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PTE

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Medical Devices

Case Studies

- Software Helps Nestle Make the "Very Best"
- Linear Actuator Helps Rein In Large-Format Automation

Technical Articles

- Nickel-Titanium Bearings the Next Best Thing?
- Spindle Metrology a Good Addition to Manufacturing Process

Power Play

- Robots Rule in "Terminator Salvation"

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www.automationdirect.com

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www.automationdirect.com/stepper-systems

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Particles and fluids have...

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New Boston Gear Stainless Steel 700 Series speed reducers are optimized for washdown applications.

Blending the trusted 700 Series worm gearing with an improved exterior design, the new stainless steel 700 series provides the trusted performance you've come to expect from Boston Gear speed reducers!

Developed for optimal performance in tough caustic environments, the rounded housing design features smooth uninterrupted surfaces, preventing particle accumulation and pooling fluids. All holes for the motor, flange, fill/drain holes, and base are counter bored and covered. Laser marked nameplate information provides added corrosion protection.

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All models are NSF certified and available for same day air shipment!

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1.800.825.6544

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Photo courtesy of Maxon Motors

Maxon Motors

AIMS FOR MEDICAL APPLICATIONS

Maxon, a manufacturer of small, high-quality DC brush and brushless motors, announced key product developments for medical technology applications including the EC 9.2 flat motor and the KD 32 planetary gearhead. The company has also released a high density 200 W power pack in the RE 50 and a compact speed controller for brushless DC motors with Hall sensors with its DEC Module 24/2.

The EC 9.2 flat motor offers a high nominal torque of 0.83 mNm and a stall torque of 1.29 mNm. Its outer diameter of 10 mm includes a cover that protects against contact and can be used as a mounting aid during installation. The EC 9.2 is equipped with an 8-pole neodymium permanent magnet and preloaded ball bearings. The motor can be utilized for medical technology applications where space limitations may be a concern. Other features include high nominal torque and lifespan-optimized bearings. It is available with or without Hall sensors.

The new Koaxdrive KD 32 combines worm and planetary gear technologies with a patent-protected design that has enabled Maxon to reduce the noise in the first gear stage where the greatest peripheral speeds occur. This planetary gearhead measures 32 mm in diameter and can be assembled with various Maxon motors. These low-noise combinations can be used for hand tools and instruments that are primarily used on or near patients in the medical technology sector.

The KD 32 planetary gearhead.

The RE 50 is an extremely dense power pack, which results in detent-free running and minimized mass inertia. The combination of a two-pole neodymium permanent magnet with the patented Maxon winding technology results in high torque and remarkable acceleration. The drive can be used in battery-powered applications such as electric vehicles, transport and logistics equipment, mobile systems and robotics. A dust and water protected RE 50 will soon be available with an optional brake.

The DEC Module 24/2 is a wireless, plug-in module that can be integrated into most applications. A wide voltage range of 8–24 VDC and a continuous output of 2A allows flexible multifunctional operation at a high efficiency factor.

For more information:
Maxon Precision Motors
101 Waldron Road
Fall River, MA 02720
Phone: (508) 677-0520
Fax: (508) 677-0530
www.maxonmotorusa.com

Renishaw's RLS Line

PROVIDES SENSOR SOLUTIONS

Renishaw recently released their new generation of position encoders for harsh environments. Traditional optical encoders are essential components in motion control systems, though it is necessary to protect them from harsh environments. This limits the diversity of applications where encoders can be deployed and can add substantial cost. According to the company's press release, RLS magnetic encoders provide many of the features of optical encoders but with increased robustness.

The RLS encoders are 100 percent solid-state devices with no moving parts, sensitive optics, or seals and bearings that can wear out or become contaminated. They offer a full range of output formats including AB quadrature, analog voltage, UVW commutation and linear voltage. They also provide absolute position output with resolution up to 13 bits. A wide range of package configurations makes the encoders practical for integration into OEM systems.

In addition, Renishaw upgraded its 13-bit magnetic encoder and presented

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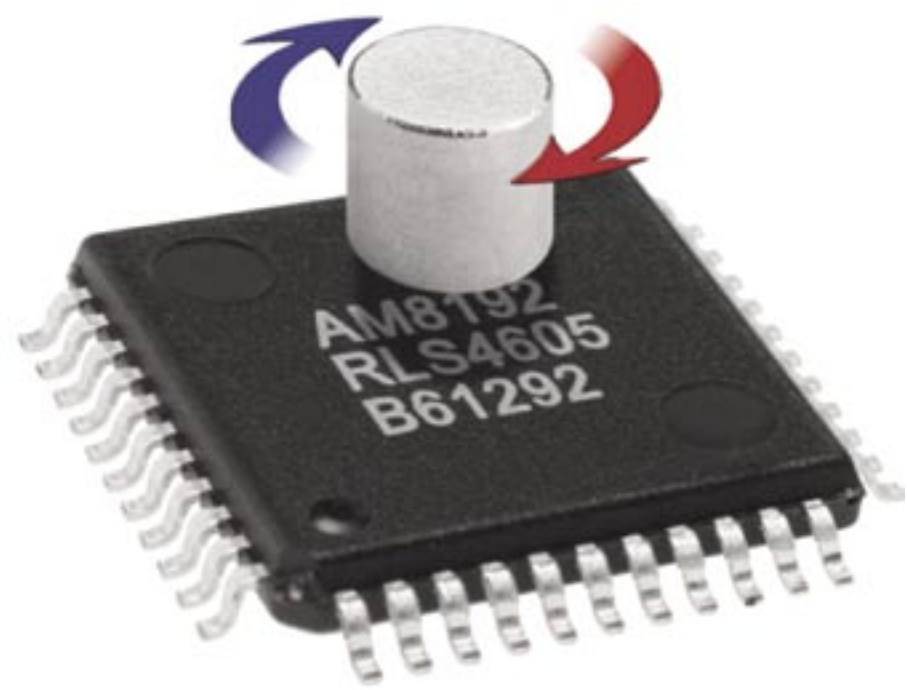


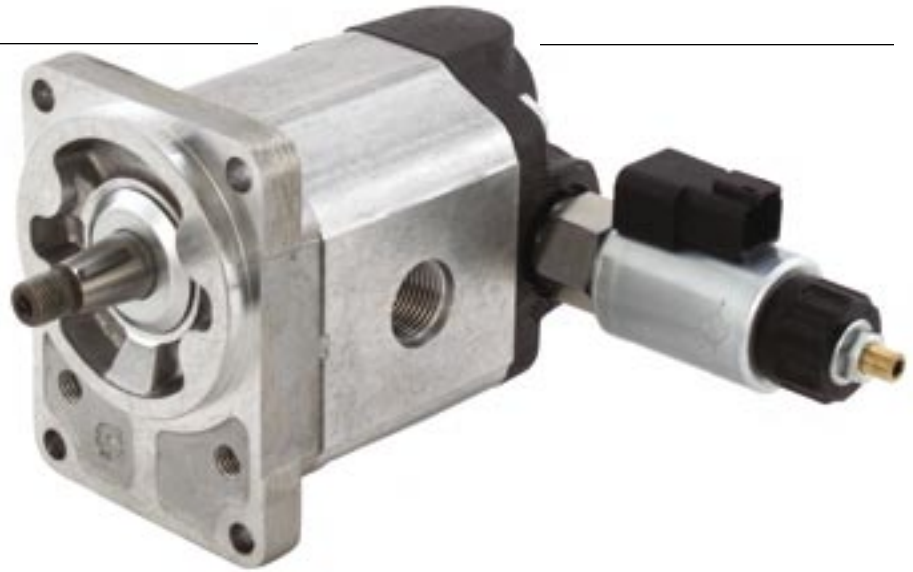
it at the show with improved time delay and accuracy, plus performance tailoring capabilities. The AM8192B increases operational speeds to 38,000 rpm at a 13-bit resolution. A software interface allows designers to choose optimum settings based on the application and provides a HEX setting file for easy upload.

The non-contact design of the encoder gives OEMs reliable solutions for difficult and extreme operating conditions. Sine and cosine voltage outputs vary with magnet position, which the encoder's interpolator converts to a range of binary and decimal resolutions. It's also able to cancel magnetic interference, permitting operation in areas of high external magnetic fields.

For more information:
Renishaw Inc.
5277 Trillium Blvd.
Hoffman Estates, IL 60192
Phone: (847) 286-9953
Fax: (847) 286-9974
howard.salt@renishaw.com
www.renishaw.com

Sauer-Danfoss Gearmotors

MEET INCREASED ENGINE COOLING REQUIREMENTS



The Group 2 and Group 3 Series fan drive gearmotors from Sauer-Danfoss are suitable for demanding off-highway applications' machine cooling needs. The SGM2Y and SGM3Y motors have several new features including a cast iron rear cover on the aluminum housing for high pressure and durability requirements; an electrohydraulic proportional relief valve that is part of the rear cover sustains performance over a machine's temperature range; and a variable speed proportional fan control allows for quick cooling on demand and improved fuel economy.

"The introduction of Tier IV and Stage III B regulations requires emission reductions and the employment of technologies that will reduce net vehicle power output by about 5–10 percent, with heat rejected into the environment up by 10–30 percent," says Jeff Brenner, product portfolio manager for Sauer-Danfoss. "The outcome is engine and transmission oil temperatures will run at significantly higher levels. Adjustments

are essential to compensate for both loss of available horsepower and higher engine and transmission oil operating temperatures. SGM2Y and SGM3Y motors can handle increasing engine and transmission oil temperatures by adjusting to both the higher heat loads and a wide range of severe duty operating conditions."

The fan drive gearmotors come in two frame sizes, and rated pressure is up to 250 bar (3,625 psi) with peak pressure up to 270 bar (3,915 psi). Various flange and shaft options are available as part of a range of configurations.

"Our fan drive motors and complete systems must consistently perform in hot, dusty environments," Brenner says. "Engine emission requirements serve to magnify tough operating conditions for customer machines such as skid steer loaders, fork lift trucks, telehandlers, mini-excavators, wheel loaders, road rollers and pavers. Overall, the design features in these products speak to higher pressure capability, durability, design flexibility and efficiency."

Several features of the gearmotors are responsible for their durability. An integrated shaft seal protects the units from dust, and high temperature seals withstand intermittent temperatures up to 110 degrees Celsius (230 degrees Fahrenheit) and down to –20 degrees Celsius (4 degrees Fahrenheit). The cast iron rear cover handles high pressure, and the EH proportional relief valve is responsible for consistent performance. Gear teeth machining was improved to reduce the noise level.

"These motors are ready to tackle the emission challenges and perform in future generations of machines," Brenner says. "More power in a small package, along with greater cooling efficiency, lower noise and increased durability sum up the SGM2Y and SGM3Y fan drive motors. The PLUS+1 Compliance environment can integrate these products seamlessly with customized software solutions to maximize machine productivity in a highly responsive control system. Greater product and system compatibility leads to shorter lead times and shorter time to market for our customers."

For more information:
Sauer-Danfoss Inc
250 Parkway Drive, Suite 270
Lincolnshire, IL 60069
Phone: (847) 876 1700
Fax: (847) 876 1799
www.sauer-danfoss.com

Motion Programming Script

FUNCTIONS WITHOUT C-CODE EXPERTISE

Kollmorgen, a Danaher Motion Company, introduces the Motion Programming Script (MPS), a network-enabled implementation of a BASIC-like programming language with specific commands for motion control. Electrical and mechanical engineers with minimal programming knowledge can use the MPS to write quick, complex motion sequences and program equipment with short, intuitively named commands.

The MPS is useful with complex motion applications that require simple commands, such as in stage gantry and robotics applications. There is no need for a special code editor, and the MPS is accessed remotely through standard Telnet or a web browser. One-step installation combined with online distribution and an electronic license key make hard distribution requirements unnecessary.

"Frequently, OEMs have electrical or mechanical engineers who are responsible for implementing the control system on their machine," says Ross McMillan, director of engineering for Kollmorgen. "More often than not, these OEMs either underestimate the software staffing necessary, or those people who do the software are also responsible for many other aspects of the machine development. MPS allows those mechanical or electrical personnel

continued

to program the equipment themselves. BASIC programs, while simple, can be very powerful and are well-suited for motion control applications. But BASIC also has a straightforward line-by-line verbose structure that allows someone with very little exposure to the language to get an immediate intuition for what's happening."

For more information:
Kollmorgen
A Danaher Motion Company
203A West Rock Road
Redford, VA 24141
Phone: (540) 633-3400
www.danahermotion.com

Rupture Disc Assembly

PROTECTS TURBINE EQUIPMENT

Continental Disc Corporation introduces a rupture disc assembly specifically designed for wind turbine hydraulic braking systems. The rupture disc assembly protects wind equipment from damage and down time in the event of overpressure conditions.

The rupture disc assembly allows for accurate and leak-free overpressure relief for the control valve/hydraulic accumulator system in hydraulic braking systems and yaw brake controls of wind turbines. The assembly is available in a range of sizes, materials and burst pressure ratings for wind turbine protection applications.

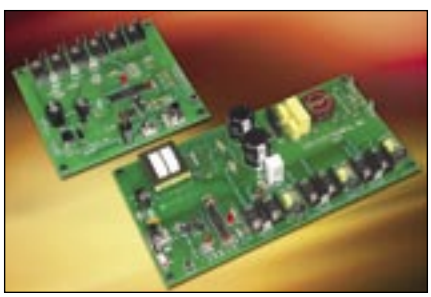
For more information:
Continental Disc Corporation
3160 West Heartland Drive
Liberty, MO 64068
Phone: (816) 792-1500
www.contdisc.com

Analog Brushless DC Motor Controls

FIT IN CONSTRAINED SPACES

Two analog brushless DC motor controls were released by LCR Electronics, for use in three-phase brushless DC motors typical of high-reliability environments. The simple user interfaces make the EC105 and low voltage EC107 suitable for portable or space-constrained applications like commercial tools, appliances and small traction systems.

The RoHS compliant boards use a potentiometer for speed command, a toggle switch to control direction, and a tact switch enables fault reset, which allows for accurate, variable motor speed control using Hall effect sensors for feedback. They feature a trapezoidal, two-quadrant control technique and soft start, resettable overload detection.



The EC105 and EC107 controls operate between 0 and 85 degrees Celsius, and optional coating is available for use in humid or wet environments. The EC105 has an input of 120/240 VAC and a 3A maximum load current, which LCR can upgrade to 20A with an output of 150/300 VDC. The EC107 has an input of 12/24 VDC and a maximum load current of 5A, also upgradeable to 20A. LCR intends to release a four-quadrant version late in 2009.

For more information:
LCR Electronics
9 South Forest Ave
Norristown, PA 19401
sales@lcr-inc.com
www.lcr-inc.com

Misumi

ADDS SEVERAL LINEAR GUIDES TO PORTFOLIO

The SSELBP, SSEBMO, SSEPWP and SSELBWP Miniature Linear Guides from Misumi feature dowel holes on rail and block for positioning that is quick and easy. These guides allow engineers to choose from several design options to suit specific application requirements and technical specifications.

The special options include advanced (preload) and standard (interchangeable and small clearance) versions; long or wide blocks, standard or wide rail in various dimensions; and varying guide rail with dowel hole lengths. The dowel holes make it easy for users to disassemble and reassemble a mechanism for routine maintenance without

realignment. The balls remain retained in all versions, even when the block is removed from the rail. They operate between –20 and 80 degrees Celsius.

For more information:
Misumi USA
1105 Remington Road, Suite B
Schaumburg, IL 60173
Phone: (847) 843-9105 or
(800) 681-7475
Fax: (847) 843-9107 or
(800) 681-7402
inquire@misumiusa.com
www.misumiusa.com

Check Valve Assembly

REDUCES COMPONENTS

Mico Incorporated released a Check Valve Assembly for full power brake systems that includes a check valve and inverted shuttle valve. The assembly supplies fluid for two accumulator circuits while reducing the system components necessary and limiting plumbing and hardware.

The Check Valve Assembly is suited for full power hydraulic brake systems that need to store energy in two accumulator circuits. It features high flow capacity up to 11 gallons per minute and a top operating pressure of 3.625 psi. Pressure is applied to the accumulators by the inlet port. While directing the lower pressure to the switch port, the inverted shuttle valve isolates the higher pressure of the accumulator circuits. Pressure leaking from the switch port to the inlet port is prevented by a check valve. The assembly limits check valve leakage to 0.25 cubic centimeters per minute at 3,500 psi.

For more information:
Mico, Incorporated
1911 Lee Blvd.
North Mankato, MN 56003
Phone: (507) 625-6426
Fax: (507) 625-3212
micomail@mico.com
www.mico.com

Direct Drive Cooling Tower System

SAVES ENERGY

The Baldor VS1 Cooling Tower Drive combines the laminated finned frame RPM AC motor with a permanent magnet salient pole rotor design. The drive replaces the right angle gearbox and jack shaft installation in conventional cooling towers. The fan attaches to the motor shaft and is controlled by the VS1 drive, which runs

quieter, requires less maintenance and consumes less energy.

The cooling tower motor is ideal for the hot, humid environment indicative of a cooling tower. A labyrinth bearing isolator and flinger prevents water ingress along the shaft. Condensation drains take care of any moisture that might build up in the motor. The system uses a vacuum pressure impregnation process to prolong motor life through extreme conditions.

The tower drive uses sensorless algorithms for smooth, low speed operation. It supports several protocols to communicate with most building automation systems.

For more information:
Baldor Electric Company
5711 R.S. Boreham, Jr. Street
Fort Smith, AR 72901
www.baldor.com

Linear Motors

IMPROVE GAS HEATER EFFICIENCY

Crouzet North America, a Custom Sensors and Technologies company, recently introduced its Linear Motor Series to the North American market. The motors are designed to provide a more efficient method of gas heating control by using proportional control of gas flow instead of straight on/off control.

Highly accurate modulation of gas dispensed results from using these motors, and this means fuel can be burned as quickly or slowly as needed, so burning efficiency improves. Typical applications include gas heaters, as fireplaces and other equipment using gas valve control.

The motors are packaged as an integrated device assembly including valve and safety function on stepper models. Regulation of the linear stepper motor allows for two electromagnets per channel to be replaced, but only one channel is required to control the global range of flow. The stepper configuration also features a dual safety system that merges the regulation and fail-safe function into one, so the motor can turn off the valve and stop gas flow in under 10 ms. The valve springs back to close if power is ever as part of the safety function.

Three digital linear models in a range of speeds, step angles and output

forces are available in the series. They each have a standard linear travel of 10 mm, and versions with an anti-rotation device built in can travel up to 35 mm. The first model in the series features synchronous motor technology and offers low- and high-speed connections. It provides 10 mm displacement at 115 volts, a linear step speed of 0.833 or 1.67 mm per second and output force between 27 and 45 N.

The other two models are stepper versions and provide 10 mm displacement with two or four phase configurations. One of the stepper models has a –7.5-degree step angle, a 0.0167 mm per step linear step displacement and output force of 38 or 58 N. The other stepper includes a –15-degree step angle, 0.033 mm per step linear step displacement and output force of 38 or 43 N.

"Crouzet's Linear Motor Series has proved extremely successful in the European market where conservation has been a priority," says Todd Ervin, Crouzet regional sales manager. "With the North American market's growing commitment to a greener earth, we believe this product will be an excellent solution for OEMs and manufacturers seeking better solutions for gas heating."

For more information:
Crouzet North America
2470 Coral Street, Bldg. D
Vista, CA 92081
Phone: (760) 597-6322
Fax: (760) 597-6320
mcnamaj@us.crouzet.com
www.crouzet-usa.com

Electric Actuator

TAILORED TO MARINE VALVE APPLICATIONS

Rotork's ROMpak range of electric actuators offers the marine industry a

lightweight, economical and compact solution for operating quarter-turn valves and dampers with various choices in control, instrumentation and diagnostic options.

The actuators feature self-locking gears, manual override, externally adjustable mechanical stops, a range of mains power options and an IP67 watertight enclosure. The ROMpak actuator also features a self-contained control package with local controls and status indication relays. Optional features include the Rotork Folomatic positional control, current position transmitter, integral data logger, non-intrusive configuration with Bluetooth and digital bus network connectivity. Bluetooth configures the network connectivity and the recovery of historical operating data from the data logger for valve diagnostics and maintenance planning.

The ROMpak range comes in three actuator sizes with operating torques from 35 to 650 Nm, and they are appropriate for ambient temperatures between –5 and 60 degrees Celsius. Orders for the ROMpak actuators have included applications on new naval vessels being built for an Eastern European country.

For more information:
Rotork Controls Ltd.
Brassmill Lane
Bath BA1 3JQ
United Kingdom
Phone: +(44) 1225-733200
Fax: +(44) 1225-333467
mail@rotork.co.uk
www.rotork.com

Small Diameter Ball Screws

FIT SMALL FOOTPRINT

Nook Industries' Small Diameter Ball Screw Assemblies (SD Ball Screws) are designed for smaller footprint applications like robots, medical equipment, guided missiles, unmanned vehicles and aerospace applications. The ball screw line was developed as an extension to Nook's Power-Trac product as a globally accepted metric product for compact, portable and lightweight applications that require high accuracy, repeatability and durability.

The SD Ball Screws feature ±100 µm/300 mm, diameters from 6 to 12 mm and standard leads from 1 to 3 mm. The basic configuration assembly is usually powered by a motor that generates torque as the rotating screw pushes the nut along the screw shaft, resulting in linear thrust. They are typically used along linear slides as part of a linear actuator. The ball screws come in a variety of materials including alloy, stainless, aluminum, titanium and other exotic metals. They come in standard sizes, but Nook can customize them for specific applications.

For more information:
Nook Industries, Inc.
4950 East 49th Street
Cleveland, OH 44125
Phone: (216) 271-7900 or
(800) 321-7800
Fax: (216) 271-7020
www.nookindustries.com

SI Couplings

DON'T WEAR, EXPERIENCE BACKLASH

Magnetic disk couplings from Sterling Instrument feature no friction or wearing parts, use no electricity and no magnetic particles to leak. These units, identified as the S50DCM (inch) and S50DCMM (metric) Series, are stocked in eight bore sizes ranging from .1875" to 1.000" (5 mm to 19 mm). The couplings consist of two opposing disk halves with rare earth magnets. The torque applied to one disk is transferred through an air gap to the other disk. Because of its flat design, angular misalignment of up to 3 degrees or parallel misalignment of up to 1/4" can exist and the couplings continue to transmit nearly full rotational torque.

These 416 stainless steel couplings incorporate an NdFeB, nickel plated magnet. The hub sections are offered singularly and with or without a keyway. They are fastened to shafts with an included set screw. The coupling O.D. ranges from 1.72" to 2.86" (43.7 mm to 73 mm). Repeatable torque control is another feature, and no friction exists because there is no physical contact between driving and driven parts.

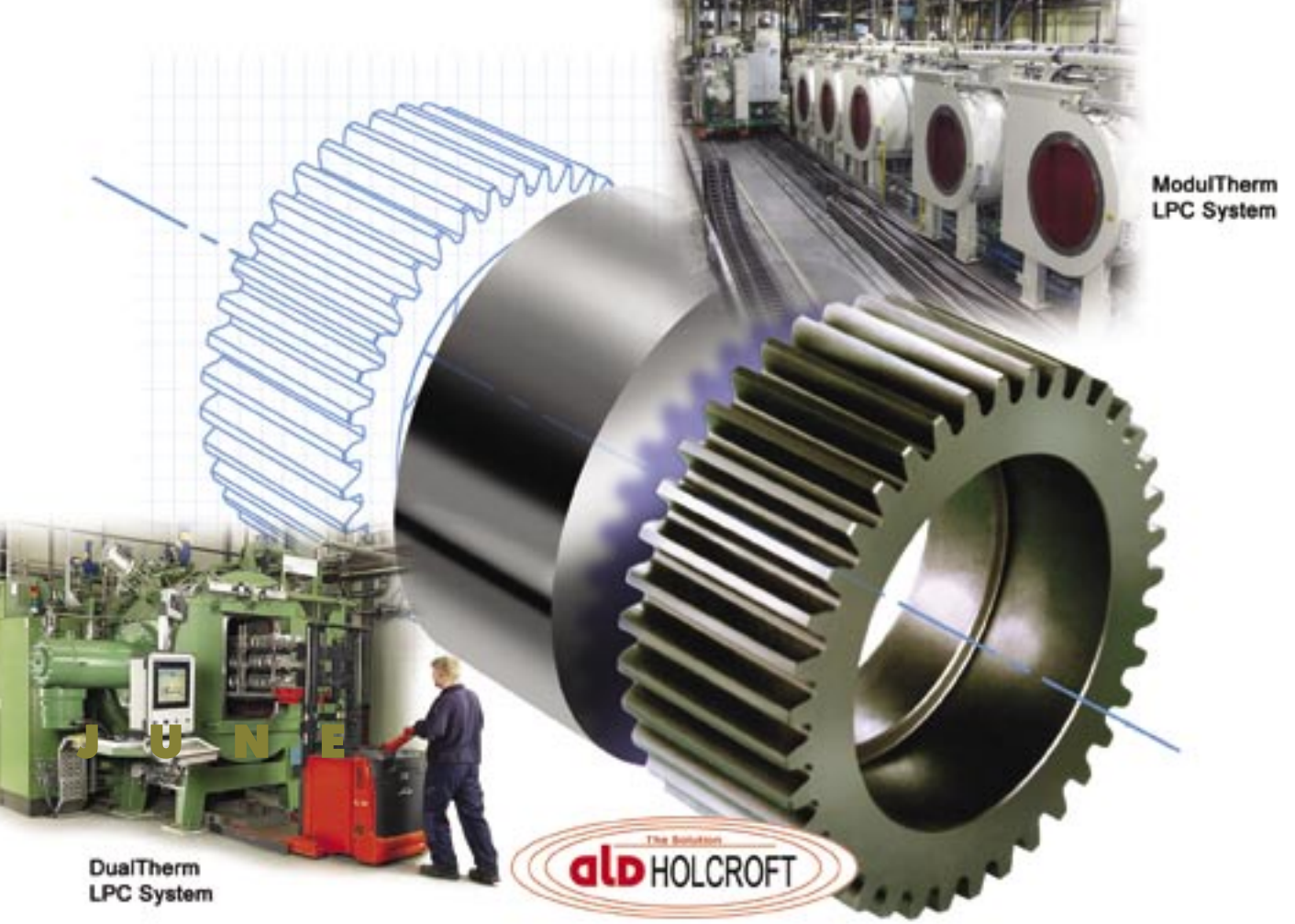
Applications include material handling such as for conveyor belts, film transport, capping of syringes or bottles, shrink wrapping, constant wire tension coil winding and film tensioning. Quotes, online orders and 3-D CAD Models are available at *www.sdp-si.com/eStore*. Detailed specifications are contained in Catalog D795, available free upon request from Sterling Instrument.

Sterling Instrument now offers a series of slit type plastic couplings that are inexpensive, UV resistant with voltage and RF isolation. The S50TLS inch and metric series are stocked in sizes 13, 19 and 25. The plastic couplings replace stainless or aluminum slit type couplings for improved operation. Windup or backlash and derating for reversing applications are not an issue for the S50TLS. A metal screw-to-metal nut design that doesn't use threads cut into a molded piece to ensure a snug fit between the shaft and coupling.

The slit type plastic couplings feature stainless steel fasteners. The bore sizes range from 0.125 to 0.500 inches (3 to 12 mm) while length starts at 0.710 to 1.400 inches (18 to 36 mm), and temperature ranges from –4 to +284 degrees Fahrenheit (–20 to 140 degrees Celsius). They accommodate applications with tight or skewed connections.

For more information:

Sterling Instrument
2101 Jericho Turnpike
P.O. Box 5416
New Hyde Park, NY 11042-5416
Phone: (516) 328-3300
Fax: (516) 326-8827
www.sdp-si.com



Yes. ModulTherm

is a powerful gear design tool from ALD-Holcroft

ModulTherm® is a low pressure carburizing (LPC) system that allows engineers to design out problems like intergranular oxidation (IGO), post heat treat machining, and poor surface finish. It gives gear designers unparalleled control over alloy selection, heat treatment, quenching, and end product performance.

What's unique about the ALD-Holcroft system is multiple quench options. In addition to 20 bar high pressure gas quenching (HPGQ), ModulTherm systems provide oil, water, and press quench capabilities. With this versatility, gear designers can work with low and high alloy steels without sacrificing strength and fatigue resistance.

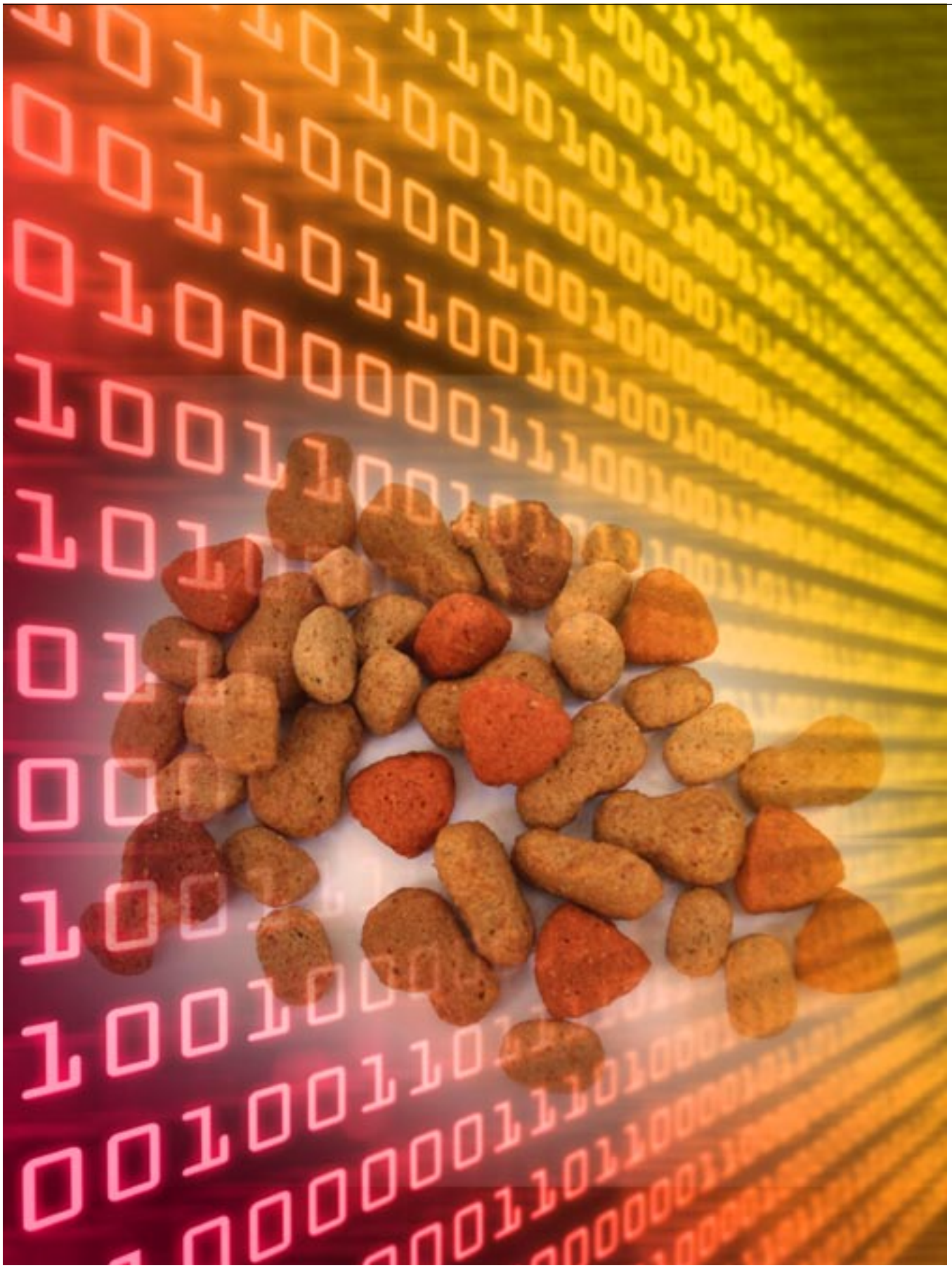
ModulTherm gear design benefits include alloy flexibility, no IGO, no decarburization, little or no part distortion, and excellent root and deep blind hole penetration.

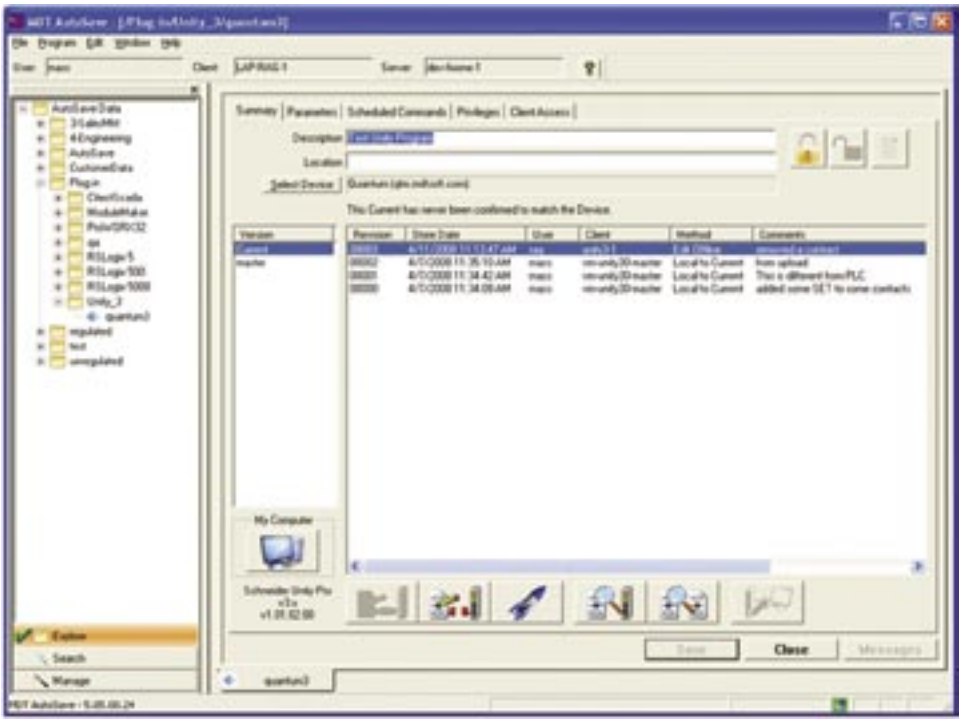
ModulTherm gear manufacturing benefits include quench flexibility, the industry's largest vacuum chambers, 15 to 25% shorter cycle times than atmosphere furnaces, part-to-part consistency, less machining, less destructive testing, lower product costs, and a low Green House Gas emission profile.

ModulTherm installations are fully integrated, fully automated systems with up to 20 vacuum chambers. Lower volumes are handled by DualTherm®, a dedicated LPC/HPGQ system.

ALD-Holcroft Vacuum Technologies Co., Inc. has 80 years of vacuum-based gear processing experience. Our e-mail address is sales@ald-holcroft.com. Our phone number is 248.668.4130. If you design, manufacture, or heat treat gears, call. With an ALD-Holcroft ModulTherm or DualTherm LPC system, everyone wins.

Go to www.ald-holcroft.com to learn more about ModulTherm and DualTherm





AutoSave

INCREASES PRODUCTIVITY AND REDUCES DOWNTIME AND SAFETY RISKS FOR NESTLÉ PURINA

As automation devices have grown more complex and have incorporated more plant data in their operation, there is an increased need for programming changes to continue smooth operation or improve performance. In environments requiring frequent changes, it is not uncommon for code to be lost or changes overwritten, resulting in increased downtime and decreased productivity.

Before MDT Software's *AutoSave* was installed at the Nestlé Purina plant in Mechanicsburg, PA, the plant used a "home grown" program to track changes in their programmable devices. Approximately 15 programmers regularly made changes by accessing the most current program from Explorer, making changes and then saving the new version of the program back on Explorer.

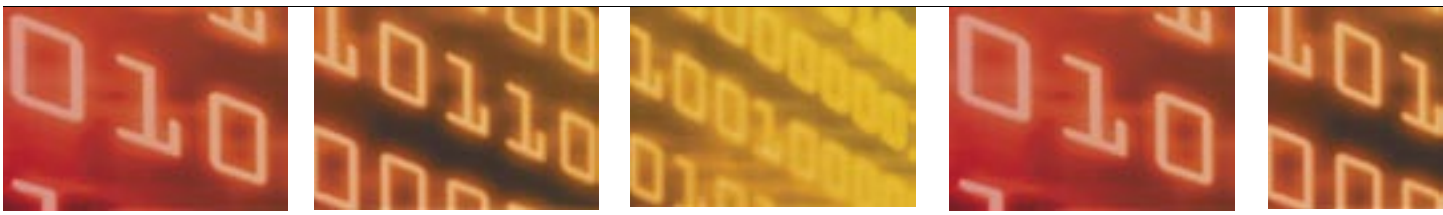
The Challenge: Maintain Plant Performance and Eliminate Risk of Downtime and Safety Issues

"Before we installed *AutoSave* (Automation Change Management Software), we really had no way to manage all the different program versions created by our programmers," explains Alan Hiler, controls engineer, Nestlé Purina, Mechanicsburg Plant. In facilities where multiple people are making changes from multiple computers, the documentation of changes is often lost, archives of older copies are non-existent and the wrong programs may be running on the devices.

"We made the decision to use *AutoSave* change management software because we wanted to get away from having different people making changes and not documenting it properly," says Mark Buettner, director of electrical and controls, Nestlé Purina Petcare.

"We didn't want a situation where an emergency occurs, such as a processor dies, and production is stopped because we

continued



don't know where the latest version of the program is located or have to decipher which program is the current one."

The Solution: Gain Plant-Wide Control of the Automation Environment

Rapid disaster recovery. There are many events that can have a negative effect on plant performance, including human error, equipment failure, sabotage, power surges/interruptions and fire. In providing a central repository of all program changes, *AutoSave* ensures that, if a device fails or a program results in undesired performance, a prior version of the program is readily available, so plant operations can be restored quickly and correctly.

Reduce downtime, increase performance. "Before we had *AutoSave*, we had situations here where somebody made a change to a program, and since there really is no way to test the new program until it is in operation, the new program created a production problem," describes Hiler. "With *AutoSave* we can easily download the previous copy of the program and get things running again quickly. If one device is down, the entire plant could potentially be down, so the ability to get up and running again is very important."

Decrease cost of operation and engineering. Stopping production because there are no older versions of a program available is costly enough, but consider the cost associated to completely rewrite a program.

"If you lose a copy of a program, it isn't just the production time we are losing, but we also lose the intellectual value of the program we have created," says Buettner. The cost to re-write, test and commission a single program is often greater than the cost to implement a change management solution.

Prevent errors and product waste. "Before *AutoSave* was installed in the plant, we had some problems with program version mismatches, the biggest issue being the assumption that the copy on file was the program running in the PLC, but in some instances, it was not," explains Hiler. This situation has the potential of creating incorrect recipes resulting in discarded product. MDT *AutoSave* periodically queries automation devices and compares the code running in the processor with what is on file. If a mismatch is detected (indicating someone went around the software to make a change), an email notification is sent highlighting the mismatch along with information pinpointing the changes. This ability to regularly verify that the correct version of the program is running significantly decreases product waste and safety risks.

Increase productivity and reduce safety hazards. The in-house program used by Nestlé Purina, before installing *AutoSave*, required multiple steps to make changes, all of which were manual.

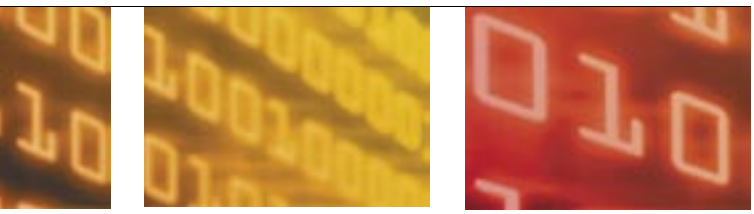
"With *AutoSave*, the right program is listed right in front of you and all you have to do is click on it and you are in the program," explains Hiler. To further complicate matters, the old program required user knowledge of all the communication parameters for connecting to a particular PLC or programmable device.

"For example, let's say we would go through Windows Explorer and copy the batching system program to our computer. And then, when you get into the programming software, you have to type in the physical address of the processor to connect," describes Hiler. Hiler estimated this manual process would take approximately four minutes each time a change was made.

Considering there are 15 programmers, if each programmer makes only one change in a day, an hour of productivity is lost just from having to perform manual routing. The time and money lost increases significantly if the current program is not readily accessible, the wrong program is downloaded, or the programmer connects to the wrong PLC.

"A big benefit for us is *AutoSave*'s ease of use for our maintenance guys. We have guys here that have never accessed a PLC program before, and they have to download a program to make a simple change. Before *AutoSave*, we had to write pretty detailed documentation on how to find the file, open it, connect to the server and so on. Not only does *AutoSave* save us time, it also significantly reduces any chance that the wrong PLC is accessed, causing big safety issues," says Hiler.

Safeguard all automation assets. If the change management solution cannot support every programmable device in the organization, only selected systems are backed-up, leaving the facility still partially vulnerable to production and safety issues. "We are a multi-platform organization; we use Modicon devices, Rockwell devices, Schneider devices and more. We needed a change management solution that would work with everything rather than using multiple types of



change management software. MDT *AutoSave* is third party. It isn't affiliated with a particular PLC manufacturer—it supports everything," says Buettner. *AutoSave* supports a comprehensive range of devices and editors in the industry from Schneider, Siemens, Mitsubishi, Indramat, Wonderware, GE, Rockwell Automation and others.

The Product: MDT AutoSave Automation Change Management Software

MDT Software is a world leader in factory automation device change management. For over 20 years, MDT Software has delivered change management and version control solutions for automated manufacturing devices. In addition to Nestlé Purina, MDT's food and beverage customers include Campbell's Soup, Coors Brewing, General Mills, Coca Cola, Iams, Kraft Foods, Miller Brewing, Sara Lee and Tropicana. MDT also serves manufacturers in the automotive, pharmaceutical, mining, petrochemical, airport and utilities industries.

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Belt Drive Offers High-Precision Alternative

BOSCH REXROTH ASSISTS BELL-EVERMAN WITH LINEAR ACTUATOR DEVELOPMENT

Bell-Everman, Inc., a manufacturer of rotary, linear and multi-axis motion devices, recently developed a linear actuator called ServoBelt for large-format automation applications. ServoBelt provides the speed and accuracy of a linear motor at a value that's comparable to belt-driven actuators. Bell-Everman saw a need for an economical linear actuator for smaller companies that may buy only one or two machines or OEMs that purchase multiple units. They brought Bosch Rexroth into the mix for product support to achieve their goal of a high-performance actuator at a lower cost.

"We're using cost-effective components and targeting accuracies that are usually attainable only with more expensive types of forcers—ball screws and linear motors," says Michael Everman, chief technical officer. "From

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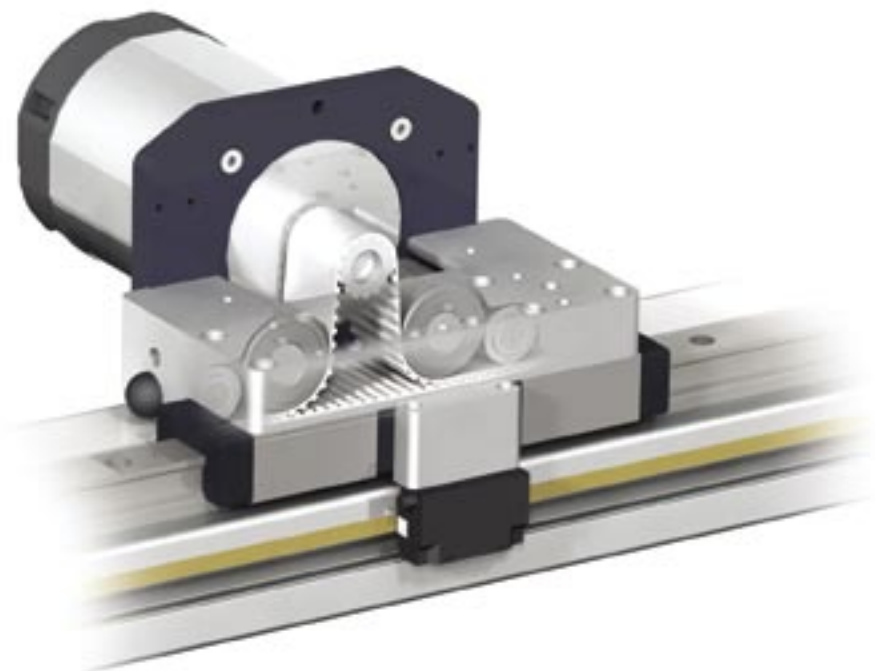

A movable carriage powered by a servo motor and belt rides on Rexroth's linear rail and aluminum framing to achieve a standard range of travel from 0.15 to 50 meters (courtesy of Bosch Rexroth).

The ServoBelt combines Bosch Rexroth ball rail guides and aluminum framing with a belt-driven carriage, providing the speed and accuracy of a linear motor at a value comparable to belt-driven actuators (courtesy of Bosch Rexroth).

a performance standpoint, a key focus is on accuracy and repeatability. And, we wanted all of the advantages of a linear motor system for far less cost."

The ServoBelt actuator is utilized for long travel and especially suited for food and packaging applications, palletizing, material handling, textile cutting, biomedical handling, large-format printing, water jets, plasma cutting, CNC wood routing and pick-and-place robotics.

The bi-directional repeatability is four to five times better than a conventional belt or rack drive +/- 60 µm, with a unidirectional repeatability of +/-10 µm, according to Bell-Everman. By using a linear encoder, the ServoBelt can match the repeatability of a linear motor. Standard range of travel for the ServoBelt is 0.15 meters to 50 meters with almost no length limitations beyond. Acceleration is in excess of 4 g with speeds up to 4 m/s with standard bearings and 10 m/s with a bearing upgrade. Life test units are recording 40,000 out-and-back cycles per day with at least 16 million stops and starts already tabulated.

The ServoBelt combines Bosch Rexroth's linear ball rails and aluminum framing as the building blocks for the system. A movable carriage or block rides on the linear rail that is mounted on a length of aluminum framing. Servo motors drive a polyurethane, steel-reinforced T5 belt for power. A static, bonded lower belt engages with the upper dynamic belt so that the active belting under tension is less than a few inches long. Stiffness, accuracy and repeatability are enhanced by the belt

mechanism, according to the company's press release. With its high open-loop accuracy, the ServoBelt mimics a linear motor by inhibiting the same force regime at a much lower dollar-per-inch cost. It offers more drive-line rigidity than conventional belt drives and can improve a machine's settling time.

"Rexroth's standard linear bearing rails are interchangeable, so we can stock lengths of rails and bearing blocks and interchange the blocks onto any rail, and it will still have the performance specs we want," Everman says.

The main hurdle in the design process was to create a belt that is rigid, as opposed to having the flexibility of a "guitar string." Everman explained that they experimented with a moving-motor belt drive, but stiffness was an issue. Rexroth's components allowed Bell-Everman to overcome this issue. One notable attribute is that the chassis of the ServoBelt is based on Rexroth T-slot aluminum extrusions, which can use a wide array of mounting hardware.

"Using the T-slot extrusions with our own belt carrier extrusion allows us to deliver standard stages in one to two weeks," Everman says. "We can cut-to-length all of the major components, with no long-travel machining operations."

Everman added that multiple carriages can also be supplied for independent motion on the same axis, and dual-motor carriages are available to double the standard linear forces. The company can also integrate other Rexroth drive and control components such as motors, pneumatic grippers, valves and a motion logic controller with robotic kinematics to produce a completely integrated robot.

"The versatility of Rexroth's linear ball rails and aluminum framing makes it easy to create the subassemblies, which makes them suitable for customers to buy in smaller quantities," Everman says. "We now have a product that is much easier to deliver as a one-off to customers who are experimenting with new machine designs. Having multiple independent carriage capability, without forcer cross-talk, is a huge plus."

Additional components such as motors, valves, a motion logic controller with kinematics and this pneumatic gripper can be integrated to produce a complete robot (courtesy of Bosch Rexroth).

"We're slated to make stages with 10 forcers on the same axis for an automated aircraft wing-fixturing system," Everman adds.

He cites the quality of Rexroth's framing products, straightness, delivery times and response to their needs as key factors in the development of the ServoBelt.

"We designed our actuator with Rexroth products because they help us remain successful in a competitive industry," Everman says.

In addition to versatility, the ServoBelt provides increased energy efficiency versus a conventional belt.

continued

"When the driveline is stiffer, you spend less time trying to maintain position when the machine is shaking around due to other processes or other axes in motion," Everman says. "It is definitely a more efficient use of energy, so smaller motors can be used."

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Intermetallic Nickel-Titanium Alloys for Oil-Lubricated Bearing Applications

C. Della Corte, S.V. Pepper, R. Noebe, D.R. Hull and G. Glennon

Management Summary

Nitinol 60 (60NiTi), an intermetallic nickel-titanium alloy containing 60 wt % nickel and 40 wt % titanium, is shown to be a promising material for oil-lubricated, rolling and sliding contact applications such as bearings and gears. NiTi alloys are well known and normally used for their shape memory behavior. When properly processed, however, Nitinol 60 also exhibits excellent dimensional stability and useful structural properties. Processed via high-temperature, high-pressure powder metallurgy techniques or other means, Nitinol 60 offers a broad combination of physical properties that make it unique among bearing materials. Nitinol 60 is hard, electrically conductive, highly corrosion resistant, less dense than steel, readily machined prior to final heat treatment, non-galling and non-magnetic. No other bearing alloy, metallic or ceramic, claims all of these attributes. Further, Nitinol 60 has shown remarkable tribological performance when compared to other aerospace bearing alloys under oil-lubricated conditions.

Spiral orbit tribometer (SOT) tests were conducted in a vacuum using Nitinol 60 balls loaded between rotating 440C stainless steel disks and lubricated with synthetic hydrocarbon oil. Under conditions considered representative of precision bearings, the performance (life and friction) equaled or exceeded that observed with silicon nitride- or titanium carbide-coated 440C bearing balls. Based upon this preliminary data, it appears that Nitinol 60, despite its high titanium content, is a promising alloy for advanced mechanical systems requiring superior and intrinsic corrosion resistance, electrical conductivity and non-magnetic behavior under lubricated contacting conditions.

Introduction

Binary nickel-titanium (NiTi) alloys are in widespread use in the medical and dental industries, in applications where their biocompatibility and unique super-elastic or shape memory effect (SME) characteristics are readily exploited (Refs. 1–2). More recently in the aerospace industry, shape memory alloy-activated structures have been proposed and demonstrated for such applications as general flow control, adaptive inlets and nozzles, variable geometry chevrons, variable camber fan blades and flaps and other hinged components (Refs. 3–4). These applications capitalize upon the large reversible train change inherent in typical near equiatomic NiTi alloys (containing approximately 55 wt % nickel) and ternary high-temperature shape memory alloys (HTSMA), even when opposed by some large force. In addition to these familiar SME alloys, nickel-rich alloys, containing approximately 57 to 60 wt % nickel, are also being pioneered for use in adaptive aeronautic systems by Boeing (Ref. 5), and have culminated in a full-scale flight test of Nitinol 60 variable geometry chevrons (Ref. 6).

Unlike more conventional NiTi alloys, the Ni-rich alloys require complicated multi-step heat treatments before they are capable of displaying shape memory behavior (Ref. 7). In this paper, we present—for the first time—evidence that NiTi alloys can be tailored to avoid shape memory or superelastic behavior, and that such alloys display excellent tribological properties under oil-lubricated contact conditions.

The NiTi family of alloys traces their origins to the pioneering work of William J. Buehler and his colleagues at the Naval Ordnance Laboratory during the late 1950s (Refs. 8–9). In fact, the designation Nitinol often used for these alloys is an abbreviation for Nickel-Titanium Naval Ordnance Laboratory. At that time, research was under way to develop high-temperature, non-magnetic alloys for missile cone applications. Their early efforts identified both the Nitinol 55 and Nitinol 60 alloys, which contained 55 and 60 wt % nickel, respectively. Nitinol 55 was softer and found to be easier to mechanically work and form than Nitinol 60, which was prone to excessive work hardening. Several hand tools were fabricated from Nitinol 60 to take advantage of its high hardness, electrical conductivity, non-magnetic behavior and corrosion

resistance. These tools were envisioned for use in disarming explosive devices, but production did not progress beyond the laboratory stage. Because their resources were limited and the SME properties of Nitinol 55 were so intriguing, research on Nitinol 60 was abandoned by the early 1960s (Ref. 10). Since then, others have attempted to develop methods to produce Nitinol 60 for structural and mechanical applications, such as rolling element bearings (Ref. 11); for now, it appears that commercial success has been elusive.

Materials for high-performance bearings, gears and other mechanical components require a number of specific properties and characteristics. Among these key attributes are high strength and hardness, high thermal conductivity and the ability to be manufactured to very high levels of precision with regard to final dimensions and surface finish. In addition, excellent corrosion resistance and good tribological properties are often of importance, especially for applications in extreme environments.

In rotorcraft, for instance, engine bearings, rotor mechanisms and drive systems are obvious examples where improved corrosion resistance is a benefit. Flight and water vehicles exposed to marine environments are also prone to corrosion-related failures despite the widespread use of lubricants with corrosion inhibitors. Even spaceflight hardware destined to operate in the vacuum of space, beyond the realm of atmospheric corrosion, often must be stored for extended periods before launch and is subject to bearing and gear corrosion problems. In select applications involving electric machines and sensitive instrumentation, good electrical conductivity and non-magnetic properties can also be highly desirable. Unfortunately, no currently deployed material possesses all of these properties.

Traditional tool steel-based bearing materials, such as M50 and 52100, enjoy widespread application due to their high hardness, ease of manufacture and good tribological properties. However, these alloys suffer from corrosion attack if not protected, and though electrically conductive, they are also highly magnetic. In addition, when used as bearing rolling elements, their high density leads to high centrifugal forces and limited fatigue life. These considerations have driven the search and development of alternate bearing and mechanical component alloys, namely stainless steels and ceramics.

Stainless steels such as 440C are widely used in the bearing and gear industry, where corrosion resistance and high hardness are required. These martensitic stainless steels are reasonably low cost, easy to machine prior to heat treatment and are dimensionally stable. When prepared through vacuum melting processes, they achieve very uniform, fully dense microstructures, which lead to fine surface finishes and good fatigue behavior. Despite being referred to as stainless, however, the 400 series martensitic steels are prone to corrosion and are more accurately referred to as corrosion-resistant alloys rather than stainless. They are also highly magnetic, which can be problematic in certain applications.

Silicon nitride ceramics, on the other hand, are essentially corrosion proof. They can be polished to very fine surface roughness and are quite wear resistant. Silicon nitride's low density compared to steels also makes it ideal for ultra-high-speed applications because lower centrifugal stresses result. These attributes make silicon nitride the material of choice for high stiffness, high load, high-speed bearings and for applications that include corrosive conditions and aggressive sliding environments.

Such applications include bearings for gas turbine hot sections, cryogenic oxidizer turbo pumps and components for diesel engine fuel injection systems. Though non-magnetic, silicon nitride is an electrical insulator. It is also more expensive to manufacture than steels, owing to the complexity and cost of the high-temperature, high-pressure powder metallurgy processing required. Silicon nitride's low thermal expansion coefficient can present challenges in applications involving wide temperature variations.

This paper assesses the feasibility of using Nitinol 60 for bearings and mechanical components. Nitinol 60 offers a unique combination of properties that are not found in any other commonly recognized material. Nitinol 60, when appropriately heat-treated, does not exhibit SME properties at normal ambient and anticipated use temperatures and is dimensionally stable. It has high hardness when properly heat-treated and yet can be readily machined prior to final heat treatment. Like silicon nitride, Nitinol 60 is non-magnetic and is intrinsically highly resistant to corrosion. Unlike ceramics, Nitinol 60 is electrically conductive. Table I contains a summary of key material properties for conventional and high performance bearing alloys in current use and, for comparative purposes, includes basic properties for Nitinol 55 and Nitinol 60 alloys. Based upon these characteristics, Nitinol 60 appears to be an excellent candidate material for bearings, provided it performs well in a tribological environment.

Historically, metallic alloys with high concentrations of titanium are poor tribological materials in that they do not respond well to lubrication by organic fluids (Ref. 12). For instance, alloys such as Ti-6Al-4V exhibit galling behavior in dynamic contacts, even under conditions well lubricated by oils and greases. During contact, titanium readily transfers to the counter-face, leading to rough surfaces, high friction and wear. In addition, titanium alloys are recognized as being chemically aggressive, causing degradation of many lubricants (Ref. 12). When titanium alloys must be used due to other attributes like high specific strength or corrosion resistance, tribological contact is avoided through the use of thick barrier coatings and claddings. Based upon a wealth of negative experience with titanium alloys in tribological contacts, Nitinol 60 would appear an unlikely candidate as a bearing material.

On the other hand, ceramic materials with high concentrations of titanium can exhibit desirable tribological properties. Titanium carbide (TiC) and titanium dioxide (TiO_2) are good examples. TiC coatings are often used to improve the surface finish and performance of stainless steel rolling elements in bearings and TiO_2, in the form of rutile, has been put forth as a potential solid lubricant under certain conditions (Refs. 13 and 14). These ceramic materials, however, are brittle and cannot be used as structural elements.

If bond strength or some other nature of the bonding in Ti-based materials has a significant effect on tribological behavior, then it is not clear how Nitinol 60 may tribologically perform. NiTi is a Hume-Rothery β-phase electron com-

continued

Table I—Nominal Comparative Properties for Conventional Bearing Alloys and 55NiTi and 60NiTi. (Representative thermophysical and mechanical properties of bearing materials.)

Property	60NiTi	55NiTi	440C	Si_3N_4	M-50
Density, g/cc	6.7	6.5	7.7	3.2	8.0
Hardness	56 to 62 RC	35 to 40 RC	58 to 62 RC	1300 to 1500 Hv	60 to 65 RC
Thermal conductivity W/m-°K	18	9	24	33	~36
Thermal expansion	$\sim 10\times10^{-6}$/°C	$\sim 10\times10^{-6}$/°C	10×10^{-6}/°C	2.6×10^{-6}	$\sim 11\times10^{-6}$/°C
Magnetic	Non	Non	Mag	Non	Mag
Corrosion resistance	Excellent	Excellent	Marginal	Excellent	Poor
Tensile/flexural strength, MPa	[a]TBD	~900	1,900	600 to 1,200 (bend strength)	2,500
Young's modulus, GPa	~114	~100	200	310	210
Poisson's ratio	TBD	TBD	0.3	0.29	0.30
Fracture toughness	TBD	TBD	22 MPa/√m	5 to 7 MPa/√m	20 to 23 MPa√m
Maximum use temperature, °C	~400	~400	~400	~1,100	~400
Electrical resistivity	$\sim 80\times10^{-6}$ Ω-cm	$\sim 80\times10^{-6}$ Ω-cm	$\sim 36\times10^{-6}$ Ω-cm	Insulator	$\sim 60\times10^{-6}$ Ω-cm

[a]TBD means to be determined.

Figure 1—Photograph of 60NiTi polished ball specimens prior to testing.

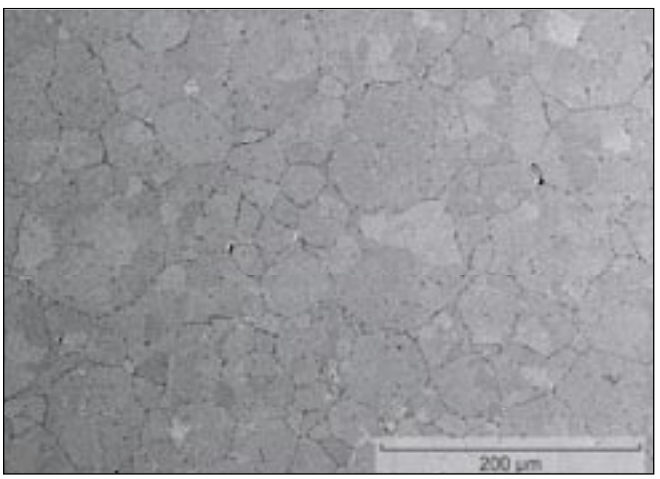

Figure 2—Cross section photomicrograph of 60NiTi ball showing grain structure typical for powder metallurgy processed materials.

pound with a valence electron-to-atom ratio of 3:2, which gives rise to the stability of a large number of ordered intermetallic alloys that crystallize in the (B2) CsCl structure with components of both metallic and covalent bonding (Ref. 15). Compared to ceramics like TiC and TiO_2, B2 NiTi is much less covalent and thus expected to show more toughness, ductility, and chemical reactivity. But compared to more common metallic alloys like Ti-6Al-4V, the bonding between the Ni and Ti is highly directional and much stronger and may therefore share tribological properties with the ceramics. In spite of these considerations, there is presently no understanding at the fundamental level of why metallic titanium alloys perform so poorly under lubricated tribological conditions. A consideration of Nitinol 60 as a tribological material thus requires an *experimental* study of its performance in a lubricated configuration.

The existing patent literature purports that Nitinol 60, in cast form, is a good bearing material, even in un-lubricated contacts, though no supporting data is provided (Ref. 11). Limited dry sliding tests of Nitinol 60 indicated rather high friction (Ref. 16). Studies on the dry sliding behavior of the more common SME alloy Nitinol 55 are sparse, but the data indicate that like the Nitinol 60, friction coefficients in dry sliding are high, typically well above 0.5 (Ref. 17). A very recent paper describing the tribological behavior of Nitinol 55 in fretting and corrosion conditions designed to simulate in vivo applications corroborates earlier findings that sliding friction and wear levels are high under un-lubricated conditions (Ref. 18). There appears to be no published examples for the tribological performance of any Nitinol alloys in lubricated contacts. Furthermore, to the authors' knowledge, Nitinol 60 has never been evaluated in the presence of a lubricant nor has it ever been evaluated under conditions simulative of a bearing application.

Consequently, the present investigation seeks to determine whether Nitinol 60 is a promising candidate material for tribological applications such as bearings. First, aerospace quality Nitinol 60 bearing balls were manufactured via a pow-

der metallurgy processing route. Cross-section metallographic analyses were undertaken to characterize the material microstructure and its basic composition and selected mechanical properties were estimated or determined. Then, a series of rolling-sliding tests was performed under oil-lubricated conditions simulative of an aerospace ball bearing. Finally, after direct comparisons were made with conventional bearing materials, an assessment is provided on the likelihood of employing Nitinol 60 for mechanical components.

Materials

The 60NiTi evaluated in this work was manufactured via a high-temperature proprietary powder metallurgy process roughly similar to that described in the literature (Ref. 19). Using hot isostatic processing, pre-alloyed 60NiTi powder was made into rough, spherical ball blanks that were then ground, polished and lapped to produce high-quality (Grade 5) bearing balls 0.5 in. (12.5 mm) in diameter. A multi-step thermal process (heat treatment) was used to enable rough grinding of the bearing balls in a softened state followed by lapping to a very fine surface finish in a final hardened condition. The finished 60NiTi ball specimens (Fig. 1) are bright and shiny in appearance and resemble conventional polished steel balls.

The elemental composition of the bearing material, as measured by atomic emission spectroscopy and energy dispersive, semi-quantitative x-ray analysis, were consistent and showed the balls are nominally 55 at. % nickel with the balance titanium. This translates to 60 wt % nickel, 40 wt % titanium, hence the historical designation of 60NiTi. Density was measured at 6.71 g/cc and is about 25 percent lower than 440C stainless steel.

Figure 2 shows the cross sectional microstructure of the 60NiTi specimens in the final hardened and polished condition. Microhardness measurements indicate values in the range of 58 to 62 on the Rockwell C scale in the hardened condition. As with most hot isostatically pressed or sintered powder compacts, the prior particle boundaries are quite evident and are delineated by oxides and other tramp phases. Despite containing only Ni and Ti, Ni-rich Nitinol microstructures can be very complex due to a series of metastable, intermetallic phases that could exist depending on thermal history (Ref. 19). Analysis of the 60NiTi ball specimens reveals multiple discrete phases (Fig. 3).

A combination of x-ray diffraction analyses, energy dispersive spectroscopy and orientation image microscopy has been used to identify the phases present. The dominant phase is B2-structured NiTi and is considered the bulk phase appearing at about a 78% volume fraction, based upon two-dimensional image area analyses. It is a continuous phase broken up by other tramp phases that delineate the prior particle boundaries. The second most predominant phase appears as narrow, rod shaped regions, several microns long and about a half-micron in diameter, and is dispersed throughout the bulk NiTi phase at a concentration of ~11 vol %. Analyses indicate it is Ni_4Ti_3, which is a relatively fine metastable phase observed in low-temperature-aged or slow-cooled Ni-rich NiTi alloys. A third phase making up about 9% of the material, appearing as irregularly shaped regions, concentrated at the

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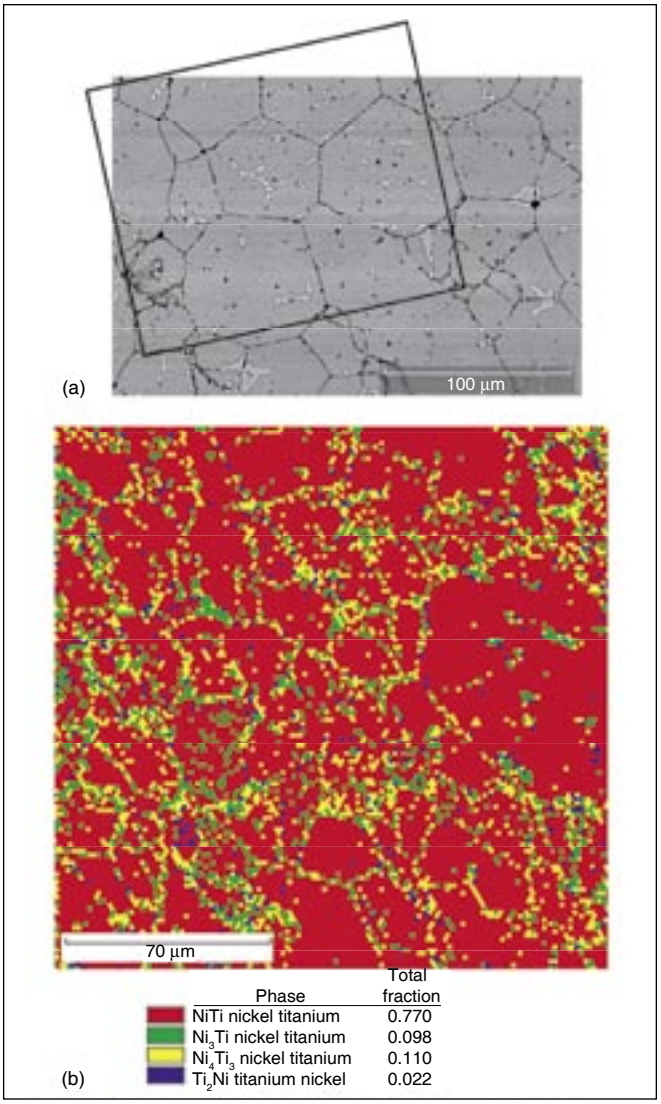

Figure 3—(a) High magnification micrograph and corresponding area image analysis (outlined box shows analyzed area). (b) Area image analyses of 60NiTi cross section showing discrete phases and their relative proportions based upon area fraction.

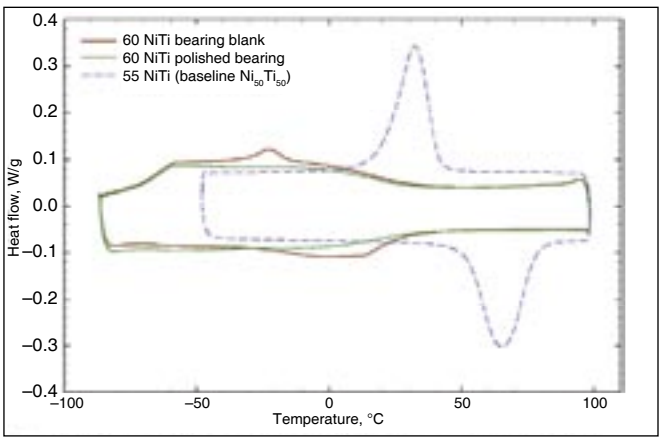

Figure 4—DSC behavior of the bearing blank material (in the softened condition) before heat treatment, and hardened and polished 60NiTi bearing ball material shown in comparison to conventional 55NiTi shape memory alloy. As expected, the 60NiTi specimens tested in this study exhibit little phase transition behavior.

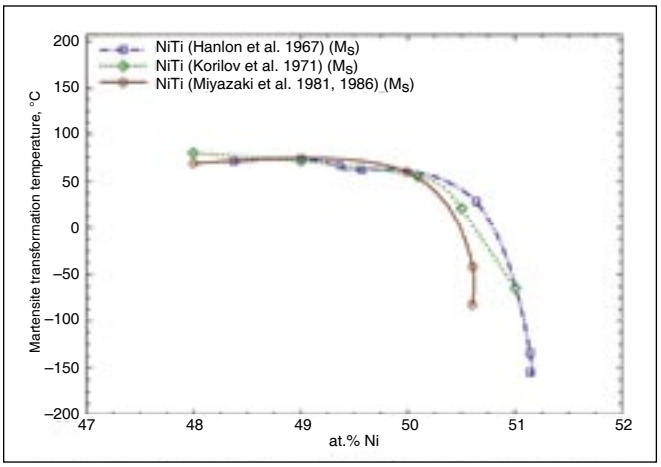

Figure 5—Effects of Ni-Ti ratio on the martensitic transition temperature demonstrating that at high Ni-contents, the martensitic transformation is suppressed to very low temperatures. This implies high dimensional stability for the 60NiTi alloy.

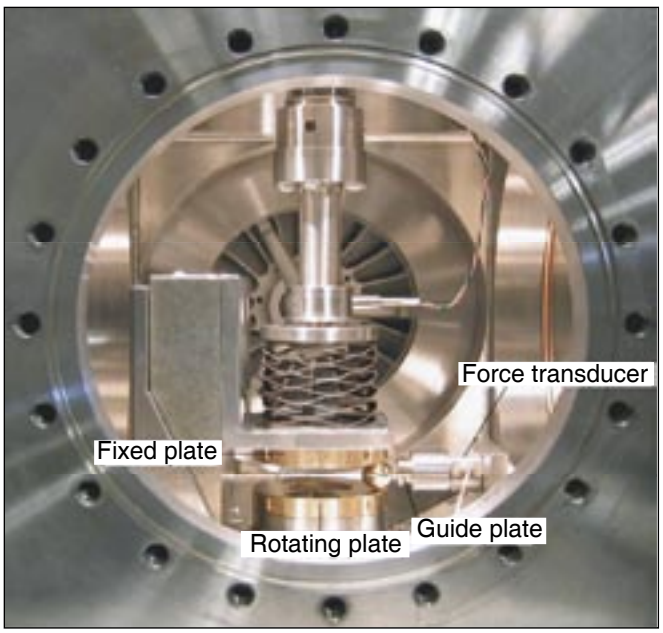

Figure 6—Spiral orbit tribometer (SOT) used to evaluate the relative lubricant life of various alloys under simulated bearing conditions.

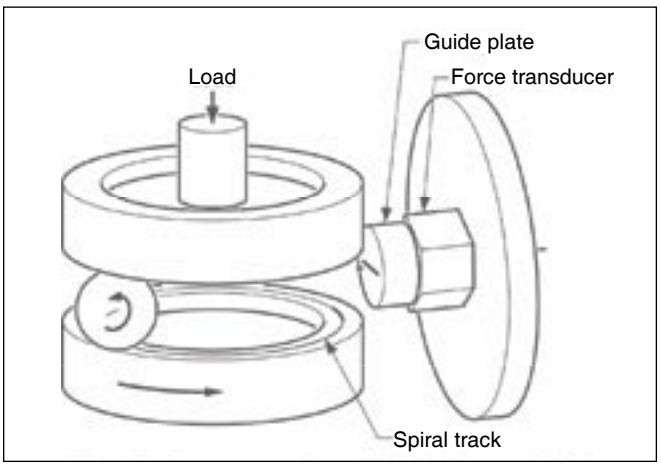

Figure 7—Components of the spiral orbit tribometer. The top plate and guide plate are stationary while the bottom plate rotates to drive the ball.

grain boundaries or prior particle boundaries, was found to be Ni_3Ti. This equilibrium phase generally appears after aging at high temperatures and long times, and depending on the volume fraction present, is partly responsible for controlling the temperature at which any shape memory properties might be observed. At higher volume fractions, it also leads to softening of the alloy, making rough machining during intermediate processing steps easier to accomplish. The fourth phase observed was Ti_2Ni. This is a tramp intermetallic phase that forms during solidification of the powder particles and has a high solubility for oxygen. It is generally segregated at grain or prior particle boundaries and occurs at less than about 2 vol %. Continued microstructural analysis of the 60NiTi is under way to corroborate the functional contributions of each phase to the mechanical and potentially the tribological properties of the alloy.

Preliminary differential scanning calorimetry (DSC) results are shown in Figure 4 for the bearing blanks and finished bearings and compared to the typical behavior of 55NiTi. The results suggest that the 60NiTi bearing blanks may have a slight amount of martensite that could form if cooled below –15°C. However, the final hardened bearings are microstructurally stable down to at least –100°C. Figure 5, which is a compilation of data from several studies from the literature (Refs. 20–22) corroborates this preliminary assessment and shows that others have found that the martensite transition temperature drops precipitously below room temperature for quenched, nickel-rich NiTi alloys.

Tribological Evaluation

For the tribological evaluation, 60NiTi ball specimens were lubricated with a thin film of synthetic hydrocarbon oil named Pennzane (Ref. 24), and subjected to a rolling-sliding contact lubricant wear life test in a spiral orbit tribometer (SOT).

The SOT is depicted in Figures 6 and 7 and described in detail in References 13 and 25. It is basically a thrust bearing with one ball and flat races (plates). It may be regarded as a simplified version of the usual angular contact ball bearing. One of the plates is stationary and the other rotates to drive the ball into an orbit that is an opening spiral. The ball contacts a guide plate at the end of each orbit, which forces the ball back into its initial orbital radius. The ball then exhibits, for a given coefficient of friction (CoF), a stable orbit, repeatedly over-rolling the track on both large plates and guide plate. The spiral's pitch and the length of the contact on the guide plate increases with the increase in the CoF. A piezoelectric force transducer supporting the guide plate senses the frictional force developed on the ball as it slides on the rotating plate during the contact of the ball with the guide plate. During this contact, the coefficient of friction is obtained from this force and the load imposed on the system. The tribometer is housed in a stainless steel chamber that can be evacuated by a turbomolecular pump to $\leq 2 \times 10^{-8}$ torr. It can be operated either in this vacuum environment or at atmospheric pressure.

The plate specimens were 440C stainless steel. They were lapped flat and their final polish resulted in an arithmetic mean surface roughness, R_a, < 25 nm (1 µin.) determined by optical interferometry. The 60NiTi balls were 12.7 mm (0.5 in.) diameter, Grade 5. The final surface cleaning procedure

for all ball and plate specimens was by lightly rubbing with aqueous slurries of silicon carbide polishing powders, followed by sonication in deionized water. This preparation results in a surface on which water exhibits zero contact angle (spreads) and which exhibits an XPS spectrum (a) devoid of impurities other than a small feature due to adventitious carbon and (b) in which the Fe^0 feature in the 440C steel is clearly evident, indicating a native oxide to be approximately 2 nm thick.

The plates were initially clean and only the ball was lubricated. For the present tests in the boundary regime, the ball is first weighed and then lubricated by dripping a dilute solution of the lubricant, ~1 µg of lubricant per µl of hexane solvent, onto the ball rotating on a small bench lathe. The ball is reweighed after evaporation of the solvent and the lubricant charge is obtained from the weight difference. About 20 µg (24 nl) of lubricant was used on the ball.

The lubricant chosen for testing with the 60NiTi balls was a multiply alkylated cyclopentane (MAC) designated by the trade name Pennzane 2001A. This oil, containing only carbon and hydrogen in its structure, is a mixture of di- and tri-substituted (2-octyldodecyl) cyclopentane. It is described more fully in Reference 24 and a sketch of its structure is shown in Figure 8.

The elastic modulus of 60NiTi is not presently known. Tests were run here at a system load of 30 lbs., which resulted in a track width of ~ 0.4 mm. This track width is close to that resulting from a test with a 440C steel ball at a load of 43 lbs., which corresponds to a Hertz pressure of 1.5 GPa at the ball/plate contact. The 30-lb. load in the Nitinol tests corresponds to a Hertz pressure of 1.06 GPa. Such a Hertz pressure is obtained if the 60NiTi material has an elastic modulus of 114 GPa, which is comparable to that of the Ti-6Al-4V alloy.

In tests in the SOT with only µgs of lubricant, the system is obviously operating in the boundary regime of lubrication. The characteristic of a test in which boundary lubrication is operative is a low and constant CoF for a number of orbits and then an eventual transition to a much higher value of the CoF. This eventual increase has been attributed to the consumption of the organic lubricant by tribochemical attack on the lubricant molecules in the ball/plate contact by the bearing materials between which the lubricant is captured. Each member of the ball/plate contact can exhibit tribochemical activity that degrades molecular structure, consuming the lubricant and leading to high CoF in the absence of lubricant and the end of the test. In a symmetric system, 440C steel/440C steel, for example, each member in the ball/plate contact contributes equally to the tribochemical attack rate, and a typical lifetime (orbits to failure per µg of lubricant initially applied) is obtained. Figure 9 displays the friction versus number of cycles for the standard 440C ball operating against 440C plates. As expected, the friction is low and stable until the lubricant is depleted, whereupon the friction rises and the test is terminated.

In the asymmetric system considered here, where each member of the contact may have different tribochemical activities, smaller or greater lifetimes may occur. An extreme case is one in which one of the partners exhibits such great tribochemical aggressiveness that the lubricant does not survive the contact at all and failure of the lubrication is immediate, with no observable lifetime. The other extreme case is that in which one of the partners exhibits no tribochemical activity at all and the test's (longer) lifetime is determined only by the activity of the other partner. The goal in this report is to provide a first assessment of the ability to lubricate the 60NiTi via vacuum SOT tests with the 60NiTi/440C steel/oil system.

Tribology Test Results

Determination of the ability of 60NiTi to be lubricated is best illustrated by first referring to a test of Pennzane 2001A on specimens that are all 440C steel. This is an oil/metal combination that is well established as a system that can be successfully lubricated. The friction trace of a typical test (Fig. 9) illustrates the characteristics referred to in the previous section—a low, constant CoF for the first ~10,000 orbits, followed by an eventual increase of the CoF to high values associated with the failure of lubrication due to the absence of lubricant.

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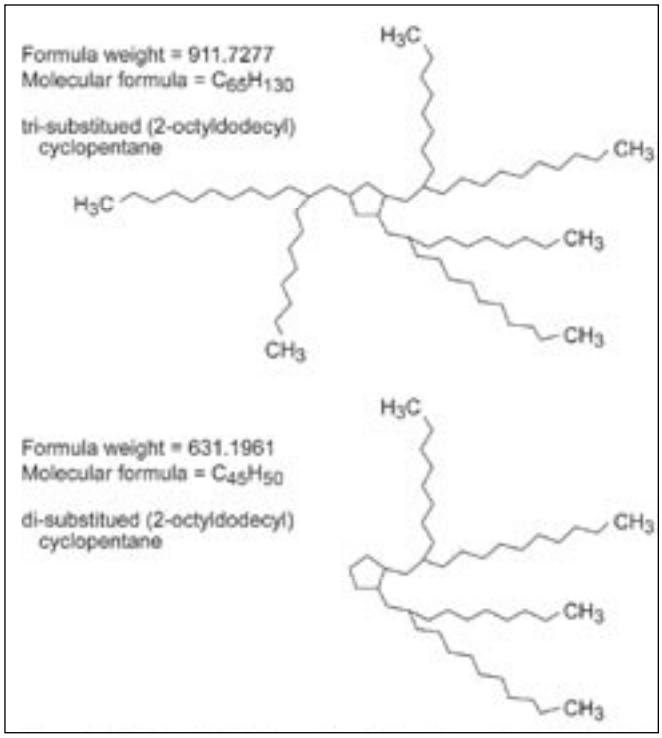

Figure 8—Molecular structure of the lubricant used in the SOT tests.

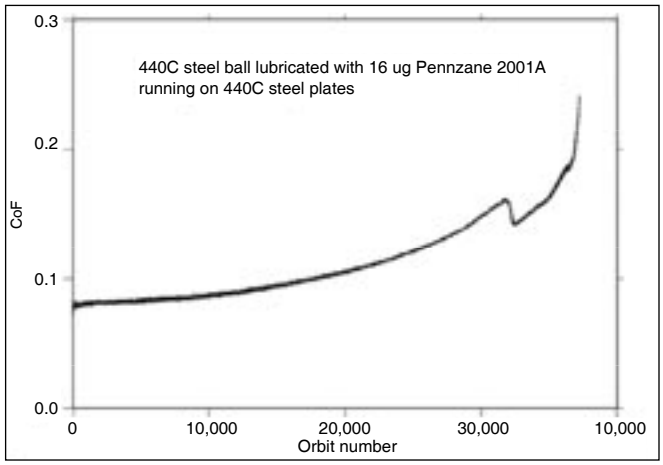

Figure 9—Typical SOT friction trace for 440C ball and disks lubricated with small volume of oil.

The sensitivity of the SOT test to the surface chemical constitution of the ball is illustrated in Figure 10, in which two friction traces are shown. One is the initial stage of the test with a 440C steel ball whose friction trace is shown in Figure 9, while the other is a test of a 440C ball coated with a thin film of titanium. Both balls had been lubricated with Pennzane 2001A and run on 440C steel plates in vacuum. It is evident from the high erratic CoF of the test with the titanium-coated ball that the system is not operating in a lubricated manner. This is attributed to the destruction of the Pennzane's molecular structure, and attendant loss of lubrication capability by the tribochemically aggressive titanium film with which it is in contact. This test demonstrates that only one partner of a tribological pair needs to be tribochemically aggressive to prevent effective lubrication. Such highly aggressive tribochemical behavior was also observed with a 60NiTi ball coated with titanium, so that the effect is not dependent on the particular mechanical properties of the ball, but it is really of chemical origin. Figure 10 illustrates the extreme cases within which a test of the capability of lubricating a particular material falls—lubrication, indicated by low and constant CoF and lack of lubrication, indicated by high and erratic CoF.

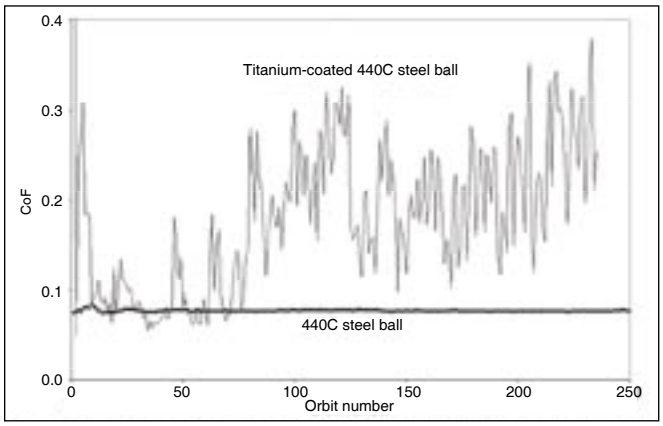

Figure 10—Friction traces of a system with a 440C steel ball and a 440C steel ball coated with a thin film of titanium. Both balls have been lubricated with ~ 25 μg of Pennzane oil and run on 440C steel plates.

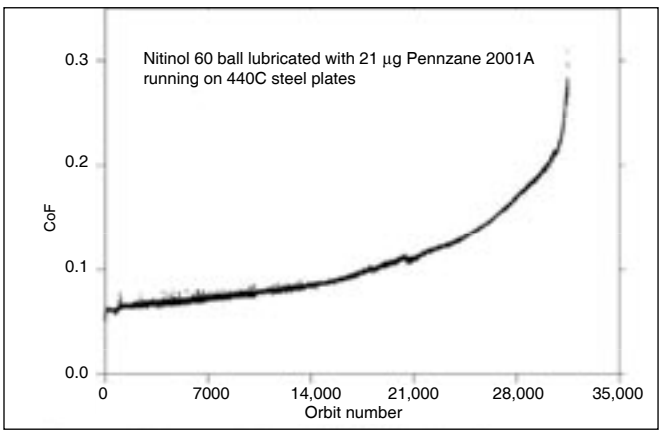

Figure 11—Friction trace of a Pennzane P2001A/Nitinol 60/440C steel system running in a vacuum.

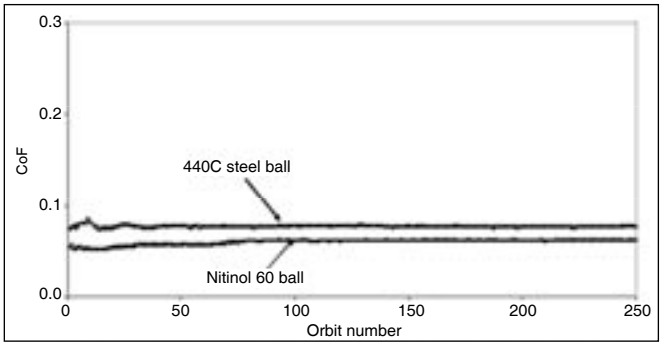

Figure 12—Initial friction traces of a system with a 440C steel ball and a Nitinol 60 ball. Both balls have been lubricated with ~ 25 μg Pennzane.

The friction trace of a test with a 60NiTi ball lubricated with Pennzane 2001A and running on 440C plates is shown in Figure 11. The trace exhibits the same characteristics of the trace for the Pennzane/all-440C steel system shown in Figure 9. There is low constant initial CoF that gradually increases to the high values resulting from the consumption of lubricant by tribochemical attack. The initial stage of friction traces comparing the all-steel system to the system with the 60NiTi ball running on 440C steel plates is shown in Figure 12. This figure illustrates the similarity of the behavior of the CoF for the two systems, although the system with the 60NiTi ball exhibits somewhat lower initial values of the CoF. All tests with the 60NiTi balls running on 440C steel plates exhibited this behavior. It is thus concluded that 60NiTi can be effectively lubricated by the popular lubricant Pennzane 2001A.

The friction traces of the asymmetric system with the 60NiTi ball generally lower initial friction, but subsequent lubricant depletion and exhibit failure at fewer orbits than do the symmetric system with the 440C steel ball. The number of orbits to achieve CoF = 0.2 divided by the lubricant charge in μg is termed the normalized lifetime to characterize the system's tribochemical aggressiveness. Shorter normalized lifetime implies greater tribochemical aggressiveness. The normalized lifetime for any given system does exhibit variability. Table 2 presents normalized lifetimes and initial CoFs obtained in the SOT for the symmetric and asymmetric systems under consideration here. The asymmetric system with a 60NiTi ball exhibits somewhat shorter lifetimes than does the symmetric system with the 440C steel ball, suggesting that 60NiTi is somewhat more tribochemically aggressive than is 440C steel. However, note that the tests with the 60NiTi ball were performed at the lower Hertz pressure of 1.06 GPa, compared to the higher Hertz pressure of 1.5 GPa at which the 440C steel balls were run. Thus the comparison is not completely direct and the relative degree at which 60NiTi attacks Pennzane 2001A remains to be better determined. However, whatever its degree, it is clear that effective lubrication of 60NiTi is routinely observed.

Finally, Figure 13 shows a friction trace of a test for which the CoF was allowed to exceed the nominal cutoff value of 0.3 and kept running into the failure region. The system is observed not to gall and seize up, but instead to continue to run, albeit with a high CoF of 0.3 to 0.4. Figure 14 shows a micrograph of the 60NiTi ball surface after this test. It is worn but does not show signs of galling or material buildup and transfer. It thus appears that 60NiTi/440C steel system fails gracefully without the self-destructive seizure characteristic of

Table II—Normalized Lifetimes and Initial CoFs for Three Typical Tests with 440C Steel Balls and Three Tests with Three 60NiTi Balls from the Same Batch. (All tests were run with Pennzane 2001A lubricated balls and initially clean 440C steel plates.)

	440C Ball			60NiTi Ball		
Normalized lifetime, orbits/μg	1981	2302	1347	1429	1024	836
Initial CoF	0.079	0.079	0.081	0.061	0.062	0.059

many all-steel tribosystems.

Discussion

NiTi alloys enjoy widespread use in applications where their shape memory or superelastic properties are considered desirable. Most of these applications are relatively static, for instance vascular stents and dental implement wire, and do not experience any sliding or tribological contact. In fact, though several patents have been awarded for Nitinol bearings, very little research has ever been reported on their tribological properties. Kolbe and Zum Gahr (Ref. 17) reported on the friction and wear of 55NiTi under dry sliding conditions using a pin-on-disk apparatus in 1998. Their work was motivated by the desire to determine the suitability of using the more common shape memory alloy NiTi in mechanical biomedical device applications such as flexible endoscopes. They found friction to be high under dry sliding but observed none of the galling tendencies exhibited by pure titanium and nickel sliding tribopairs.

Recently, Miyoshi and his colleagues conducted similar dry sliding tests of the 60NiTi alloy under vacuum conditions to determine feasibility for use in non-specified aerospace applications (Ref. 16). Though the tests were carried out at room temperature, anticipated applications included elevated temperature conditions that precluded the use of oils and conventional solid lubricants. Miyoshi's results for 60NiTi generally corroborated the earlier findings of Kolbe and Zum Gahr. Under dry sliding conditions, the NiTi alloys exhibit mild, abrasive wear tendencies without the galling behavior normally associated with metallic titanium alloys (Ref. 12). Despite the existence of Nitinol alloys for more than four decades, it appears that no lubricated tribology tests have ever been conducted—until now.

The lack of lubricated test experience for NiTi alloys is, in retrospect, not surprising. Most current applications of NiTi are biomedical and the presence of oil or grease lubricant would be medically problematic. Emerging applications for NiTi shape memory alloys include a replacement for conventional actuators, such as hydraulic, pneumatic or motor-based systems in adaptive aerostructures, and by design, they do not incorporate any sliding contacts (Refs. 3–6). The apparent lack of contacting surfaces, when used in actuating settings, may explain why there has been little incentive for investigating the tribological properties of NiTi alloys under lubricated conditions. Further, the patent literature makes claims that NiTi alloys do not require additional lubricants for tribological applications, and may actually be lubricated by salt water (Refs. 11 and 26). No supporting data is given, but such unsubstantiated performance claims may have also contributed to the absence of lubricated tribology data for NiTi alloys. A more important factor may be that NiTi alloys are generally exploited for their ability to change shape, whether in terms of shape memory characteristics or super elasticity, and such variable geometry makes their use in bearings and mechanical components difficult.

On the other hand, recent patents indicate that with proper thermal and mechanical processing, the properties of NiTi alloys of varying composition can be readily controlled (Refs. 11, 27 and 28). These controllable properties appear to include hardness, ductility and transition temperature. In other words, NiTi alloys can be tailored in such a manner as to suppress any transformation to martensite outside the intended use application, thus assuring dimensional and microstructural stability over the range of application for typical bearing elements. Since the transition temperature for the 60NiTi bearing material studied here is estimated to be well below –100°C, shape memory behavior is not relevant.

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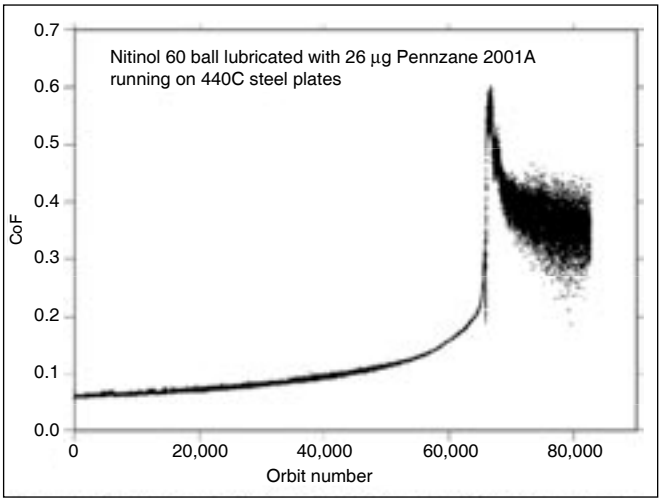

Figure 13—Friction trace of a Pennzane P2001A/Nitinol 60/440C steel system running in vacuum and continued until failure.

Figure 14—Surface of a 60NiTi ball after operating well beyond lubricant life of the oil. Surface shows evidence of mild abrasive wear but no galling behavior traditionally associated with titanium metallic alloys.

An interesting parallel could be drawn between the Ni-Ti materials system and the one based upon iron and carbon, Fe-C. Figure 15 shows the basic Fe-C phase diagram. Compositions containing small amounts of carbon, when properly processed and heat treated, yield tough, hard steel alloys. Higher carbon-containing materials conversely are observed as soft grey cast irons and as hard white cast irons. It has only been through the centuries of dedicated experimental and analytical investigations that a complete picture of the property-composition-processing relationships for the Fe-C system has been revealed. The Ni-Ti system may well offer a similar complexity belying its apparent simplicity.

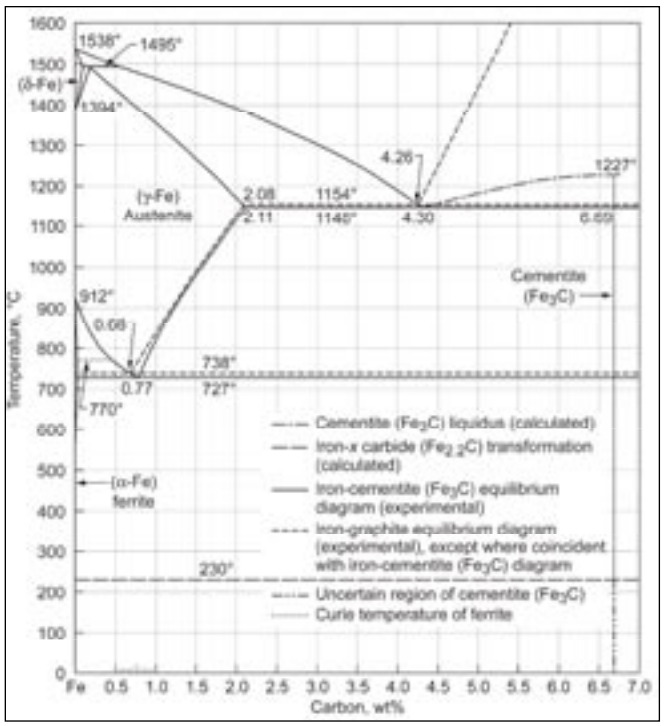

Figure 15—Fe-C binary phase diagram.

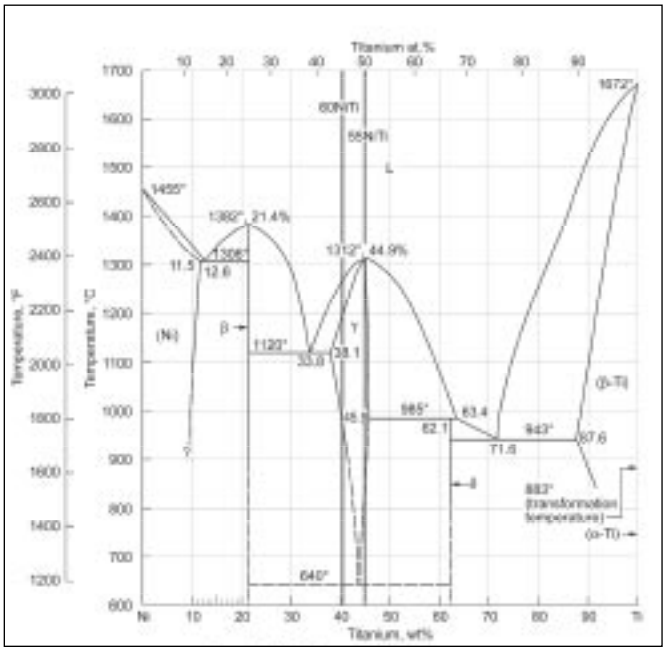

Figure 16—Ni-Ti binary phase diagram.

Figure 16 shows the phase diagram for the Ni-Ti system with callouts at both the 55NiTi and 60NiTi compositions. These alloys have widely varying properties and thus differ in their applicability to engineering uses. Though they share similar metallurgy, the more equi-atomic 55NiTi is relatively soft and displays remarkable shape memory effects; the nickel rich 60NiTi can be thermally treated to behave similarly to 55NiTi or, conversely, can be processed in a manner that essentially suppresses the martensitic transformation and hardens the alloy to such an extent that fracture can occur simply from rapid cooling.

In between, 60NiTi can be processed in a manner that yields a fine-grained structural material with high hardness that can be polished to a smooth surface finish yielding excellent, lubricated tribological properties. Thus the Ni-Ti binary system may contain hidden characteristics that have only recently begun to be revealed and understood.

Summary

This research effort has identified Nitinol 60 alloy as a promising candidate material for bearing and mechanical component applications. Nitinol 60, when appropriately processed and fabricated, is dimensionally stable, hard, wear resistant, non-galling and tribochemically benign in the presence of liquid lubricants. This behavior is in stark contrast to conventional alloys that contain such large amounts of the metal titanium. It is believed that the good tribological performance under oil lubrication observed for Nitinol 60 may extend to the entire NiTi family of alloys since they all share similar phase constituents and basic atomic level bonding. The tribochemistry of Nitinol 60 and its metallurgical relatives is under further study.

The identification of a viable bearing material that is non-magnetic, electrically conductive, hardenable, displays favorable tribochemistry and is non-corrosive is a major research finding. No other bearing material yet discovered has such a broad combination of properties. While it is clear that near-term niche applications such as aerospace bearings and gears exist, many non-obvious applications are also likely to present themselves. These include wear resistant, corrosion proof knives and cutters, electric machine structural and dynamic components, high-performance fasteners, valve components and many others.

Clearly, much more research will be required to understand the Nitinol 60 material and its metallurgical relatives. The relationships between mechanical and physical properties, atomic structure and microscale ordering and surface chemical interactions remain to be investigated. Nonetheless, the NiTi metallurgical system clearly has engineering potential well beyond shape memory alloy applications that has only begun to be exploited.

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Axis of Rotation Metrology

Drew Devitt

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Introduction

In the history of machine tools, spindles have been very good relative to other bearings and structures on the machine. So quality professionals have developed a cache of tools—ball bars, grid encoders displacement lasers, etc.—to help them characterize and understand the geometry of the structural loop. But as machine tools have improved in their capability and precision, and the demands of part-geometry and surface finish have become more critical, errors in spindles have become a larger percentage of the total error.

Once you have done all you can to improve the stiffness, damping, geometry and thermal stability of your machine, the next frontier is to study the errors in the spindles. The ultimate roundness and surface finish that may be achieved by a precision metal-cutting machine tool is determined by the performance of its spindles. By characterizing and routinely checking spindles, part quality can be predicted and controlled.

The focus of this article is to summarize the groundwork already established for using spindle metrology to deterministically improve manufacturing processes. As a bonus, and something the pioneers of spindle metrology would all be quick to point out, is that spindle testing, which is defined in the standards now as "tool to work," is also an excellent new diagnostic tool for other error sources in the machine.

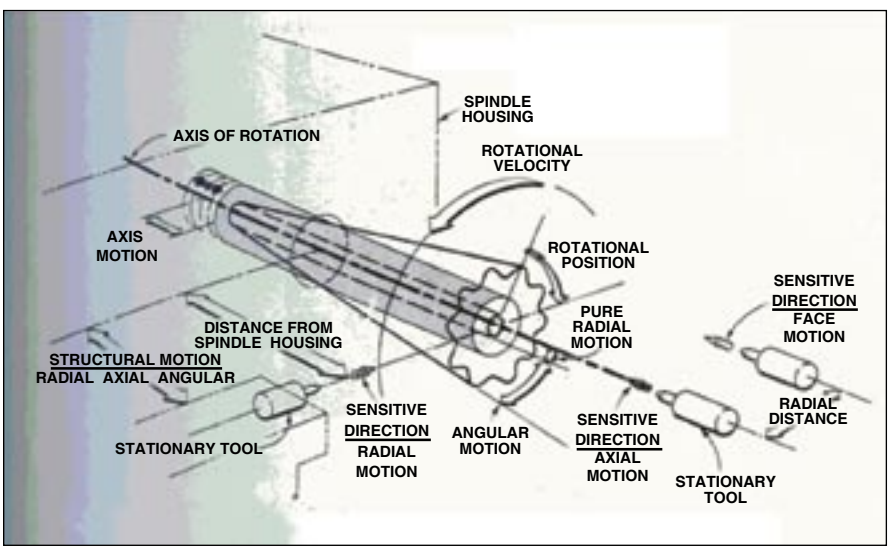


Figure 1—The three primary unwanted motions of a spindle are tilt motion, axial motion and radial motion. There are also two secondary motions: face motion, which combines axial and tilt motion; and radial motion, combining radial and tilt error. The term "angular motion," used in the illustration above, was changed to "tilt motion" in 1970 to avoid confusion with angular displacement of a rotary axis.

The standards that most specifically refer to the quality of precision spindles are ISO-230-7, "Geometric Accuracy of Axes of Rotation" and ASME B89.3.4-1985, "Axes of Rotation, Methods for Specifying and Testing." These standards are based on the concept of an "axis of rotation," which is a line segment about which rotation occurs. Spindle "run out" is an often-used term, but it is not consistent with standards for describing spindle precision. Surfaces have run out; axes have error motions.

There are three basic spatial error motions in spindles: radial, axial and tilt (Fig. 1). We will see later that spindle error motions are also characterized by frequency and by sensitive direction.

How the Testing was Done

Over the last 50 years, axis of rotation metrology has developed into a standard for characterizing spindles and understanding the capabilities of a machine. The measurement technique involves high bandwidth, non-contact capacitive sensors with nanometer-level resolution. The sensors reference precision pins or spheres that are mounted to the rotating spindle as targets. So with a three-probe system, (two probes arranged radially at 90° from each other, and one axially centered on the axis for X, Y and Z), a point may be referenced in 3-D space. A five-probe system (Fig. 2) with two spherical targets may reference two points, so tilt errors of the spindle may also be known.

The signals from these five probes each represent a fire hose of information about the spindle's performance, recording spatial errors and clocking them by frequency. Data can be taken at over 100,000 rpm. The signals may be viewed on an oscilloscope, run through Fast Fourier Transform (FFT) and/or software used to conceptualize the results (Fig. 3). Because the spherical artifact is difficult to perfectly align with the axis of rotation, it will have an eccentricity. This eccentricity may be used as a tachometer to phase the data streams with the rotation of the spindle (when an encoder is not conveniently available) and represents an error that is easily subtracted out (like a roundness measuring machine would). This technique allows for phasing a linear data stream (Fig. 7) into polar plots (Figs. 4–6).

What we find in the data, after subtraction of eccentricity, is that some errors are asynchronous; that is, different every time around. If we average the asynchronous data we have what is called Average Error (per the ASME B89.3.4-1985), now called synchronous error by the ISO 230-7, and defined as the portion of the total error motion that occurs at integer multiples of the rotational frequency (Figs. 4–6). We will see that asynchronous errors are a main determinant of workpiece surface finish, and synchronous errors are the main determinant of workpiece geometry.

Synchronous (Average) Error Motions

After subtracting out the eccentricity mentioned above, and averaging asynchronous motions, we have what's called "synchronous error motion." In most cases this would be considered the spindle error motion. In cases of very high precision spindles, where the 25 or 50 nanometer errors in the target become a significant percentage of the total error motion, another measurement procedure called "Donaldson reversal" may be employed to subtract out the errors that are in the target.

Synchronous (average) errors are clearly illustrated in plots of air and hydrostatic spindles as the error repeats, every time around (Fig. 5). This is in large part due to the fact that there is just one rotating element. Error motions in air-bearing spindles are often less than 25 nanometers (or one-millionth of an inch). In such a case, Donaldson reversal would be a necessary methodology as the error motion of the spindle is likely less than the non-roundness of the target.

For a lathe, unbalance, which results in vibrations that you may think would affect surface finish, actually does not. Unbalance causes a once-per-revolution disturbance that is repeatable. It is a synchronous error. If you have a part in a lathe spindle that is not balanced and you bore a hole in it, it may have good surface finish and roundness, but when you slow the spindle down, the hole will be eccentric.

With capacitance probes, it is possible to measure the eccentricity (run out) of the turned surface at different speeds. With perfect balance, the radial load on the spindle does not change with speed, so there would be no run out at any

continued

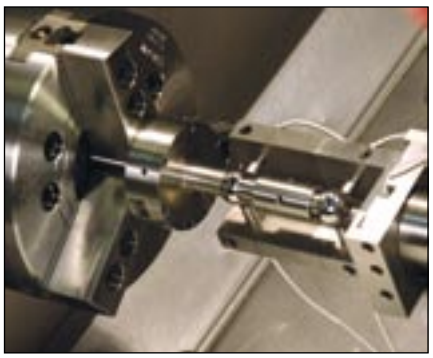
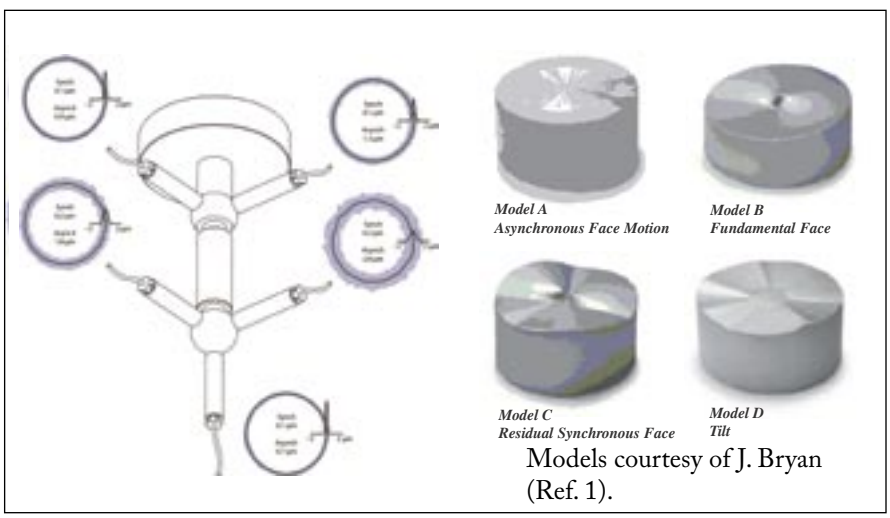


Figure 2—A two-sphere target is chucked in a lathe spindle, and the probe nest with five probes is attached to the tool turret in order to measure the errors described in Figure 1. Turning a part would be an example of a fixed sensitive direction (courtesy of Dr. Eric R. Marsh).

Figure 3—The spindle for a CNC vertical machining center with variable speed, AC motor and angular contact ball bearing spindle. The five probes are configured in a stiff nest for measuring motions of a two-sphere target rotating in the spindle. The probes will measure the total of bearing error motion, structural error motion, target eccentricity and target non-roundness. Boring a hole with this spindle would be an example of a rotating sensitive direction (courtesy of Dr. Eric R. Marsh).



Models courtesy of J. Bryan (Ref. 1).

Figure 4—This illustration shows polar plots generated from the individual signals of each of the five probes shown in Figure 3. The blue band thickness indicates the amount of asynchronous error motion, and the black line shows the synchronous or average error motion. Notice that tilt error motion causes both the synchronous and asynchronous radial error motion plots to double in their amplitude at the outboard spherical target (courtesy of Dr. Eric R. Marsh).

speed. In a different situation, the unbalance of a grinding wheel spindle will have a surface finish effect determined by the relative speed of the spindle and workpiece.

Fundamental synchronous and asynchronous axial motion is measured on the axis of rotation. It is very important when flatness or form at the center of the part is key. This would be the case in manufacturing optics. The face motions are measured some noted distance from the center, and would be the same as the axial motion in the absence of tilt motion. Because they are both measured on the face, both are axial motions and so they cause flatness errors when facing parts.

However, fundamental axial face motions will create a part that has the property of circular flatness, that is, the overall surface is not flat, but provides a "flat sealing surface" at any given radius. If you were to put the part on a roundness checker, and measure flatness at some radial distance from the center, you could adjust the part into reading flat at that radius, but the flat surface will not be perfectly square to the axis it was turned on, or the reference surface the part was chucked on. This may be acceptable for a sealing surface, but it would not be a good thing for a bearing surface.

The utility of measuring error motions in spindles became evident as hydraulic systems were being applied to military aircraft. Leaky hydraulic fittings were a maintenance headache and a hazard. A study by the military to improve the effectiveness of taper seals revealed that residual face motions of spindles making tapered seals would compromise the geometry of the tapers produced and their ability to seal.

Residual synchronous face motions are motions left over after the fundamental (the once-around) errors are subtracted; they are still synchronous but are at other integer multiples of the rotation frequency. Residual face motions result in parts that are not flat at all, not even circularly flat. Controlling the property of residual face motion is critical whether you are making seals or bearing races and, because tilt is involved, this is especially true with large diameters.

Asynchronous Error Motions

Asynchronous error motions are a predictor of surface finish, and they are best illustrated in error motion plots of rolling-element bearings. Because rolling element bearings have "constituent elements" (rollers, inner race and cages) that are not perfect and have different rotational frequencies, error motions of the spindle appear random. They are not actually random; the determinist viewpoint is that they can be predicted. In rolling-element spindles, these asynchronous motions are generally much larger displacements than the synchronous motions (Figs. 4–6). Over many revolutions, the polar plot develops into a fuzzy band and the thickness of this band represents the asynchronous error motion of the spindle. This is likely to be 100 nanometers in the very best rolling-element spindles; 1,000 nanometers (1 micron) in good spindles; and 10 microns or more in 500 mm or larger diameter bearings.

The linear plot (Fig. 7) shows how the different elements, with their different rotational frequencies, produce what appears to be non-repeatable motion in the summation of their signals (top). The portion of the signal that is asynchronous is the determinant of surface-finish capability. The error motions do repeat though after many revolutions, and can be predicted to some degree. An analogy can be made with the sun, which rises differently each day but is, after many rotations, repeatable.

Figure 7 also shows that the error motion signal may be decomposed into frequency components, and that doing so can result in a better understanding of the factors causing observed motion. For rolling element bearings, characteristic frequency equations can predict error motion encountered during rotation that are a function of the geometry of the bearing (diameter of races, number of rolling elements, diameter of rolling elements, etc.).

The Fast Fourier Transform (FFT) is the most common method for separating the frequency components of a signal. An example of this can be seen in Figure 8 for a single-row, deep-groove bearing. Note that the cage, ball pass and outer race frequency spikes are identified in the chart.

Rolling element bearings can have nanometer (one-thousandth of a micron) repeatability when turning, though angles of less than 360°, and then returning to the starting position. This is because, in less than one revolution, the constituent elements do not precess. That is, all of the components come back to their original locations with respect to each other.

If the error motions of the spindle are plotted for 10 revolutions and then reversed, the error motions will retrace exactly, showing that the motion of the roller-bearing spindle is deterministic. So the Gaussian distribution shown in Figure 8 across the asynchronous error

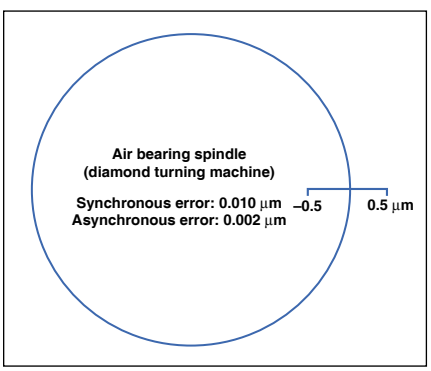


Figure 5—The difference between fluid film spindles and rolling element spindles is intuitively obvious when compared in error-motion polar plots (see also Figure 6). Notice that the air bearing spindle shown here has synchronous error of only 10 nm, and asynchronous error is a small fraction of that.

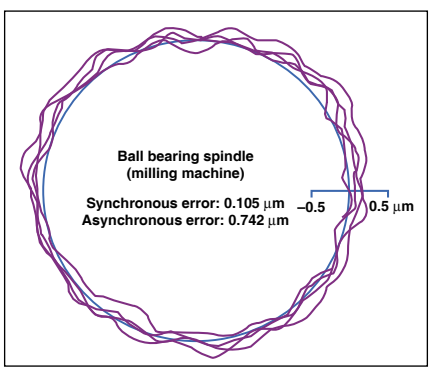


Figure 6—The ball bearing spindle shown here has more than 100 nm of synchronous error, and the asynchronous error is a large multiple (7X) of the synchronous error. This is why an air bearing spindle (Fig. 5) diamond turning or fly cutting machine can produce a mirror surface finish, while the rolling-element spindle lathe or milling machine cannot.

band indicating random motion is not correct but is of utility, illustrating at a glance the distribution of the errors in the band.

Summary

So, what is important if you are selling bearings for spindles? First, talk about low error motions, not "Non-Repeatable-Run Out" (NRR or Run Out)—to show you are familiar with axis of rotation metrology. Remember, error analysis data encompasses all spindle errors, including structural errors both thermal and from external vibrations. Don't let your bearings get blamed for structural vibration from someone's coolant pump. Motion can be measured quickly and simply by indicating from the tool to the spindle headstock. This is called stationary-point run out. Spindle drive systems can influence and print through into the error motion plot too. Error at the frequency of the motor poles is a dead giveaway that this is the case. Thermal drift of the spindle axis as it warms up will be the biggest error, but remember that it affects position, not roundness or surface finish, and is caused by heat, not bearing precision.

If you are *manufacturing* bearings or spindles, take care that the error motions of your spindles are not limiting the quality of the bearings you manufacture. The synchronous error motions of your work-holding spindles will determine the roundness or flatness of the parts you manufacture. Residual face error motion of work spindles can cause flatness errors of races for large roller bearings. These errors can also change the intended profile of a spherical race. Surface finish is dependent on the asynchronous error motion of both the work spindle and the grinding wheel spindle. Dramatic surface finish improvements can be made by characterizing and improving spindles using axis of rotation metrology.

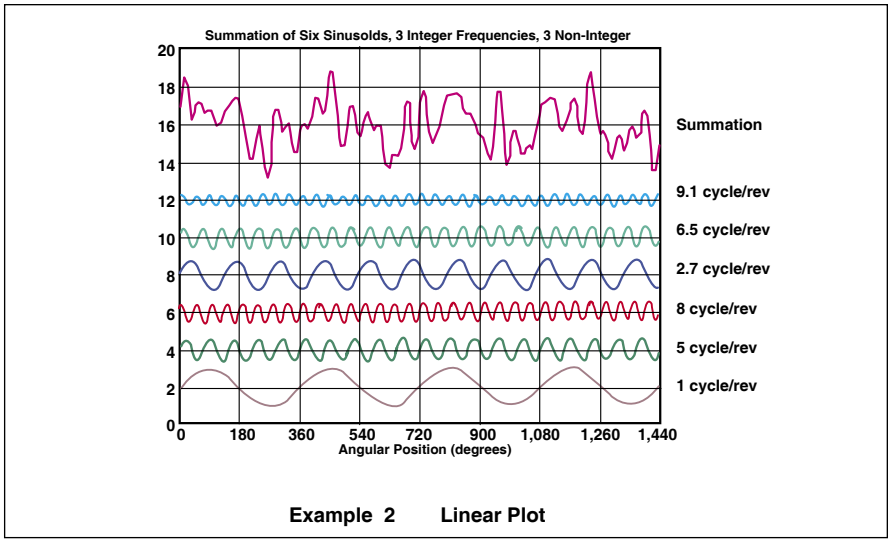


Figure 7—The signals above represent isolated frequencies from a single signal. The 1 cycle/rev is fundamental, 5 and 8 cycles/rev are integer multiples, and so these are all synchronous errors. 2.7, 6.5 and 9.1 cycles per revolution are not integer multiples and so are asynchronous errors. The errors, all acting at the same time, result in a summation that appears to be random. When the signal is phased to the rotation of the spindle being measured, polar plots as in Figure 6 may be generated (courtesy of Dr. Wolfgang Holzhauer).

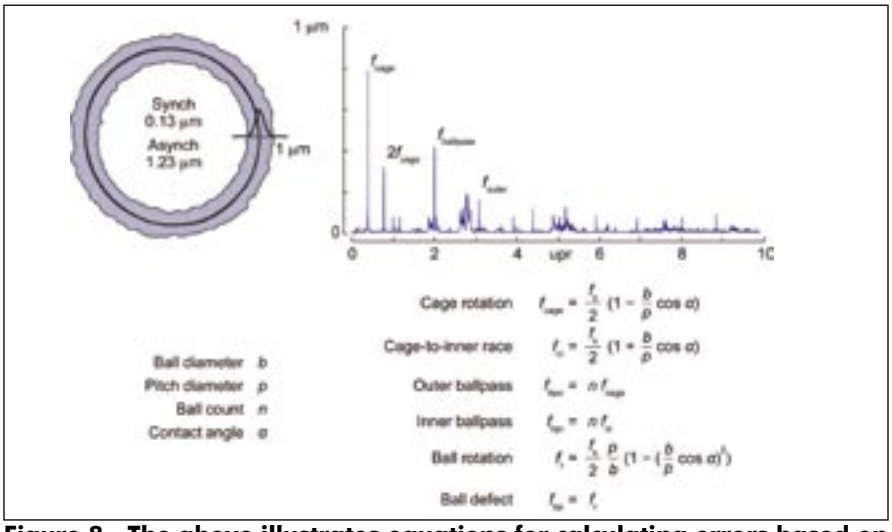


Figure 8—The above illustrates equations for calculating errors based on the relative size and number of constituent elements. A typical error motion polar plot, top left; and an FFT plot showing frequency spikes of critical elements, top right (courtesy of Dr. Eric R. Marsh).

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Drew Devitt *is the founder and Chief Technology Officer for New Way Air Bearings, Aston, PA. He is past president of the American Society for Precision Engineering, and wrote this paper as a member of the Bearings Specialist Association, Education Committee.*

Six-Shows-In-One

MAXIMIZE DESIGN, MANUFACTURING OPPORTUNITIES

There's something for everyone with 40,000 manufacturers convening outside Chicago September 22-24 (courtesy Canon Communications).

What was formerly held under the banner name of National Manufacturing Week returns to Rosemont, IL, as the largest design and manufacturing event in the Midwest, now produced by Canon Communications. One show badge grants access to all six co-located trade shows: Design and Manufacturing Midwest, Assembly Technology Expo, Electronics Midwest, Medical Design and Manufacturing Midwest, Quality Expo and Green Manufacturing Expo. The usual sales, networking, new technology and equipment opportunities make this an important event for the anticipated 2,000 exhibitors and 40,000 attending manufacturers.

Some special events open for all attendees include the Lean Factory, providing free educational sessions, and the Innovation Briefs Theater, presenting 30-40 minute free sessions with industry experts. There are four Innovation Briefs Theater presentations each day, organized under Design and Manufacturing, Medical Design and Manufacturing and Quality Expo tracks.

Here's a breakdown of what the individual shows cover:

Design and Manufacturing Midwest. From design to distribution, visitors will find new technology in computer-aided design and manufacturing, rapid prototyping, engineering, components, automation and assembly, lasers, motors and drives, packaging, materials handling, electronics, plant engineering, quality systems, networking, enterprise technologies/IT, and a range of contract services.

Assembly Technology Expo. Assembly tends to be covered piece by piece, but this is one instance where solutions for the entire process from start to finish are on display from gauging equipment to calibration and measurement tools and software. Check out booths for Renishaw, American Stress Technologies, Balluff, Bosch Rexroth, Euro-Tech Corp., Misumi, QC Industries, RBC Bearing, Suhner Manufacturing and Techno-Sommer.

Electronics Midwest. This show is considered part of the Assembly Technology Expo, but it is separate to basically group all the electronics assembly suppliers together for visitor convenience.

Quality Expo displays the latest in gages, quality software, calibration, CMMs, data collection, electronics test, non-contact inspection and other products designed to ensure the highest level of value. The corresponding conference includes sessions on quality management, reliability, statistics and problem solving, using technical risk assessment and other techniques for effective product development, strategies for software technology in green manufacturing and supply chain management.

Green Manufacturing Expo is designed for OEMs looking to improve process efficiency and reduce costs while conserving energy and other resources. Products to see include solar and wind energy systems, CAD/design for sustainability, energy management software, recyclable and bio-compostable packaging, energy-saving machinery and components and sustainability consulting.

Medical Design and Manufacturing Midwest, known as MD&M Midwest, features new technologies in materials, components, electronics, machinery, systems and services for designing medical products of all types. Day-long conference sessions include managing issues in supply chain, developing and streamlining design control,

process validation for medical devices, using quality systems to avoid 483s, streamlining product development and risk management and applying ISO standards.

All six shows will fill the Donald E. Stephens Convention Center outside Chicago, in Rosemont, IL, Tuesday through Thursday September 22–24. Conferences run from 9 a.m. to 4 p.m. and expo halls open at 10 a.m. to 4 p.m. For more information, visit *www.manufacturingweek.com* to find links to the individual shows, or visit *www.canontradeshows.com*.

Photo courtesy of Indiana Convention and Visitors Association.

Have Gearing Questions? Gear Expo 2009 is the Place to Be.

Chances are you do use plenty of gears in your automation processes or plant maintenance. Plenty of business and educational opportunities exist for non-gear makers at Gear Expo, the only event of its scope and niche market focus in North America, and it only comes around once every two years. If you're not exhibiting, there are many benefits to reap from walking the show floor, at least for a day. You may find you need more than a day to take in everything Gear Expo has to offer.

"It is a place people can come and evaluate tooling or equipment or suppliers who are working in the industry, and they can come and evaluate gear manufacturing," says Joe Franklin, president of the American Gear Manufacturers Association (AGMA).

To maximize convenience for attendees, AGMA returns to Indianapolis as the Gear Expo host city for the first time since 1995. That show served as one of the best in attendance and experiences. Indy has great amenities to offer visitors and is easily accessible by car for much of the North American gear industry.

All the hotels downtown are connected, so convenience is maximized for visitors going from place to place in any weather. "(Indianapolis) is convenient for being together and networking in that everything is connected and close," says Franklin.

The show floor at the Indianapolis Convention Center will be divided into five new pavilions this year including aerospace, breakdown, energy, powder metal/plastics and tooling.

Also, brand new this year at Gear Expo is its co-location with the ASM International Heat Treating Society Conference and Exhibition, which will add 3,000 people and 180 exhibitors to the mix, allowing visitors to take advantage of an additional technical program. The genesis for this partnership goes back to 2006 when Thom Passek, executive director of the ASM, began discussing the idea with Kurt Medert and Franklin of AGMA. "We approached the AGMA about bringing our two shows together since the connection between gear manufacturing and heat treating is so strong," Passek says. "We both agreed that this was an opportunity to achieve a great deal of synergy, where someone attending one show could simply cross the aisle to learn about the other industry as well."

More international visitors should be drawn to Gear Expo by the U.S. Department of Commerce, which selected the show for its International Buyer's Program. The program attracts more than 125,000 qualified foreign buyers, sales representatives and business partners to U.S. trade shows every year. This allows U.S. commercial service trade specialists to promote Gear Expo abroad. Participating in the program also provides opportunities for exhibitors to find foreign partners, and other perks too for those interested in taking advantage of international trade prospects.

Gear Expo takes place September 15–17 at the Indiana Convention Center, downtown Indianapolis. For more information, visit *www.agma.org*, or check out *Gear Technology*'s Gear Expo Showroom at *www.geartechnology.com/gearexpo*.

calendar

September 21–22—Bearing Specialists Association Fall Meeting. Hilton Suites, Chicago, IL. Members of the Bearing Specialists Association convene for the annual fall meeting where its committees address the important issues and association projects. Besides the networking opportunities, members are encouraged to attend in order to influence the direction of the industry over the next few years. To enhance the networking opportunities, there is a presentation on the pros and cons of social networking and examples of how it's being used. The guest speaker is Jeff Risley, vice president, public relations and social media analyst for Barkley advertising agency. Both meeting and hotel reservations are due by August 31. For more information, visit *www.bsahome.org*, or call (630) 858-3838.

September 22–23—Human Error Prevention Seminar. Chattanooga, TN. This seminar provides the most current developments in human error prevention, which significantly contributes to improved productivity, safety and quality. The principles and practices of human error prevention are universally applicable to any industrial, commercial or governmental enterprise regardless of the type of function performed. Instructor B.W. (Ben) Marguglio's taxonomy of human error causal factors and human error-related models demonstrate his leadership in the subject. He uses examples and case studies to reinforce the human error prevention principles and practices. For more information call (845) 265-0123, e-mail *ben@hightechnologyseminars.com* or visit *www.hightechnologyseminars.com*.

September 23–25—EPTDA Annual Convention. Marriott Park Hotel, Rome. The 12th annual European Power Transmission Distributors Association brings its 200 distributor and manufacturer member companies together to network around the theme of "excellence in relationships." The goal for this year's convention is to restore confidence and inspire the PT/MC industries to overcome economic challenges and create business opportunities. Experts will address topical issues such as risk and cash flow management, opportunities of the global economic situation and human resource retention. The convention also features a day of private meetings for open discussions on the latest product offerings, innovations and industry developments. A Manufacturer-Distributor Idea Exchange is considered a major highlight. For more information, visit *www.eptdaconvention.org*.

October 4–8—IEEE Industry Applications Society Annual Meeting. Hyatt Regency Houston. The 44th annual meeting of the Industry Applications Society (IAS) of the IEEE, a global association for technology advancement, is a source of continuing education for practicing engineers who work with and research electrical systems for industrial applications. The tutorial program has been expanded this year, which along with papers presented, covers applications-related topics like power systems, lighting, mining, metals, appliances, drive applications for industrial power systems and IEEE Color Book Standards. For more information, contact Bruno Lequesne, IAS '09 conference chair, at *bruno.lequesne@ieee.org*.

October 5–7—Pack Expo. Las Vegas Convention Center. Las Vegas. The Pack Expo trade fair is the North American packaging and processing industries' main event. Manufacturers can assess how the newest technology can function compatibly with their own product lines. The products on display include packaging machinery, converting equipment, processing technology, materials and containers. Visitors will see the latest in security packaging, instrumentation and printing and graphic advances. Pack Expo is co-located with Process Expo, featuring developments in food processing equipment; Converting & Package Printing (CPP) Expo, which caters to the package printing, converting, finishing machinery and supplies industries; and the Reusable Packaging Association's annual meeting. For more information, visit *www.packexpo.com*.

October 19–22—Canadian Manufacturing Technology Show. Direct Energy Centre, Toronto, Ontario. The CMTS serves as Canada's main showcase for the latest machine tools, automation technologies, production methods, management strategies and more. Over 600 exhibitors present new technologies and ideas to hasten product development times, reduce cost and provide the best quality. An Automation Rendezvous Two-Day Technical Conference looks at improving industrial processes, budding technologies, successful partnering and other topics. Keynote speeches and town hall panels are part of the program designed for Canadian manufacturing professionals. For more information, visit *www.cmts.ca*.

October 19–22—InfraMotion. Bally's Hotel, Las Vegas. This is the 10th anniversary of the annual InfraMotion show, the international conference for infrared camera applications. Visitors and exhibitors are involved in infrared developments and practical applications for manufacturing and industrial automation, diagnostics, building sciences, predictive maintenance, R&D and other industries. For more information, visit *www.inframotion.org*.

October 25–29—Materials Science and Technology Conference and Exhibition. David L. Lawrence Convention Center, Pittsburgh, PA. MS&T '09 is the premier professional forum addressing structure, properties, processing and performance throughout the materials science community. The technical program focuses on ceramic and glass materials, electronic and magnetic substances, environmental and energy issues, fundamentals and characterization of the materials industry, iron and steel, nanotechnology as well as processing and product manufacturing. The trade show is the result of a four-way partnership between the American Ceramic Society (ACerS), Association for Iron and Steel Technologies (AIST), ASM International and the Minerals Metals and Materials Society (TMS). For more information, visit *www.matscitech.org*.

Centa

MOVES INTO LARGER FACILITY

In light of significant sales growth over the past few years, Centa Corporation moved into a facility more than three times the size of the former plant. The building is 23,000 square feet of office, warehouse and manufacturing and assembly space. The larger facility will provide the space necessary for Centa's forecasted growth, manufacturing flexible couplings and shafting for power transmission systems in the marine and industrial markets.

"The growth in demand for Centa's products over the last three years, and the forecast for further growth in marine, oil/gas and windpower generation markets made this move necessary," says Bob Lennon, director of sales and marketing. "The new facility gives us the capacity for additional staff and added inventory to better serve our growing customer base. The in-house manufacturing capability adds to our local manufacturing initiative and further lessens our dependence on deliveries from our parent company in Germany while lowering our exposure to global currency fluctuations."

NKE

EXPANDS AUSTRIAN HEADQUARTERS, ADDS SALES OFFICE IN SHANGHAI

Bearing manufacturer NKE Austria GmbH moved into its new headquarters in the Stadtgut Steyr industrial park in June. The company invested over fifteen million euro in the 10,000-square-meter facility, with 3,000 square meters of office space, a 6,000-square-meter production hall and 1,300-square-meter automatic high rack warehouse.

The move improves NKE's manufacturing capacities to include small-lot production and more efficient logistics. "With the new works, we can double our capacity and are significantly more flexible," says Heimo Ebner, NKE's commercial managing director.

Hansen Mao is heading NKE's first sales office in China.

The headquarters sit on a 35,000-square-meter lot in the industrial park, which supports NKE's long-term expansion plans. Currently, 180 people are employed at the facility and NKE intends to increase its workforce to 230 people in the next three to five years. In 2007, the company had planned a fourth extension of its former site in Steyr-Gleink, but management decided this would limit its ambitious growth goals. "Eventually the soft facts made us decide for Steyr," Ebner says. "70 percent of our employees come from Steyr and the brand NKE is closely connected with Steyr."

Another sign NKE is weathering the global recession successfully is the July opening of its first sales office in China. NKE intends for the office to improve service to OEM customers and establish a nationwide distribution network. Hansen Mao, with several years experience in the bearing industry, is heading the office as chief representative.

China stands as the fourth largest international market for NKE, but the company expects it to jump to the second largest market this year. "The sales office in Shanghai enables us to act faster in the Chinese market as well as better attend to our customers technically and commercially," Ebner says. "Customer proximity is the cornerstone of our success. With the new representative office, we have now 15 sales offices in 12 countries."

NKE Austria's new headquarters in the Stadtgut Steyr industrial park spans 10,000 square meters.

CST

APPOINTS PRESIDENT


Eric Pilaud

Eric Pilaud was appointed president and CEO of Custom Sensors and Technologies (CST) effective July 1. He previously was in charge of strategy, customers, innovation and technology for Schneider Electric.

Pilaud began his career as a university professor, researcher and consultant in the IT sector. He began work for Schneider Electric subsidiary SES in 1986. He was chosen in 1991 to head SF Gandy in France, and from 1995–1998, he served as director of Westinghouse Systems and then the automation and control division, both in the U.K. He worked his way up to executive vice president of the strategy, customers and technology division and the services and products business unit in 2006.

Hal Grant was serving as interim CEO between March and June this year after Chuck Treadway left the company following a three-year tenure as president and CEO.

"Despite the current challenging economic environment, Custom Sensors and Technologies has the ability to grab huge opportunities," Pilaud says. "In a world where intelligent and communicating sensors play an increasing critical role in every application, we will invest in technologies and customer intimacy to create a reference in our industry."

ASTM

PUBLISHES STANDARD FOR HYBRID ROLLER BEARINGS

Increasing use of silicon nitride rollers in recent years has led to the development of ASTM F2094/F2094M, Specification for Silicon Nitride Bearing Balls. It was developed by ASTM Subcommittee F34.01, which is under the jurisdiction of Committee F34 on Rolling Element Bearings.

Examples of where hybrid roller bearings are found include high-speed machine tool spindles and high-pressure turbopumps that move liquid hydrogen in a space shuttle. End users of bearings, bearing manufacturers and roller manufacturers will use the standard to procure finished bearings to ensure they're made with sufficient material. Bearing companies can use the new standard to acquire finished silicon nitride rollers from the manufacturers, who will use the standard to ensure that unfinished roller blanks meet the material capability they need.

ASTM F2730/F2730M complements ASTM F2094/F2094M, Specification for Silicon Nitride Bearing Balls, according to William Mandler, general manager of Enceratec Inc. and task group chairman for the group responsible for developing the standard. "ASTM F2730, like ASTM F2094, provides a specification for the material used to make the roller—three levels of capability are included, so the material can be specified for the severity of the intended application," Mandler says. "The specification also provides dimensional specifications for form and surface condition of the finished roller."

Sumitomo

PROMOTES VP, ENGINEERING DIRECTOR


Matthew Roberson

Matthew Roberson was promoted to vice president of sales at Sumitomo Machinery Corporation of America (SMA) in June, and in March, Dr. Arthur S. Pantelides was promoted to Director of Engineering to oversee the engineering, design and research and development groups.

Roberson has a bachelor's degree in business management from Hiram College and a Masters of Business Administration from Ashland University. He has more than 20 years of experience in the power transmission industry with positions in field service, sales, sales management and channel management.

Roberson started with SMA in August 2006 as regional sales manager in Cleveland. He worked his way up to national sales manager in June 2008 where he led the U.S. sales force, customer service, marketing communications, aftermarket sales and distribution channel management divisions.

In his acceptance speech, Roberson said, "Like many of you, I am convinced when we emerge from this economic crisis,

Dr. Arthur S. Pantelides

the lessons we learn today and the processes we develop in these challenging times will make us a more efficient, more effective and more customer driven organization than we ever imagined. I accept the challenges and responsibilities of this new role and promise you I will not let you down."

Pantelides has over 15 years of international manufacturing experience in the heavy industrial, automotive and consumer-related gear markets. He has a doctorate and master's degree in engineering management from George Washington University and a master's in mechanical engineering from Boston University.

Pantelides' recent accomplishments include standardizing the R&D process on a global scale and integrating regional facility engineers under centralized control at SMA's Virginia headquarters.

Ron Smith, CEO of SMA, says, "Arthur possesses a passion for our business, loyalty to our company and employees and a leadership style that brings out commitment and enthusiasm in those fortunate to work directly with him."

Executive Director, Board Members

NAMED TO CSIA

At the annual Control System Integrators Association's (CSIA) Executive Conference, Robert Lowe was appointed executive director while Joseph Martin, Jeff Miller and Piercarlo (PC) Romano were elected as board members.

Lowe replaces Norm O'Leary upon his retirement. In his new position, Lowe's responsibilities include overseeing CSIA programs, meetings, certification and audits; developing and maintaining key relationships with CSIA members, partner executives, partner program managers and affiliate associations; representing the organization at affiliate and partner trade shows; and helping the CSIA executive council and committees achieve their goals.

Lowe shares the executive director position with Lynda J. Patterson, president of CSIA. She is responsible for managing the business and administrative functions, including

continued

membership, meeting planning, finance, public relations and communications.

Previously, Lowe served as vice president of Loman Control Systems, Inc., a founding member of CSIA, which he co-founded and co-owned for 17 years. For eight years, he served on the CSIA Best Practices and Benchmarks Committee and was involved in designing the CSIA certification audit.

"I'm grateful to have been given the opportunity to lead this vibrant and exciting organization," Lowe says. "Norm has left big shoes to fill, but I'm up to the challenge and committed to providing member companies with the resources and support they need to be the industry's best."

Martin was elected chair of the CSIA Membership Committee, and he is president of Martin Control Systems, Inc., of Dublin, OH. Miller is chair of CSIA's Best Practices and Benchmarks Committee, and he is director of automation services at Interstates Control Systems, Inc., of Sioux Center, IA. Romano is chair of CSIA's Statistics Committee and president of Avid Solutions of Winston-Salem, NC.

The 16th annual CSIA Executive Conference, held in Naples FL, also took time to recognize Mark Moriarty of Rockwell Automation as CSIA Partner of the Year, and Schneider Electric, of Knightsdale, NC, was named Company of the Year. The late Nels Tyring, formerly of TVC Systems, was honored with the Charlie Bergman Award for his commitment to leadership and promoting the control system integration industry.

Power Up!

If you have a background in gears, bearings, motors, belts, couplings, sensors or actuators, we'd like to talk to you. Power Play, the back page feature in *PTE*, is all about your industry. If you've got a funny anecdote, an interesting observation or perhaps a limerick on motion control, feel free to send it our way. This column is dedicated to the stories too radical to make the cut in industry or product news. We need story ideas, and we're confident you can provide them.

The rules are quite simple: submit a story idea about the power transmission industry, make it entertaining as well as informative, and become a *PTE* magazine editor-at-large today (salary not included). Submit your award-winning material to:

publisher@powertransmission.com

NEMA Index

INDICATES FUTURE GROWTH

The Electroindustry Business Confidence Index (EBCI) for future North American business conditions rose for the fourth month in a row in June. It went up three points, to 68.2, which is the highest level since August 2005. This is an indication that electroindustry executives foresee some improvement in the business environment over the next six months.

EBCI measures the business confidence of the electorindustry in Asia, Europe, North America and Latin America. It is published by NEMA, the Association for Electrical and Medical Imaging Equipment Manufacturers, and is based on the results of a monthly survey by senior managers of NEMA member companies, which represent over 80 percent of the electroindustry.

The future forecast comes on the heels of the current EBCI that declined 6.6 points to 41.3, its second decline in the past six months.

classifieds ad index

Gear Manufacturing

Gear Manufacturing

NOW THAT'S PRODUCT PLACEMENT

ABB ROBOTICS GETS FREE ADVERTISING VIA SUMMER BLOCKBUSTER

Summer is guilt-free at the cineplex. There are no Oscar-contending speeches, lavishing period pieces or three-and-a-half-hour docudramas. It's all bang and whoosh from May until September with explosives, cheesy dialogue and computer-generated effects. It's also the time of year when product placements truly shine. General Motors cars transform, Coca-cola quenches teenage thirst and iPods seem to be the only MP3 players on the market.

ABB Robotics, a supplier of industrial robotics, took advertising to a whole new level this summer when Warner Brothers cast 12 IRB 6620 and six IRB 1600 robots in *Terminator Salvation*.

"The robots were used to simulate the manufacturing of the Cyberdyne Terminator T800 robots," says Ted Wodoslawsky, vice president of marketing at ABB. "They're standard ABB products. One is frequently used for welding and material handling and the other for laser-cutting and picking and packing applications. The 18 robots have since been sold to other customers under our used robots sales program."

Academy-award winning set director Victor Zolfo and production designer Martin Laing were intrigued by the product line that ABB offered.

"We looked at a variety of different robot manufacturers, but were most struck by the presence of ABB's robots, especially the larger units," Zolfo said in a press release. "They had the right lines and they provided the feel that they could actually be making Terminators."

Wodoslawsky was thrilled by the exposure that came from the film. "We were able to generate some worldwide buzz about being in a summer blockbuster. The story was picked up by news media in Europe and Asia. I haven't seen a sales lead stating that they saw them in the film, but I expect to."

Since it was a simulation of a real factory, ABB's robots fit right in and had no trouble adjusting to life on a Hollywood set. "While it was a fun experience, it was really no different than the work we do for our customers every day," Wodoslawsky says.

Erik Ryskamp, field engineer at ABB, spent 10 weeks during the summer of 2008 installing, programming and operating the robots. "Erik and his team worked with us very closely creating an incredible ballet with the robots, actors and stuntmen," Zolfo says. "The robots are very visible and instrumental in the final, climatic scene of the movie."

Ryskamp says director McG fit the robots into a couple more scenes in the film when he saw how cool they worked. The machines were covered in black soot to appear dingy and banged-up for their respective roles.

"The robots were really an evolutionary character," Zolfo says. "Like an interim step between the humans and Terminators."

Now that ABB has some Hollywood exposure with a set director like Zolfo, Wodoslawsky hopes to get its products in other films in the future.

"It was a great deal for both parties. *Terminator Salvation* got to use ABB robots and engineering expertise and we got the exposure of our robots being featured with ABB logos prominently displayed," Wodoslawsky says.

From what they were told, everyone involved on the production enjoyed working with the ABB robots and the ABB employees.

Even rumored set disrupter, Christian Bale.

"After seeing the movie, I think the ABB robots were a welcome presence," Wodoslawsky says.

For more information on ABB, please visit *www.abb.com*. *Terminator Salvation* was released in May 2009.

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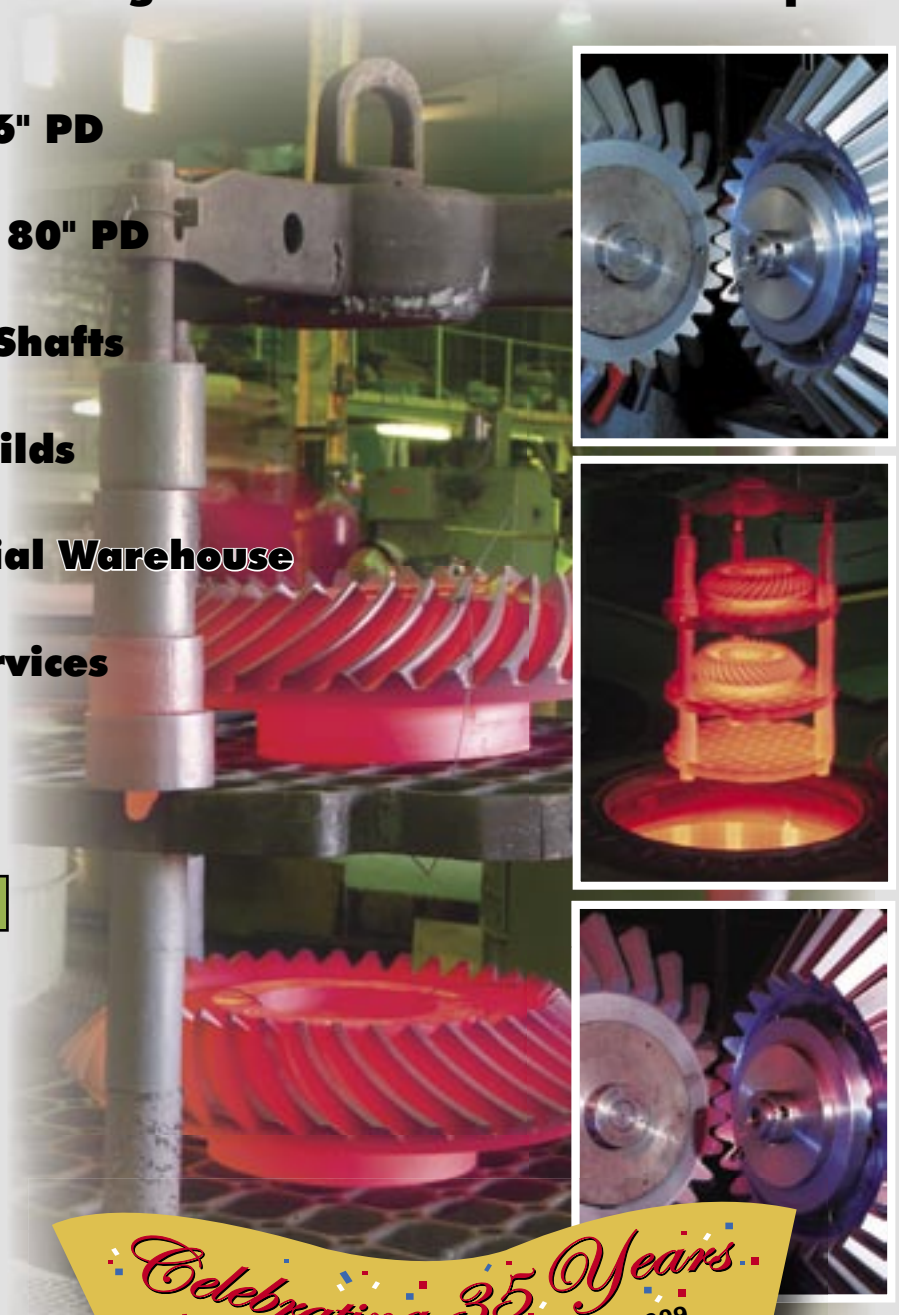

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