MiTi® Developments

Mohawk Innovative Technology, Inc.

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HIGH-SPEED, OIL-FREE, MOTORIZED SPINDLE

Oil-Free Motor Driven Compressor

Immediate and enthusiastic industry acceptance of the newly introduced Samsung Plant Air Compressor (Figure 1) has confirmed validity of the MiTi® advanced concept of universally adaptable, high-speed, motorized spindles, supported by compliant foil gas bearings.

The single frame size of this compressor can be rated for 125; 150; or 175 hp through motor length selection. MiTi®'s patented, oil-free, hydrodynamic gas foil bearings eliminate the need for a lube oil system and, being self-pressurizing, do not require a separate pressurized air source, a very basic concept.

Additional benefits include: high speed for optimized aerodynamic performance, extended maintenance intervals, longer bearing life, higher overall operating efficiency, and improved environmental impact. Elimination of pump and gear noises enables achievement of noise levels of 65 db (A). Waste oil and filters are no longer a burden. Reduced weight and size simplify installation requirements. And, oil-free product (i.e., plant air) is delivered to the process.

Figure 1. Samsung Turbo-Master® Micro TM Series 150 HP Plant Air Compressor

Mohawk Innovative Technology, Inc. (MiTi®) has now introduced a product line of oil-free spindles that mount an integral drive motor between two compliant foil radial gas bearings. Either or both ends of the spindle can be tailored to mount impellers or an impeller/expander mix (see Figure 2). This breakthrough concept enabled Samsung to attain its design objectives. The two impellers, operating at high speed, outperform the work of competing higher power designs.

MiTi® can customize this motorized spindle design to accommodate needs and optimize performance for individual applications. For instance, our breakthrough engineering capabilities enabled Samsung to design for optimum aerodynamic efficiency operation at 70,000 rpm, well above the third critical speed (i.e., the first bending critical speed) of 42,000 rpm. Over a year of flawless operation at several in-service beta test sites confirmed commercial quality performance and reliability of the unit before release to the market. (*Newsletter 19 details the Samsung design.)*

Figure 2. 130 kW permanent magnet motor rotor with compressor wheels as used in Samsung Turbo-Master Micro TM Compressor, MiTi® foil bearings and MiTi® high-speed induction motor rotor

MiTi® Oil-Free, High Performance Drive Motors

Fully developed, and now available for applications, is a 460V, 3 Ǿ, 2-pole induction motor drive spindle with a calculated electrical efficiency of 93%. The stator is water cooled, while the bearings are air-cooled. Torque is 6.0 N-M (4.42 lb.-ft.) continuous, producing 32 kW @ 60,000 rpm or 19 kW @ 30,000 rpm. The mounting dimensions, centerline height, and shaft diameter conform to a NEMA 48 frame size. Overall length is 12 inches and overall height is 6 inches. Bearing sets are selected to meet specified duty cycles. Figure 3 shows the major motor components prior to assembly. The photo shows an assembled motor, plus

a water cooled housing with the stator installed, an end cap, foil bearings, and the shaft with rotor laminations.

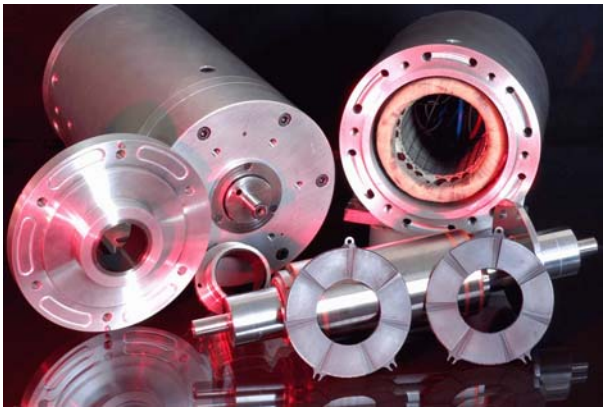

Figure 3. MiTi® 32 kW Motorized Spindle Components

MiTi® can work with you or your vendors to design a new product or to integrate one of our motor drives with one of your existing product designs to enhance operating capabilities and performance.

Controller and power source size and selection for the induction motor are determined according to the application requirements. These can be provided by MiTi® or others. Normally specified is a drive unit that will provide up to 500 Hz or 30,000 rpm shaft speed.

Additional induction motor spindle designs that are currently available for development and application include:

Torque	Speed (rpm*1000)				
(N-M)	18	24	30	42	60
	Power (kWe)				
6.0	11	15	19	26	32
11.5	22	29	35		
15.8	31	40	50		
21.0	40	52	64		

Individual requirements other than those satisfied by the above can also be readily accommodated. MiTi® welcomes inquiries and will offer guidance, opinions and budgetary estimates, including recommendations for detailed reviews and system engineering developments.

The above cross section (Figure 4) shows the locations of the two radial foil bearings and the double acting foil thrust bearing. A standard 0.50-inch diameter by 1.00-inch long stub shaft is provided on each end of the shaft. Custom shafting to accommodate customer needs may be substituted. The motor assembly is very compact and has only one moving part, making for a simple and robust configuration. To ensure high efficiency cooling, the motor housing is made of aluminum and incorporates internal water passages. A broad selection of motors is readily available for integration into systems.

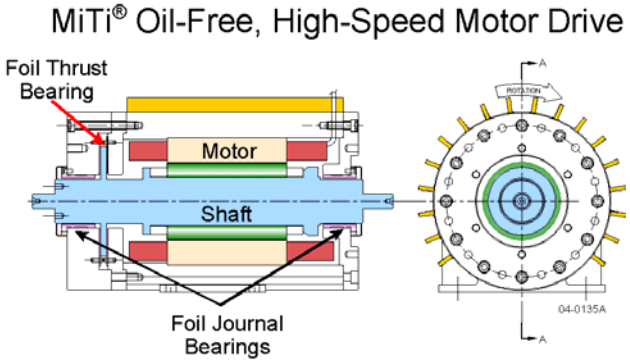

Figure 4. Cross section and end views of MiTi®'s 32 kW, 60,000 rpm Oil-Free, High-Speed Motor.

Since the foil bearing is a class of hydrodynamic bearing, static loads (e.g., weight of the entire rotating group, thrust loads, etc.) and operating speeds will affect the selection of the bearings to be used in the motor. Several classes of MiTi® foil bearings and coatings are available to meet varying duty cycles, according to maximum and operating speed ranges, bearing chamber temperatures, impeller sizes and rotating group weight, thrust loads, etc.

The MiTi® compliant foil gas bearing design (Figure 5) combines hydrodynamic and mechanical structural elements to achieve load capacities and damping properties that exceed by several orders of magnitude those of competing gas bearing designs. Through our patented design and unique actions within the bearing components, the damping properties of MiTi® foil bearings rival oil film bearings, permitting operating above a bending critical speed, something that has not been achieved using any other gas bearing designs to date.

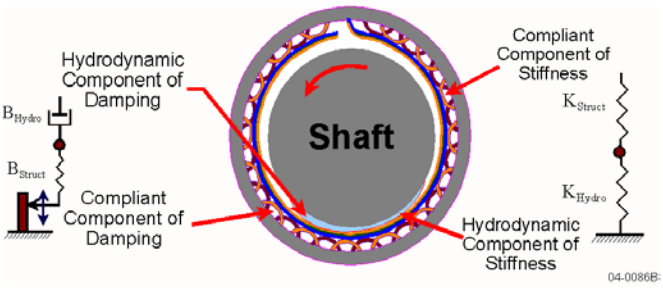

Figure 5. MiTi® Foil Bearing Design Features

Supported by a bearing cartridge, the compliant structural element has a corrugated shape that enables the designer to incorporate a desired mechanical

stiffness value through metal gauge selection and geometry of the corrugations. The flexing of each corrugation, when under dynamic loading, causes small sliding motions at the contact points between the corrugated foils and the bearing cartridge surface. The combined static and dynamic friction values of all corrugation contact points provide the major portion of the mechanical damping action.

The smooth top foil rides on top of the corrugations and provides the surface needed for the generation of a hydrodynamic air wedge to levitate the rotor. Hydrodynamic levitation by the air film wedge eliminates wear-inducing contact with the bearing so that non-contacting operation is achieved when the rotor is spinning at its desired speeds. Since the viscous losses of gases are a fraction of that incurred by oil film bearings, a significant operating efficiency advantage is possible with compliant foil gas bearings. Additionally, hydrodynamic gas foil bearings are not speed limited once rotor levitation is achieved. MiTi® has operated rotors on foil bearings at speeds exceeding 705,000 rpm. A heavy-lift, proprietary foil bearing system is available for special very heavy rotors weighing more than 1000 pounds. Figure 6 shows several of the different foil bearings sizes MiTi® manufactures for applications ranging from compressors and motors to cryogenic turboexpanders, turbochargers and gas turbine engines.

Figure 6. Range of MiTi® compliant foil bearing sizes

Due to the nature of hydrodynamic bearings, rotor dynamic evaluations are used to quickly determine the practical operating ranges and stability of various candidate rotor-bearing system configurations. Operation can be in a horizontal, vertical, or intermediate rotor orientation. The outstanding load and damping capacity of the MiTi® foil bearing design assures smooth, stable operation throughout the entire operating range. Shock loads of up to 100-g's have been imposed without adverse effects.

Besides the radial (or journal bearing), hydrodynamic thrust foil gas bearings are also designed and manufactured for use in our high-speed motors and many other machines. Like the journal bearings, the thrust foil gas bearings employ the multi-dimensional corrugated structural stiffness and damping to achieve high load carrying capacity. A double acting thrust bearing controls rotor axial position under thrust loads to ensure that tip clearance of impellers meets design requirements. As with the journal bearings, the thrust foil bearing may be changed to accommodate load conditions of the selected application.

The persistent development work pioneered by MiTi® engineers has created the technology needed to respond to the urgent needs of government advanced technology programs for over 20-years. These resulting powerful, validity proven, proprietary analytical procedures are now being applied in conjunction with highly developed computer controlled simulation test routines to optimize the design of commercial quality foil bearing supported rotor-bearing systems for industrial applications. Besides developing sophisticated analytical design tools, patented bearing designs, and the manufacturing know how to produce a quality high performance product, MiTi® has also developed the lubricant and wear coatings necessary to ensure low start up torque and long life of our bearings.

Tests of MiTi® foil bearings, protected by our proprietary KOROLON™ bearing surface coatings, have been conducted by government agencies, commercial machinery manufacturers and by MiTi® using our own test facilities. The MiTi® Korolon™ coatings have been shown to have low friction coefficients, and very long life even at temperatures exceeding 800 deg C. They are resistant to alkalis and solvents and have extremely durable surfaces that also have self-healing properties for foreign debris induced penetrations. Outstanding wear characteristics provide long, maintenance-free operational life. The friction coefficient is a fraction of that of polymers such as Teflon®. The low coefficient of friction, combined with the bearing design, support rapid acceleration to rotor levitation speeds (lift-off) with minimal power and torque requirements.

Thermal management of the bearing systems cooling requirements is effectively integrated with air and/or process gas cooling for the shaft mounted portion of

the integral drive electric motor rotor mounted between the bearings.

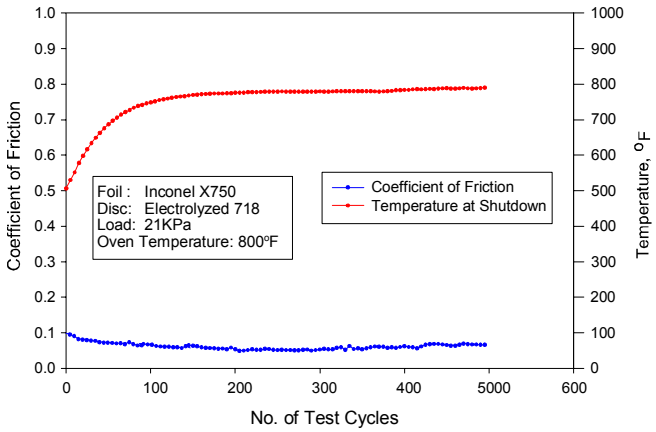

Figure 7. Coefficient of Friction for Korolon™ 800 at 425°C (800°F) over 500 start-stop cycles.

The use of highly developed, computer controlled simulators, located in modern, test cells enables the structured optimization of specific design features of commercial grade foil bearings, providing enhanced prototype testing, outstanding performance and assured reliability.

MiTi® bearings have passed many rigorous testing programs, including those related to turbochargers for off-highway and transportation applications. Bearing chamber temperatures can be held at very high values, reducing challenges in system design thermal management while improving efficiency through reduced cooling air requirements.

Key Features of MiTi® Generation IV Foil Bearings

Extraordinary Load Carrying Capacity*
-Radial, 100 psi; thrust, 85 psi
No Speed Limitation
-Demonstrated speeds exceeding 705,000 rpm
-Surface velocities greater than 1800 ft/sec
Stand-Alone Application Features
-Extreme temperatures from cryogenic up to 1500F
-Uses process gas/fluid
-Can operate in two-phase flow conditions
-Eliminates liquid lubricants and lubricant supply support system
-Fulfills needs where no other bearing can
Completely Self-Acting Hydrodynamic Action
-Requires no external pressurization
Capable of Providing Aircraft Quality Tip Clearances
-Increased compressor/turbine efficiencies
Exceptional Start/Stop Characteristics
-Low friction enhances rapid lift-off,
-Low wear rate results in long life
-Low drag minimizes starting power needs
Drastic Reduction in Power Losses/Heat Generation
-Low viscosity of gas reduces drag
Unlimited Bearing Size Scalability Demonstrated
Self-Alignment Adjustment for Rotating Group
-For static, magnetic & dynamic misalignments
Unparalleled Price to Performance Ratio
-Huge savings shown by life cycle evaluations
High Shock & Vibration Survivability
-Vehicular & mobile system maneuver tolerance
Operation Orientation
-Can operate in any orientation, including vertical
Bearing Material Flexibility
-Material can be altered to suit the application
KOROLON™ Coatings Eradicate Metal-to-Metal Contact
-Low friction coating yields low starting torque
-Wear resistance properties greatly extend life
-Over 100,000 start/stop cycles demonstrated
-Exceeds air cycle machine life requirement by 300%
-Electric resistance capability is 3+GΩ/mm
-Extraordinary elastic properties (i.e.,50% elongation)
-Low conductivity for good thermal barrier properties
-Self-healing property mitigates foreign element contamination/debris infusion.

The Company

Mohawk Innovative Technology, Inc. (MiTi®) is a high-speed rotating machinery company dedicated to applying and producing oil-free components and subsystems. System design integration and engineering services, foil bearing/seal/damper customization and oil-free product development and testing are all offered. We manufacture foil bearings, seals, dampers, oil-free motor drive systems and high performance friction, wear and lubrication test equipment.

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* Load capacity is defined at the steady state applied load divided by the bearing projected area (length times diameter)