufacturing processes.

It is well-accepted that permanent magnet motors can achieve higher motor efficiencies than induction motors because of the reduction of losses in the rotor. In addition, the rated efficiency of a permanent magnet motor is specified with the assumption it will be operated from an electronic drive, so its rated efficiency performance can actually be achieved in real-world applications. However, permanent magnet motors to date typically cost more than induction motors due to the cost of the magnet materials used in these motors. (This is especially a concern at present as rare earth permanent magnet materials are experiencing unprecedented price increases and supply problems.) Back on the plus side, permanent magnet motors are also generally more power-dense than induction motors because their manufacture requires less electrical steel and conductor material than does an induction motor of equivalent output power.

However, while it is true that neodymium iron boron formulations are used in most new high-performance, permanent magnet motors, they are not the only permanent magnets available for constructing a permanent magnet motor. The fact is, most small permanent magnet motors utilize low-cost ferrite magnets as the permanent magnet field source. Such motors are widely used in many applications in automobiles, motion control systems and toys. Many of these motors are of the brush-type variety, but brushless motors have been widely used in fans, disk drives and many motion control applications. This paper focuses on the design considerations for integral-horsepower, brushless permanent magnet motors.

The problem with ferrite permanent magnets is that their power density is only about one-third that of rare earth-based permanent magnets. This generally results in either a motor with less performance or a motor that is substantially larger and, therefore, requires more electrical steel and conductor material. However, as a result of the mentioned recent concerns over rare earth permanent magnet materials, there now exists a renewed interest in ferrite-based permanent magnet motors. And given that ferrite magnet material is now selling at less than one-tenth the cost of rare earth magnets, along with the fact that there is a wide range of supply sources for these magnets, look for that interest to intensify.

Loss Sources in Permanent Magnet Motors

To achieve high motor efficiency, careful attention must be paid to all of its potential sources of loss. Too, the motor designer should take advantage of any inherent performance characteristics of different motor geometries in order to achieve the goal of a high-efficiency motor with low material and manufacturing costs.

Motor *efficiency* is inversely related to the total amount of power losses in the motor. Motor *losses* are often divided into two major areas: conduction losses and speed-related losses. Conduction losses result from motor drive current flowing in the motor coils with a finite resistance. These losses are related to the motor current squared, times the motor resistance (I^2R). All of the conduction losses occur in the stator of a brushless, permanent magnet motor. The speed-related losses consist of iron losses, hysteresis and eddy currents in the motor components; frictional losses from the bearings; and windage. Iron losses can occur in both the motor's stator and rotor; frictional losses are all related to the rotor of the motor.

A remaining category of losses includes those that depend both on torque and speed and especially occur in the extremes of motor operation. These losses are generally related to magnetic nonlinearities that increase harmonics, hysteresis and eddy current losses at a rate faster than predicted by normal operating conditions.

Conduction losses generally dominate the efficiency performance of a motor when the motor is operated at lower speeds; iron losses generally set the efficiency performance at high speeds. To achieve a broad, flat efficiency curve, both conduction and iron losses must be addressed and kept at a low value. Motor losses are summarized in Table 1.

Table 1—Motor Loss Summary

	Location
Conduction losses – torque-related losses	
Coil I^2R losses	stator
Speed losses – speed-related losses	
Iron losses – hysteresis and eddy currents	stator and rotor
Frictional losses – bearings and windage	rotor
Other – torque and speed related	
Excess losses – hysteresis and eddy currents	stator and rotor

Motor Design: *Radial and axial windings*. For low-speed operation—most fans, for example—conduction losses will be of primary importance, as they are directly related to the volume of conductor that can be incorporated into the motor. Radial and axial motors differ greatly in the way additional conductor is added.

In a radial motor the amount of conductor is limited by the slot width available in the tooth design (Fig. 1A). As the slot width is increased to allow for more conductor area, the amount of flux that can be carried by the tooth is decreased. Since a motor's torque is directly set by the amount of flux linked by the ampere turns of the coil, this creates a no-win tradeoff with respect to efficiency.

In the radial motor design, more flux-per-turn is realized by increasing the length of the motor, but this makes the winding shape more rectangular. Rectangular windings have a longer winding

continued

perimeter for the amount of enclosed area and, therefore, higher winding resistance (Fig. 1B). The area enclosed by the winding is shown as A_R and the perimeter of the winding is P_R.

Rectangular Winding Extends the Length of Motor

In an axial motor the winding shape can be designed so that it is nearly circular (Fig. 2); a circular winding encloses the maximum possible area for a given winding perimeter, thereby minimizing winding resistance. The enclosed area is shown as A_N and the perimeter as P_N. In axial motor design, the addition of more conductor volume is relatively straightforward, as the conductor volume can be increased by simply lengthening the linear coil dimension and the overall motor. While this in fact increases the amount of iron in the stator, at low speeds it will not lead to a significant increase in iron losses—compared to the decrease in the conduction losses. As available conductor volume is increased, a wire with a larger cross-sectional area is used while keeping the number of turns constant, thus reducing winding resistance. This technique to lower conduction losses is applicable until such time that the cost of increased material volume precludes its usage, or the additional iron losses negate the lower conduction losses.

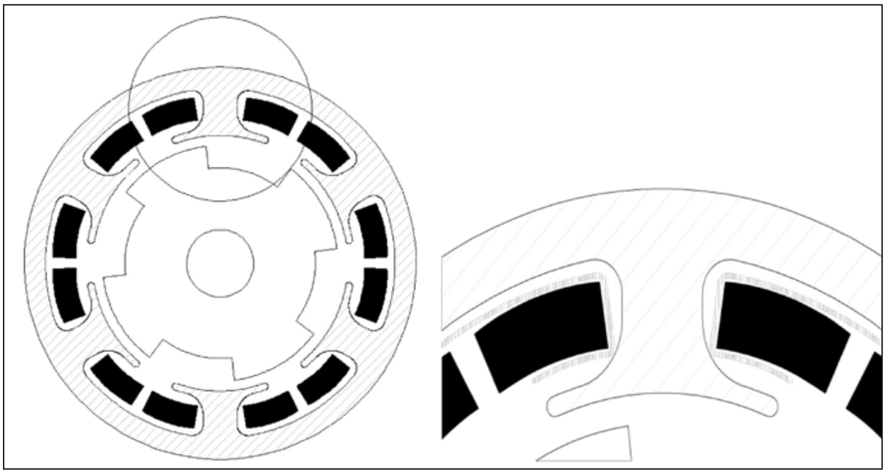

Figure 1A—Radial motor winding.

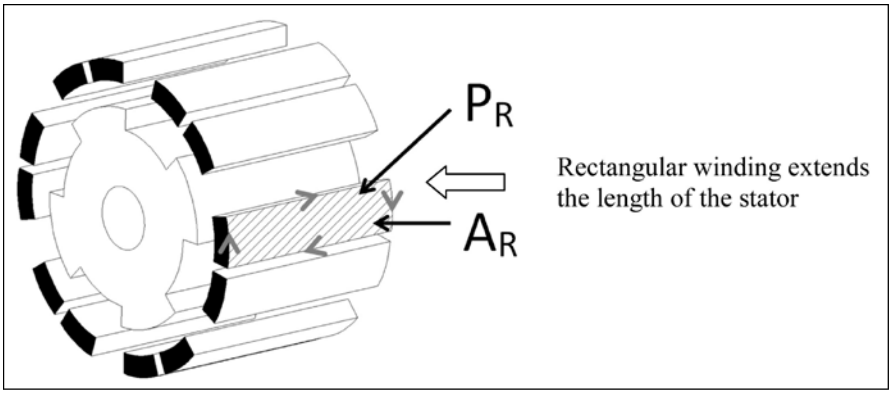

Figure 1B—Radial motor winding.

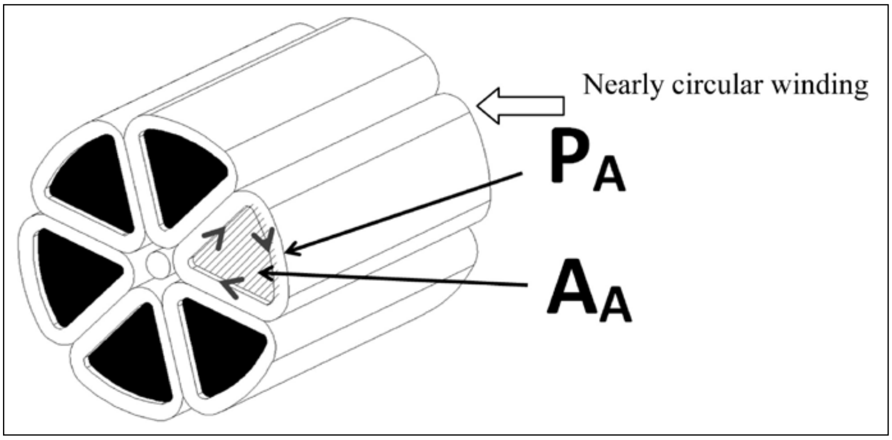

Figure 2—Axial motor winding.

Motor Design: ***Back EMF waveform.*** When designing a motor for high efficiency, the often discussed choice between sinewave and trapezoidal back electromotive force (EMF) waveforms is relatively easily resolved. A trapezoidal back EMF waveform means that the motor naturally has higher harmonic content. As a motor approaches a pure sinewave back EMF, the harmonics approach zero. Since hysteresis losses are directly related to frequency, and eddy current losses are proportional to frequency squared, it is important to minimize higher frequency content in the motor to achieve low losses and high efficiency. Therefore, it becomes obvious that a high-efficiency motor should be designed to minimize harmonic content as much as possible. A high-efficiency motor should be designed so that the magnetic flux in the stator is sinusoidal versus rotation angle at no load. Under excitation this sinusoidal condition should also be maintained as the motor is taken from no load to full load.

While it is often asserted that a motor with trapezoidal back EMF driven with a trapezoidal drive waveform delivers more output torque than an equivalent-sized motor with a sinewave back EMF operating with a drive with a sinewave drive waveform, the sinewave solution can have lower losses and higher efficiency. Also, the higher power assertion of the trapezoidal solution may be true in an instantaneous condition, but it does not consider the thermal limit of the motor, which is set by the motor losses. Indeed, most motors are limited in power output by their thermal limit and not by inherent magnetic or other physical limitations.

Motor Design: ***Pole count.*** If a motor is going to generally be operated at high speeds, it is much more important to ensure that the motor iron losses are minimized. If, on the other hand, a motor is designed for low-speed operation such as some direct drive fan applications, the conduction losses must be considered foremost by the motor designer.

The pole count of the motor must be considered here. As pole count increases, the motor frequency increases, leading to higher iron losses. For low-speed applications, a high-pole-count motor can be used since the speed losses will not be of overriding concern. For high-speed applications, a low-pole-count motor may be the best choice so that the speed losses can be minimized and efficiency kept high.

Motor Design: ***Magnet type.*** There are two types of permanent magnets commonly used in motors. Until the last decade the most common magnet type was ferrite magnets. Over the last 10 years most new permanent magnet motors moved to rare earth type permanent magnets (neodymium-iron-boron formulations) because they have a much higher flux output and energy product. The cost of these rare earth magnets dropped for many years until the price was competitive to ferrite on an overall performance basis. However, during the last two years, unprecedented price increases have occurred in this type of magnet, which has resulted in a return to ferrite permanent magnet motor designs.

Ferrite magnets are considerably weaker than most rare earth magnets. Typical ferrite magnets have a Br of about 3,800 gauss compared to about 10,000 gauss of a rare earth style permanent magnet. The coercivity of ferrite magnets also is proportionally lower. This results in an energy product for ferrite that is about ⅛ to ⅒ that of rare earth magnets. This is why flux concentration is so important with ferrite magnets. However, magnet volume for a motor is dependent on the flux ratio and not on the energy product ratio, so the volume of ferrite magnet material needed for equivalent performance is only about three times the volume of rare earth magnet for similar flux output.

Since the coercivity of ferrite magnets is low, care must be taken in the motor design to prevent the energized coils of the motor from causing demagnetization of the magnets in fault conditions. However, the coercivity of a ferrite magnet increases with temperature, so demagnetization is most likely to occur when the motor is cold.

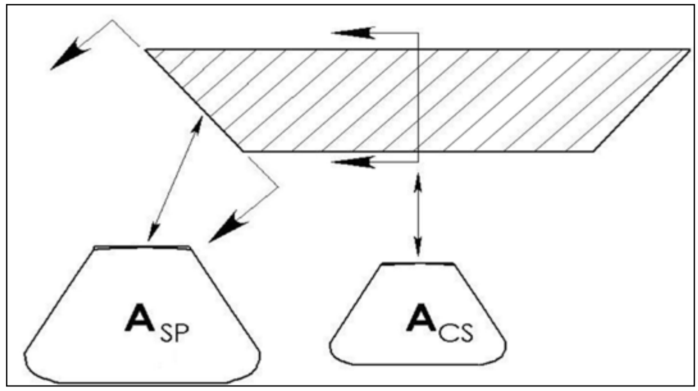

Figure 4—Conical motor flux concentration.

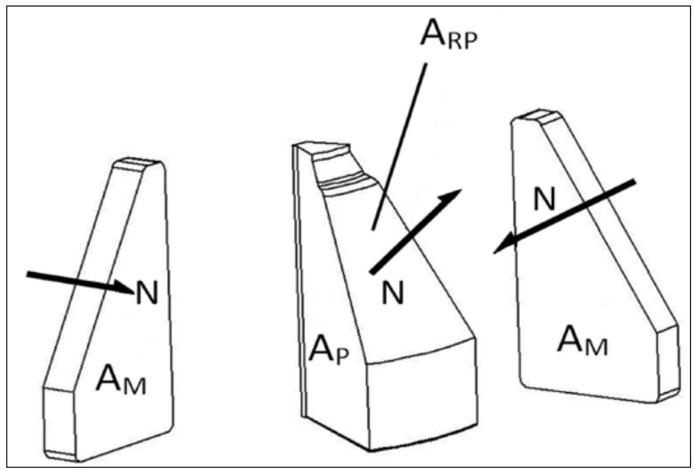

Figure 3—IPM spoke-type flux concentration.

All magnets lose flux strength with increasing temperature and ferrite unfortunately experiences about twice as much flux loss with each increment of temperature compared with a typical rare earth type magnet.

The mechanical strength of ferrite and rare earth magnets is about the same. Advantages of ferrite magnets compared to neodymium-iron-boron magnets include (1) they are non-conducting so they do not have eddy current losses associated with them and (2) they are corrosion-resistant and therefore do not need to be coated with any protective coating.

Motor Design: ***Axial motor flux concentration.*** For a ferrite magnet motor to achieve the high power density and performance of a motor designed with rare earth magnets, flux concentration must be employed. Flux concentration is achieved in several ways in a motor.

One method of flux concentration is to use an interior permanent magnet design where the magnet surface areas are greater than the pole piece surface area; this is best illustrated in Figure 3. A radial spoke-type interior permanent magnet (IPM) structure is utilized to increase the total magnet surface area that feeds flux to the pole piece. A magnet with surface area B_M sits on each side of a pole piece so the flux area into the pole piece is two times B_P. This flux is concentrated into an area of the pole piece of A_{MP}. Of course only so much flux concentration can be obtained this way, since the magnets feeding the pole piece are in opposition, which lowers their load line, thereby reducing their effective flux output.

To further enhance the concentration of flux into the active pole of a motor, a conical rotor structure can be implemented for an axial motor. This cuts the axial field pole at an angle, thus increasing the surface area available compared to the axial flux carrying area of the field pole core (Fig. 4). With this design the magnet surface area A_{FP} is greater than the field pole cross sectional core area A_{CS}. This provides flux concentration proportional to the ratio of the two

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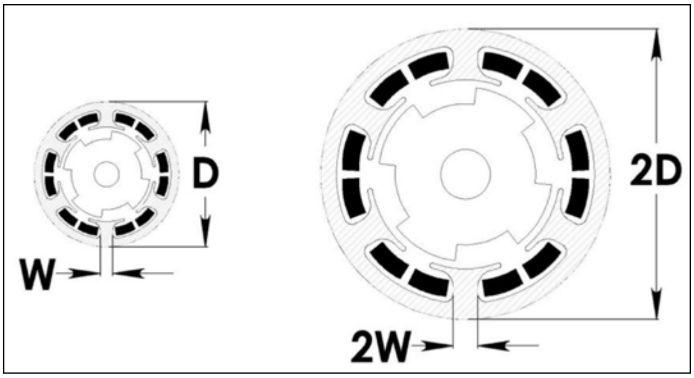


Figure 5—Radial motor with diameter D and 2D.

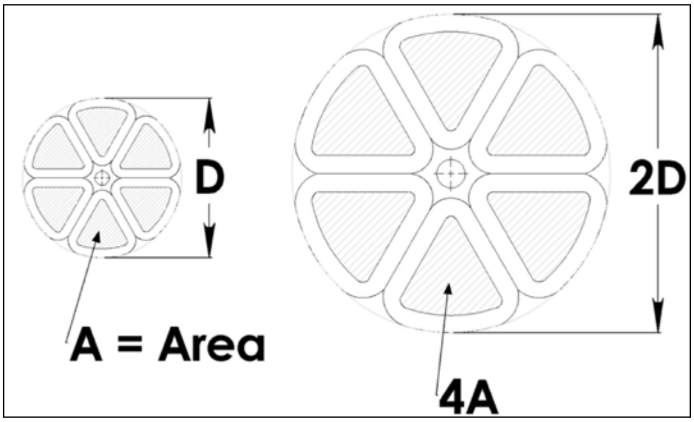


Figure 6—Axial motor with diameter D and 2D.

areas. Combining both techniques increases the flux available from a ferrite magnet to near rare earth magnet levels and results in a high performance motor with low magnet costs.

Motor Design: *Magnet configuration.* Another important permanent magnet design issue is the choice between surface-mounted and IPMs on the rotor. Ideally, for a surface-mounted PM machine, the flux in the rotor does not undergo any change with rotation under any condition. In this condition, there are no hysteresis or eddy current losses in the rotor. This allows the use of a solid core for the return path flux in the rotor without any penalty of additional rotor losses. However, if the flux output of the rotor changes as it rotates due to tooth gaps or other reluctance path variations, this can result in losses in the rotor. In general, surface-mounted magnet motors can be designed to have very little rotor loss.

IPM motor designs are proving to be highly desirable because they can reduce the speed limitation that is inherent to permanent magnet motors when surface-mounted designs are employed. This IPM design uses both permanent magnet torque and reluctance torque to create a motor with many highly desirable characteristics.

As with surface-mounted motors, the IPM motor should have a sinusoidal back EMF in the stator and should ideally have sinusoidal flux throughout the motor. However, given the use of reluctance torque in this style of motor, it is impossible to avoid flux changes in the rotor soft magnetic structure. This changing flux in the rotor therefore requires the rotor to have a laminated or highly resistive material to limit eddy current losses in the rotor. This flux change also leads to hysteresis losses in the rotor. So with IPM motor designs, losses in the rotor cannot be avoided and must be taken into account in any thermal modeling of the motor.

Motor Design: *Radial and axial torque scaling.* There is another fundamental difference between radial and axial permanent magnet motor configurations. This notable and often misunderstood difference is the relationship of output torque with respect to motor diameter.

In all cases, torque is the result of force applied at a radius. In all motors, the radius increases directly with the increase in diameter of the motor, resulting in a linear increase in torque with diameter solely due to the increased radius. Also, in a permanent magnet motor, the available force is directly proportional to the flux-carrying capability of the stator. So, as diameter increases and the amount of flux that can be carried in the stator increases, the torque of a motor will also increase.

With a radial motor, as diameter increases, the circumference where the stator pole shoes are located also directly increases (Fig. 5), meaning that the flux-carrying area of the pole shoes linearly increases with diameter. Therefore, torque increases with the square of diameter, since both the radius and the total flux are linearly increasing with motor diameter.

In addition, for a radial motor the flux-carrying area also directly increases with stator length. Since force is directly related to total flux, increasing the motor length also increases torque in a linear manner.

Therefore, in a radial motor, torque increases with the square of diameter and also increases with additional length of the motor, resulting in an overall cubic function for torque. This results in a radial motor increasing torque proportional to the volume of the motor, since the motor volume also increases with the square of diameter and linearly with the length of the motor.

For an axial motor, the torque increases with the cube of diameter and does not increase with motor length. The reason for this is, again, that torque is force times radius. As the axial motor diameter increases, the radius increases, so the torque increases linearly with diameter due to this radius increase. The force in an axial motor is also directly proportional to the amount of flux that the stator of the motor can handle without saturating. The amount of flux is dependent on the area of the stator, and this area increases with the square of the motor diameter. This is shown in Figure 6 as areas A and 4A. Four times the area can carry four times the flux and this is the result of the stator poles increasing in two dimensions as diameter increases.

Because the radius of the motor increases directly with motor diameter, and the force increases with the square of motor diameter, torque of an axial motor increases with the cube of diameter. Notice that since only the diameter is changing, the axial motor volume only increases by the square of the diameter, even though the torque increases by the cube of diameter. This leads to the fact that for larger motors, an axial motor can use less material to achieve the same torque, compared to a radial motor. Please note that the above is a theoretical approach, and in actual practice the length of an axial motor does need to increase somewhat with increasing diameters, since the air gap dimension, strength of materials and realistic sized bearings must be considered. This still leaves the axial motor design at an advantage over radial motor designs when compared on the basis of torque generated per unit volume of active material required.

Increasing the length of an axial motor does not provide any additional torque capability for the motor, since the flux in the stator is along the axis of the motor. Adding length to an axial motor does provide more room for additional conductor volume and more surface area for heat dissipation. Adding conductor volume can decrease the total motor resistance and thereby decrease the total conduction (I^2R) losses of the motor. This is an excellent approach for achieving high motor efficiencies at low motor speeds and leads to a broad, flat motor efficiency curve. Of course, the extension of the length of an axial motor adds both additional stator steel and conductor material, increasing both the weight and cost of the motor. In addition, the extra stator steel adds additional iron losses in the motor, which hurts high-speed efficiency performance. However, up to a limit, by using low loss electrical lamination steel in the stator, overall efficiency can be improved by adding length to an axial motor configuration.

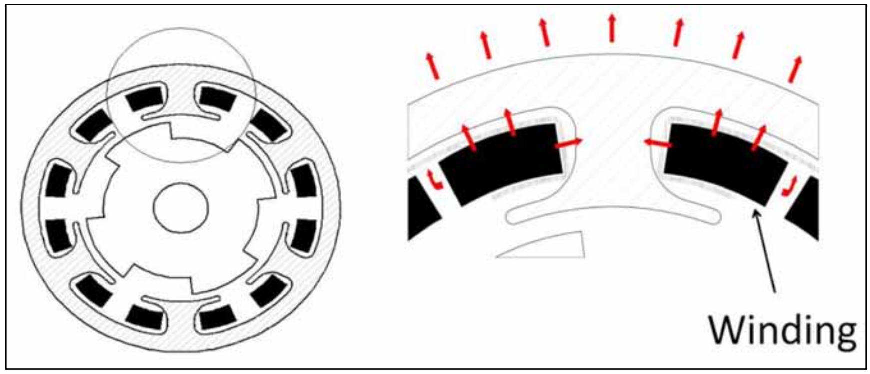


Figure 7—Radial motor thermal path.

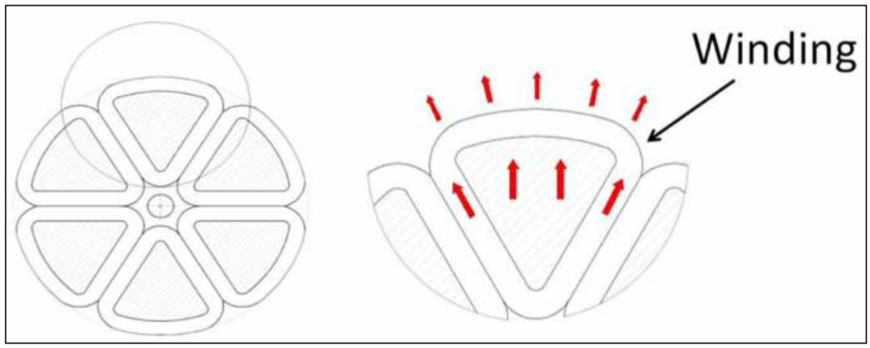


Figure 8—Axial motor thermal path.

Figure 9—Axial permanent magnet 3.7 kW motor.

Thermal Considerations

Another factor that affects motor efficiency is the ability of a motor to shed excess heat to the external environment. This is expressed in terms of a motor's thermal resistance. When a motor is operating near its maximum efficiency, approximately half the dissipated power is in the winding from conduction losses and the other half is in the stator iron and rotor iron. In a typical radial motor, the winding is inside the motor, leading to higher thermal resistance and lower continuous output power. With an axial motor, a major portion of the winding is exposed on the outside of the motor. This leads to a lower thermal resistance and higher operating power.

The thermal paths for a radial and axial motor are illustrated in Figures 7 and 8.

For the radial motor the coils are inside the back iron so the heat must be transferred from the coils to the back iron and then out of the motor.

For an axial motor a large portion of the coil resides on the outside of the field pole iron and there is no back iron. This allows access to the coil directly for more effective cooling of the motor.

Motor Efficiency Improves with Increased Size

When considering what constitutes a high efficiency motor, the power rating and speed of the motor must be taken into account. Motor efficiency generally increases with larger physical sized motors and higher power levels. While a 1 kW machine may be considered very efficient at an 87 percent efficiency rating, a 50 kW machine would need to

continued

be 95 percent efficient to be considered highly efficient.

Efficiency improves as radial motors get larger, because motor torque increases directly with motor volume, while losses increase at a lower total rate. While iron losses scale directly with motor volume, conduction losses proportionally decrease with larger motor sizes. This is the result of the increased area having more flux carrying capability. High flux means that for the same operating voltage, fewer turns of conductor are needed to achieve the same output torque. Given that the larger size has also increased the area available for conductors, fewer turns of heavier wire can be used, which reduces the motor resistance in two ways.

For an axial motor, the output torque increases faster than the motor volume increases, so the iron losses are proportionally smaller as motor size increases. In addition, axial motors also experience reduced conduction losses proportionally as motor size increases. This gives the axial motor design an even better increase in efficiency with increased motor size.

Example of axial ferrite PM motor. A motor implementing many of the concepts presented above has been designed and is currently being fabricated to achieve high efficiency over a broad speed and torque operating range. The actual performance of this motor will be established with exacting dynamometer testing later this summer and the measured results added to this paper. For now, estimated values are provided in brackets [ ] in the discussion below.

Figure 9 shows a picture of a brushless permanent magnet axial flux motor constructed with ferrite permanent magnets using flux concentration from both a conical air gap and interior permanent magnet rotors.

The specifications and performance of this motor with ferrite magnets using flux concentration are given in Table 2.

This motor is a 3.7 kW (5 hp) mo-

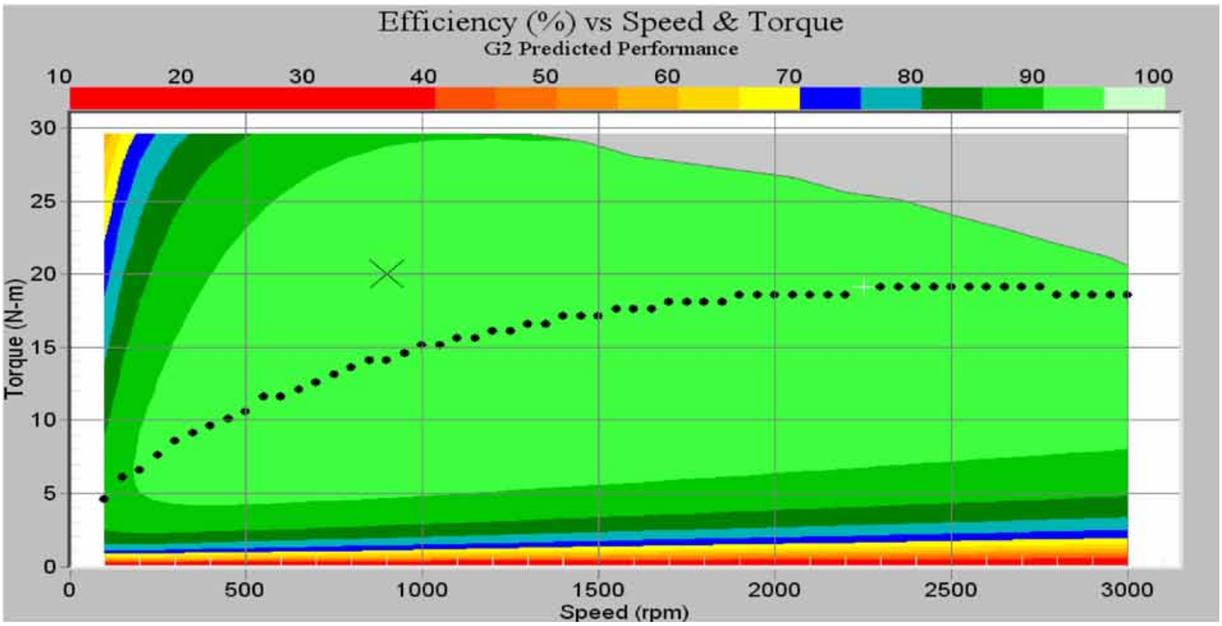


Figure 10—Predicted motor efficiency versus speed and torque for 1,800 rpm motor.

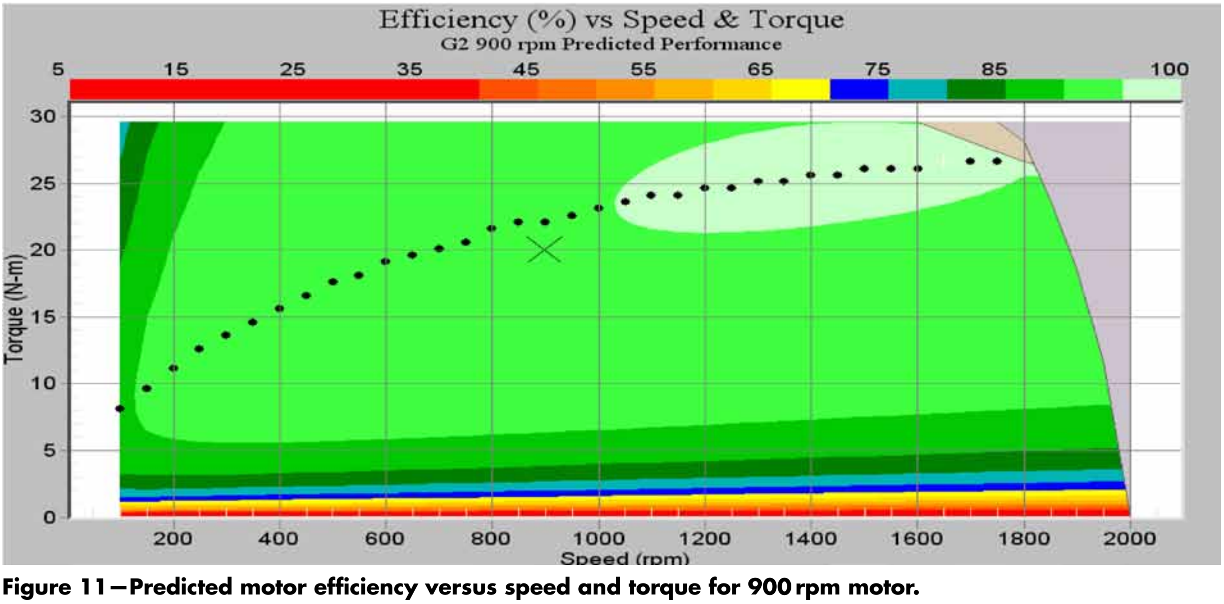


Figure 11—Predicted motor efficiency versus speed and torque for 900 rpm motor.

Table 2—Basic Motor Specifications	
Rated Power	3.75 kW
Rated Speed	1,800 rpm
Rated Torque	20 N-m
Peak Efficiency	93.0 percent
Diameter	179 mm
Length	300 mm
Weight	30 kg

tor with 20 N-m of torque at 1,800 rpm and runs at an efficiency of (93–94 percent). The efficiency is flat over a broad range of speeds and torques (Fig. 10); it requires only [8] kilograms of steel (including scrap), [2.2] kilograms of copper and [3.7] kilograms of ferrite magnet material. It weighs a total of [30] kilograms and has a base diameter of [179] mm and a length of [300] mm.

In Figure 10 the color bar above the graph provides a key showing the color which represents each efficiency percentage, in 5% range increments. The bright green color represents efficiencies in the 90–94% range As shown in the figure, this motor is expected to be over 90% efficient at most speeds (horizontal axis) and torques (vertical axis). Efficiency over 90% over such a wide operating range of speeds and torques is exceptional for a motor of this size. Most motor designs provide such high efficiencies only near their rated load, and display a significant decrease in efficiency at lower speeds and torques.

This motor can easily be scaled to higher power ratings since the torque of this motor increases with the cube of diameter and the length of the motor is relatively constant. It can also achieve much higher rotational speeds, allowing for very high power density in applications that need high speed or can accept a gear box reduction.

For low-speed applications (maximum 900 rpm), a second version of this motor incorporates additional winding volume by lengthening the motor by [60] mm. Since the speed is lower, the number of turns on the winding can be increased, which reduces the required drive current. This reduction in current more than offsets the increase in winding resistance, so that the conduction

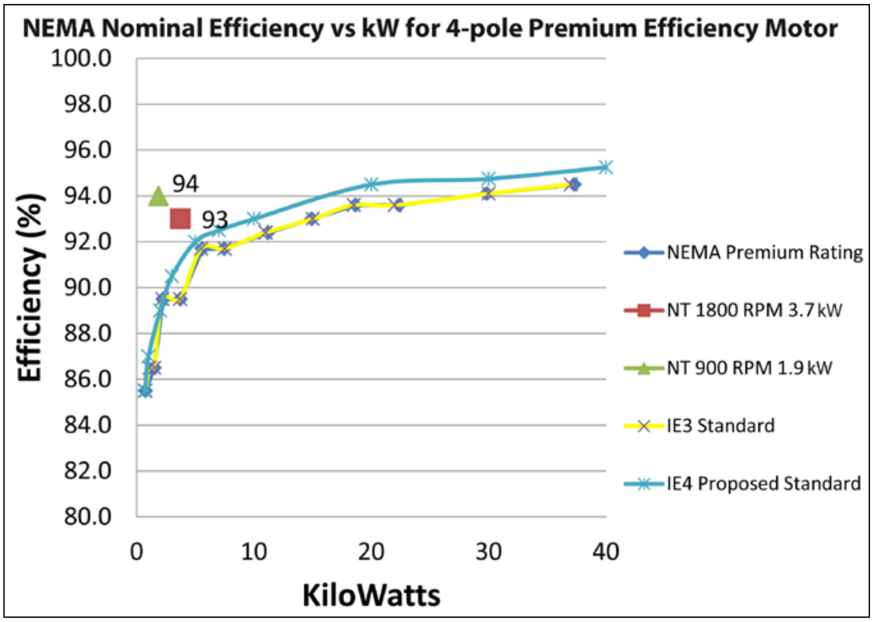


Figure 12—NEMA Premium Efficiency, IE3 standards and predicted motor efficiency.

losses are reduced. This then further increases the motor efficiency, and especially extends the motor efficiency to lower-speed operation (Fig. 11).

Efficiencies of this motor peak at (94–95 percent, represented by the paler shade of green in the figure above), which is remarkable for a motor of this size and weight operating at this low of a speed range. The cost of this higher efficiency is the addition of [3.5] kg of steel from the extension of the motor length and [2] kg of copper in the extended winding. Because the speed of this motor is so low, very little additional speed loss is introduced with the additional magnetic path length.

Conclusion

Figure 12 illustrates the estimated performance of these two motor designs with respect to the current NEMA premium efficiency standard and the IE3 and IE4 proposed efficiency standards for 1,800 rpm motors. The standards for 900 rpm motors have even lower efficiency requirements. This makes the 1.87 kW, 900 rpm motor stand out as especially efficient compared with the existing motor standard. It is believed that this motor will exceed all of the currently proposed energy efficiency standards for electric motors.

From the discussion above, it can be seen that axial motor designs have some outstanding characteristics that are particularly attractive for the construction of highly efficient electric motors. In particular, a flux concentrating design using interior ferrite permanent magnets can make a highly efficient, compact motor using low cost materials. This improvement in motor technology is capable of greatly improving the efficiency of motor driven systems, even beyond the level of the IE4 proposed standard, while avoiding the supply source issues of rate earth magnets.

John Petro, *with degrees from the University of Virginia (BSEE) and Stanford University (MSEE), has forged a career in electrical engineering working with electromechanical systems such as robotics, high-pressure pumps, down-hole seismic sensing and electric valves and actuators. He began his career at the Stanford Research Institute (1975–1982) before joining Phase 2 Automation in 1982 as a project leader for robotic systems design. His next stop—in 1985—was Quizix, Inc., where until 2005 he was president/oil field research equipment. In 2005, Petro founded NovaTorque, Inc. and continues there today as the company's chief technical officer, working exclusively on high-efficiency electric motors.*

Motoman

INCREASES EDUCATION/TRAINING PROGRAMS

Harrisburg Area Community College (HACC) is now a Motoman Endorsed Robotics Instructor Training (MERIT) center. Through the MERIT program, universities and community colleges such as HACC offer the same level and quality of Motoman training to the regional manufacturing workforce. On March 1, representatives from HACC and Motoman Robotics cut the ribbon at the grand opening of the MERIT center located at the Chambersburg Mall. The center will deliver the NX100 Basic Programming, Advance Programming and Maintenance courses. "We are very excited about collaborating with Harrisburg Area Community College and manufacturers in eastern Pennsylvania," says Doug Schenher, vice president of Motoman Robotics, customer satisfaction group. "We view HACC as an extension of our Motoman training department. With an installed base of over 1,000 robots in this area, this is a significant win for the regional workforce and manufacturers. Increasing the skills of the workforce in the areas of robotics and advanced manufacturing enables companies to achieve new levels of productivity and profitability."

"Today represents another milestone," said Ron Young, HACC's provost and vice president of academic affairs and enrollment management. "We are, of course, increasing our mechatronics program, and we will be able to do that through the Robotics course."

The ribbon cutting ceremony for the Harrisbug Area Community College MERIT center took place on March 1 (courtesy of Motoman).

Additionally, Evansville Vanderburgh School Corporation (EVSC) recently announced the opening of the Motoman Robot Laboratory at the Southern Indiana Career and Technical Center (SICTC). The center received an advanced manufacturing grant this year, allowing it to purchase eight HP3JC robots with NXC100 controllers. The robotics program is one of several new programs SICTC has started in order to better prepare students for careers in post-secondary education related to manufacturing. SICTC's new Motoman Robot Laboratory will equip students with the skills needed to support advanced manufacturing in the southern Indiana region. For more information, visit *www.motoman.com*.

Motoman also opened a Robot Laboratory at the Southern Indiana Career and Technical Center (courtesy of Motoman).

Eva Woo

JOINS BISHOP-WISCARVER

Linear motion technology manufacturer Bishop-Wisecarver has announced that a new vice president of marketing has been hired to support the company's forward-thinking communications and branding efforts. Eva Woo joined the company in early March, bringing with her a wealth of experience in online and offline marketing. She will play a leading role along with the executive team to develop innovative ways to build the BWC brand as it grows into new markets. Bishop-Wisecarver President Pamela Kan said the company chose Woo because of her knack for building brands from the ground up, her energy and her ambitious vision. "I am very excited at the new skill sets and expertise that Eva will bring to the team," Kan said. "Eva shared many ideas through the interview process and I look forward to seeing the impact that her changes will make on our company. It is a very exciting time for us and I feel very lucky to have Eva on the team to help us achieve all aspects of our strategic plan."

Eva Woo

An industry veteran, Woo has spent the last 20 years shaping existing brands in various fields, from apparel to online games, and launching new ones, like toys and search/display advertising. Woo started her marketing career as a product manager for Levi Strauss International, where she marketed U.S.-manufactured apparel to the Asia market. Woo then went on to become a start-up product marketer for companies such as MySpace, LeapFrog Enterprises and AdScape Media. Woo worked as the product marketing manager at Google, where she launched the Google Certified Partners Program for Google AdWords Professionals, Google Analytics Authorized Consultants.

"I saw the position at BWC as a chance for me to apply my skills and experience with marketing to an industry that could use more marketing breakthroughs," Woo said. "I have been fortunate enough to be part of some very successful companies, all of which were known for quality and consistency. I see that BWC has a lot of similar traits." Woo holds a bachelor's degree in international business and marketing from San Francisco State University and a master's degree in Organization Development from the University of San Francisco.

ABB

ACQUIRES NEWAVE ENERGY HOLDING

ABB recently announced that is has completed the public tender offer for Newave Energy Holding SA. The acquisition of Newave advances ABB's strategy to strengthen its position in the power control and quality market and it facilitates the sale of Newave products and services beyond their traditional markets in Europe through ABB's worldwide distribution network. Newave is well known in Europe as a manufacturer of uninterruptable power supply (UPS) systems. ABB plans to integrate Newave in its Discrete Automation and Motion division, with Newave's headquarters in Quartino, Switzerland, to become a main location for ABB's UPS systems. The management of Newave will assume leading positions in ABB's UPS business, which is expected to grow significantly because of the strategic and operational advantages resulting from the integration of Newave into ABB's UPS business.

"Combining ABB's and Newave's market presence and technological expertise will allow ABB to offer a complete range of UPS solutions to industrial, commercial and datacenter clients with a comprehensive alternating current (AC) and direct current (DC) solutions portfolio, reinforcing its strategic differentiation," said Ulrich Spiesshofer, ABB executive committee member responsible for the Discrete Automation and Motion division. "I am confident that the knowledge, experience and determination in both organizations will result in a strong, cohesive team focused on delivering exceptional products and services to our customers in Europe while opening new growth opportunities around the world."

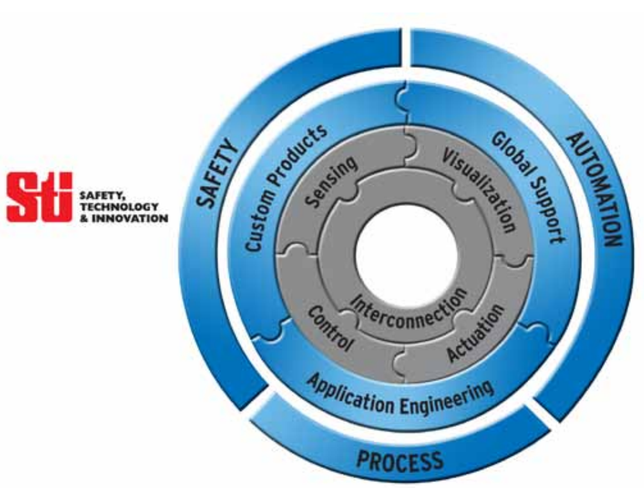
"We are very glad that our shareholders accepted ABB's offer. With ABB's resources we can significantly extend the reach of Newave's products and grow further," said Newave's Chairman Vllaznim Xhiha. "With the integration into ABB, Newave and its employees have a bright future ahead."

Omron

INTEGRATES SUPPORT FOR INDUSTRIAL AUTOMATION AND SAFETY

Omron Industrial Automation and Omron Scientific Technologies Inc. announced an internal realignment of support for machine automation systems and safeguarding to satisfy the needs of a wider range of customers. The sales and support organizations of Omron Industrial Automation and Omron STI will report to the same management while maintaining individual expertise in established areas at their current locations. The path to market using distributors remains unchanged: those specializing in either Automation or Safety will continue with that product portfolio; those distributors authorized for both will support both product categories. Customers will experience "business as usual" when the internal change takes effect on April 1, 2012.

"This sales realignment is the planned next phase of integration to provide our customers powerful machine automation and safety solutions, backed by application expertise and support acknowledged to be the best in the industry," explained Gregg Holst, president/chief operating officer of Omron Industrial Automation for the Americas.



"In 2006, when Omron acquired STI, we started down a path that would allow us to leverage the combined strengths of a global automation company while providing us with the resources to invest in and grow our safety business in a very competitive market," says Jim Ashford, president and chief operating officer of Omron STI. "This arrangement has turned out to be a great success for all of us. The subtle, but important next step in our evolution capitalizes on our organizational synergies and strengthens our ability to deliver exceptional customer value."

"There are four goals we seek to accomplish with this new arrangement," states Tony Canonaco, Omron STI vice president sales. These include strengthening automation competency, presenting one Omron automation company, providing employee enrichment and transforming the company.

The realignment consolidates internal management responsibilities for automation and safety sales and support into three regions: USA and Canada; Mexico and Latin America; and Brazil. The arrangement enables greater sensitivity to local regulatory requirements to provide appropriate products and systems to customers.

PTDA Foundation Contributors

KICK OFF 2012 FUNDRAISING EFFORTS

With the anticipated retirement of more than 80 million baby boomers over the next 20 years and only 43 million younger workers in line to replace them, the time is fast approaching when recruiting talented individuals will once again be a serious challenge for every business. For the power transmission/motion control industry, the problem is even more profound as it endures a lack of recognition among young people as well as a well-publicized skills gap. The Industrial Career Pathway (ICP) initiative—founded and significantly funded by the PTDA Foundation—is taking major steps to ensure the workforce is aware of the satisfying and rewarding careers available in industrial distribution.

And to help, 15 organizations stepped up by making contributions of more than $48,000 to fund the initiative's activities in 2012. These organizations are "in the vanguard" or leading the fundraising charge. By contributing to the PTDA Foundation as part of the Vanguard Campaign, they are taking a leading role in the movement to drive talented workers to the key positions of sales and customer service in industrial distribution.

"The 2012 Vanguard contributions show us just how many companies understand the importance of reaching out, connecting with and preparing young people to become our industries' outstanding employees and future leaders," said Barbara J. Ross, vice president sales and marketing, Timken Drives LLC, and president of the PTDA Foundation. "I give my sincere thanks to all 15 organizations for supporting the PTDA Foundation and its key initiative—Industrial Careers Pathway (ICP)."

2012 Vanguard contributors include BDI Worldwide, NSK Americas, Rexnord Industries, SKF USA, The Timken Company, Altra Industrial Motion, Bearing Service Inc., U.S. Motors/Nidec, AMI Bearings, Climax Metal, Hitachi, IBT, Koyo Corp, Lafert North America, Goodyear Engineered Products and Technologies, Inc.

The Vanguard campaign kicks off the PTDA Foundation's 2012 fund drive. For more information, visit *www.ptda.org*.

AMT and AMTDA

ANNOUNCE MERGER

The Association for Manufacturing Technology (AMT) and the American Machine Tool Distributors' Association (AMTDA) recently announced the merger of the two associations that will integrate their products and services to better serve the members of both associations. The announcement was made at The MFG Meeting (Manufacturing for Growth) held in Orlando, Florida. The new AMT will be headquartered in McLean, Virginia. All current employees of AMTDA will be joining the new AMT immediately.

Steve M. Wherry, chairman of AMTDA said, "This merger is a logical evolution for the manufacturing technology industry. We are uniting the entire manufacturing technology supply chain from engineering and building machines, to integrating automation and support, to distribution services, which will well serve the users of manufacturing technology for their future."

Eugene R. Haffely, Jr., chairman of AMT added, "This move exponentially increases member benefits and services to both organizations. We are now a stronger, more complete organization, representing the entire value chain of the manufacturing technology industry. Most important, this will give our industry a more clarified and unified voice." Both boards of directors voted unanimously for the merger, and an unprecedented percentage of the combined membership participated in the vote to approve the move.

As a result of the merger between AMT and AMTDA, the organization took on an intensive process to design a new logo, and hence, a rebranding of the newly conjoined group. The logo was inspired by the Al Moore Award, which recognizes extraordinary service to the industry. The design is a mathematical Lissajous curve suggestive of a three-dimensional knot. This pyramid style shape is evocative of a solid base with stability and strength. "It has always been our goal to find better ways to serve the manufacturing industry," said Douglas K. Woods, president of AMT. "This process, upon which we embarked two years ago, is a natural partnership that will help both organizations as we seek to advance manufacturing in the United States."

For more information, visit *www.amtonline.org*.

April 23–27—Hannover Messe 2012.
Hannover Fairgrounds, Hannover, Germany. The world's leading trade show for industrial technology returns in 2012 with a full lineup of trade shows. The eight co-located shows include Industrial Automation, Energy, MobiliTec, Digital Factory, Industrial Supply, CoilTechnica, IndustrialGreen Tec and Research and Technology. China is the official partner country in 2012. Discover new perspectives on energy, automation and industrial supply and engineering topics as well as a broad range of events and displays affecting the global industrial market today. Other Hannover highlights include Metropolitan Solutions, TectoYou, Job and Career Market and Energy Efficiency in Industrial Processes. For more information, visit *www.hannovermesse.de*.

April 29–May 1—BSA Annual Convention. Bonita Springs, Florida.
Business programming at the Bearing Specialists Association's (BSA) 2012 Annual Convention will help attendees plan strategically for the latest developments in technology. Help your company focus on the cost- and time-saving ways in which the latest mobile technologies deliver sales and solutions. How will you move your business forward in this new mobile communications culture? How will you and your customers benefit? How will this differentiate you from your competition? BSA challenges the industry to consider how to best leverage the latest business tools with "Technology Drives Productivity." Business programming at the 2012 event will provide an overview of how authorized distributors and their supply chain partners can differentiate themselves in the marketplace, providing customer solutions and products using the latest technology. Speakers at this year's convention include Daniel Burrus, Guy Blissett, Matthew Bookspan and Brian Eccles. For more information, visit *www.bsa.org*.

May 1–3—SMMA 2012 Spring Management Conference.
Fort Meyers, Florida. The SMMA is a manufacturing trade association, founded in 1975, comprised of motors and drives manufacturers and their suppliers. The vision of SMMA is to serve as the voice for the motor and motion industry, providing a forum for education, communication, research and networking. The Spring Management Conference will be chaired by John Wolfe, vice president sales and marketing for Ametek. Paul Cherry, Performance Based Results, will present three discussions during the event, including the keynote address. The conference will also feature an economic update from Alan Beaulieu, Institute for Trend Research and a presentation on global motor market trends from Alex Chausovsky, IMS Research. Dan Jones, president of Incremotion Associates will offer a motors and motion college course prior to the beginning of the conference. For more information, visit *www.smma.org*.

May 8–10—Mfg4 2012. Hartford, Connecticut.
GE Energy, Medtronic, Boeing, Raytheon, Sikorsky and other manufacturing organizations know the best source of innovations and solutions may be outside their industries. That's why they—in partnership with a dozen additional industry innovators—are presenting Mfg4 with the Society of Manufacturing Engineers (SME). Mfg4 presents solutions for buyers and sellers across the aerospace, defense, medical and energy manufacturing industries. Conference sessions include improving manufacturing processes, digital manufacturing, machine accuracy and volumetric compensation, fundamentals of robotics and many more. Exhibitors include Carl Zeiss, Fanuc, Heidenhain, Marposs and many more. At the heart of the Mfg4 event floor is the Insight Intersection, an area where small groups of professionals meet for practical exchanges of information. Each morning at Mfg4, exhibitors and sponsors can reserve this space to host breakfast meetings or working sessions with customers and prospects. For more information, visit *www.mfg4event.com*.

May 20–23—40th Annual PTRA Conference.
Hotel del Coronado, San Diego. The PTRA Conference will focus on new high-tech sales tools, choosing the right CRM software, PowerPoint for successful sales presentations, insights into applied industrial technologies, communication vs. call reports and an economic forecast. Conference speakers include Alan Beaulieu (Institute for Trend Research), Joseph Miller (Miller Management Services), Robert Curley (Applied Industrial Technologies), David Inniss (San Diego CRM) and Steve Turner (Turner Time Management). Highlights include a charity walk, golf tournament and dinner/reception aboard the USS Midway. The PTRA is made up of independent manufacturers' representatives and manufacturers dedicated to promoting sales representation in the power transmission and motion control industries. For more information, visit *www.ptra.org*.

June 7–9—PTDA Canadian Conference.
Fairmont Empress Hotel, Victoria, British Columbia. Since its debut in 2002, the PTDA Canadian Conference has become a powerful business conclave for Canada's power transmission/motion control industry. The event features intimate business networking and educational opportunities along with "The Industry Showcase," a program designed for those specifically marketing product in Canada. "The PTDA Canadian Conference delivers unmatched value for members," said Mitch Bouchard, secretary treasurer of Ottawa-based General Bearing Service Inc. and the newly elected PTDA board of directors' president. "There is no other organization that can deliver such thorough networking and educational opportunities in such an efficient package." Bouchard said the planning committee is optimistic about 2012, as the latest PTDA Market Forecast indicates the Canadian market will be steadily increasing in strength and growth throughout the year. "We believe the Fairmont Empress will be the ideal location on the West Coast to host this important Canadian-specific networking event," said Bouchard. For more information, visit *www.ptda.org*.

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THE SHOW MUST GO ON

Nook Customized Components Fit Talk Show Set... By a Thread

Chicago Scenic Studios, Inc. (CSSI) knows a thing or two about set construction. From studio sets and exhibits to special-event stages and theatrical productions, CSSI combines practical applications of technology, craftsmanship and project management into each assignment. These assignments have included television sets for the *Big Ten Network*, scenic pieces for *The Addams Family* musical and plenty of technological bells and whistles for various Shakespeare productions.

When a broadcast set for an afternoon talk show in Chicago was needed—one that required nearly 50 points of motion—CSSI was called in to provide some much needed innovation. "The set design included some engineering and construction challenges," says Mark Ewing, CSSI head of automation. "We had to develop a system for vertically lifting and retracting transparent, 300-pound acrylic walls that contain light boxes so they could be hoisted away from the set with rigging."

A series of mechanized devices supported numerous stage configurations and provided great flexibility, but there was a bit of a snag when it came to controlling the walls.

"The walls are 16-feet high and the studio ceiling is 30 feet high," Ewing says. "We needed a means for cutting the height of the wall in half by lifting and retracting the lower portion inside the upper portion so the collapsed eight foot wall could be removed from or brought onto the set. We needed to achieve this movement relatively quickly and quietly to facilitate fast set changes. We were also working with frosted Plexiglas with double-sided light boxes that you can see through and needed to hide the linear motion control system in the side of the upper wall in a space that only provided a few inches in which to work."

Enter Nook Industries.

CSSI had used linear motion systems from Nook in the past and knew from experience that a customized solution was possible. Nook offered a 50 mm ball screw solution in which the system uses an AC motor that drives a miter gearbox to turn the ball screws, raising the ball nut on the lower wall and lifting the wall.

"There were not any standard systems that could accommodate an eight-foot travel length in such a small space," Ewing says. "Nook provided an effective solution with specially configured ball screws having a custom length and diameter."

In addition to the travel length and footprint challenges, the retractable wall system had to move the wall at a rate of six inches per second without creating excess noise, resonance or vibration. Because the walls needed to retract while other portions of the broadcast set were in use, the retraction had to be relatively quiet and vibration free.

"We had no time for trial and error or trying different prototypes of possible systems. We needed something that worked out of the box and had zero margin of error."

Nook's success helped lift the 300-pound set walls over a travel length of eight feet, dampened vibration and resonance with 50 mm diameter lead screws and achieved six-inches-per-second-lift speed with steep pitch thread pattern. This all occurred on-time and on-budget without any further need to customize the television talk show set.

"We turned to Nook because we had confidence in their engineering expertise and ability to come through for us," Ewing adds. "Nook's responsiveness contributed to the on-time, on-budget delivery of this sophisticated, technically challenging project."

The end result was a television production set that provided multiple ways for guests, bands and special sets to be revealed. It further enhanced Nook's reputation as a component manufacturer that can offer timely, customized solutions on tight deadlines without compromising quality. Most importantly, they saved CSSI in a pinch when the show had no choice but to go on.

For more information on this or other unique power transmission applications, visit *www.nookindustries.com*.