AFTERMARKET FOCUS
FIRMS PUSH FOR SERVICES

FORECAST 2020
NATGAS GROWTH CONTINUES

HOTSTART CERTIFICATIONS
COMPANY EXPANDS COVERAGE

A KHL Group publication

COMPRESSOR TECH²

DEDICATED TO GAS COMPRESSIO… APPLICATIONS

AUGUST-SEPTEMBER 2019 | VOLUME 24 | ISSUE 7

www.compressortech2.com

The return of Cooper

Archrock buys Elite Compression

Take Five with Eric Petersen

Turbine Specs-At-A-Glance

The MONO CBA:
Howden releases new steam turbine

Capturing the benefits of electric-driven, oil-free compression trains utilizing magnetic bearings

TCO, environmental upsides seen. By: **José L. Gilarranz R.**, **Mayank Kumar Dave**, **Troy Jamison** and **Joachim Denk**

Oil and gas operators continue to face increased pressure to simultaneously reduce the total cost of ownership (TCO) and environmental impact of their operations, particularly rotating equipment assets. In light of this, the concept of oil-free compression trains has gained traction.

Oil-free compression trains offer numerous benefits when compared to traditional compression systems, including more efficient use of the available power, enhanced reliability, and fewer health, safety, and environmental (HSE) impacts. Some of the components that make oil-free compression possible, such as active magnetic bearings (AMBs), have existed in the marketplace for more than three decades. However, for various reasons, they failed to gain acceptance by the majority of oil and gas operators.

This has changed in recent years, as advancements in AMBs, along with other important building blocks of mechanical drivers, has led to the development of robust and reliable oil-free compression systems that offer low OPEX, enhanced operating flexibility, and minimal weight and space requirements.

An overview of oil-free compression trains

As the name suggests, an oil-free compression train refers to a combination of rotating equipment used for gas compression for which oil is not required. In conventional compression systems, oil is used for lubrication and cooling purposes in the bearing system that supports the rotors. It is also required in the gearbox, which is used when the compressor and the mechanical driver are operating at different speeds.

In recent years, the evolution of high-speed motors and variable frequency drives (VFDs) has enabled the development of reliable electric drives that can achieve high power levels and operate at the same speed

AUTHORS CORNER

JOSÉ L. GILARRANZ R. joined Dresser-Rand in 2002 and, at the time of writing this article, was the manager for Technology Development & Commercialization of the DATUM ICS & Subsea Compression Product lines. Previously, Gilarranz was a Senior Aero/Thermo Engineer at D-R. Prior to joining Dresser-Rand, he worked as a rotating equipment engineer for Lagoven S. A. in Maracaibo, Venezuela. Gilarranz received a B.S. in Mechanical Engineering from the Universidad Simón Bolívar and a M.S. and Ph.D. in Aerospace Engineering from Texas A&M University. He is a member of ASME, AIAA & ΦΚΦ. He has authored or co-authored 25 technical papers and 15 U.S. patents.

TROY JAMISON is the director of Business Development for Synchrony magnetic bearings, with more than 20 years of experience in the fields of magnetic bearings and power electronics. He holds a degree in Mechanical Engineering from the Georgia Institute of Technology and a MBA from the Kellogg School of Management at Northwestern University.

MAYANK DAVE joined Dresser-Rand in 2012 and is currently the regional manager – Proposal (MEAP). Dave was involved in Technology Development & Commercialization of the DATUM ICS & Subsea Compression product lines. Dave has also published technical papers at various conferences including ADIPEC & SPE O&G events. He received a B.E in mechanical stream (2005) from India and he is currently located in Kuala Lumpur, Malaysia.

DR.-ING. JOACHIM DENK graduated from the Institute of Automatic Control Engineering at Technical University in Munich in 2004 with a Ph.D. degree in the field of robotics. In 2004 he joined Siemens Motion Control Systems in Erlangen as a development engineer and became head of the advanced development of drives for machine tool applications and team leader for the Mechatronic Support Service "Machine Optimization and Analysis." In 2014, he was appointed the product manager for SIMOTICS Active Magnetic Bearing-Technology.

as the driven compressors. This, coupled with advancements in AMB technology, along with the use of dry gas seals, has allowed for elimination of the gearbox, oil lubricated bearings, and supporting systems/ components.

A typical oil-free compression train is comprised of a high-speed electric motor (2-pole, induction or synchronous) directly driving the compressor, with each shaft supported by AMBs. A VFD is used to adjust the speed of the motor and allow it to operate at frequencies above the available power grid frequency, typically 50 or 60 Hz. The VFD also allows for variation of the motor speed which improves operating flexibility by giving the compression train the capability to precisely adapt to variations in process requirements without the use of suction or discharge throttle valves, thereby optimizing the use of the available energy, and reducing overall operating costs.

Advantages of AMBs vs. traditional fluid film bearings

Contrary to widespread belief, the AMBs used in oil-free compression solutions have been in use for more than 30 years. Despite this, they are often viewed by operators as an unproven and less reliable alternative to conventional fluid film bearings. Much of this is due to issues that were experienced when magnetic bearings were originally introduced into oil and gas turbomachinery applications in the early 1980s. However, compared to traditional oil bearings, AMBs have many advantages, including:

- **CONTACT-FREE OPERATION** AMBs operate on the principle of magnetic levitation,

TABLE 1 OPEX SAVINGS COMPARISON

OPERATING POWER CONSUMPTION ANALYSIS (4 TRAINS)	VARIABLE SPEED	CONSTANT SPEED	OIL FREE
Total Average Compressor Power (KW)-4 Trains	**71,194**	**73,550**	**71,145**
OEM Tolerance %	4%	4%	4%
Compressor Power -4 Trains	**74,160**	**76,614**	**74,109**
Overall Train Efficiency Calculation			
Switch Gear Efficiency	100%	100%	100%
VFD System (Transformer and Drive)	97.22%	99.20%	97.22%
Motor Efficiency	98.00%	98.25%	98.00%
Average Gearbox Efficiency	98.27%	98.27%	100.00%
Train Efficiency %	**93.63%**	**95.78%**	**95.28%**
Total Average Train Power Consumed (KW)-4 Trains	**79,205**	**79,992**	**77,781**
Auxiliary Power Consumption (Continuous) (kW)/Train			
MV Motor	60	60	60
VFD Converter	46	0	46
Lube Oil System	67	67	0
Active Magnetic Bearing System / Train	0	0	19
UCP Control Panel	2	2	2
Total Auxiliary Power Consumption (kW)/Train	**175**	**129**	**127**
Total Auxiliary Power Consumption (kW)-4 Trains	**700**	**516**	**508**
Total Operating Power Consumption (kW)-4 Trains	**79,905**	**80,508**	**78,289**
Total Average Power Savings (KW) @ OF Compressor	**1,616**	**2,219**	**REFERENCE**
Assumed Cost of Electricity $/kW-hr	0.07	0.07	0.07
Operational Costs/ Day (USD)	**134,241**	**135,254**	**131,525**
Operational Costs/ Year (USD)	**48,997,891**	**49,367,632**	**48,006,719**
Operational Years	**20**	**20**	**20**
Operational Cost @ 20 Years (USD)	**979,957,830**	**987,352,643**	**960,134,382**
Additional Operating Cost (20 Years) (USD)	**19,823,447**	**27,218,261**	**REFERENCE**
Assumed Discount Rate	6%	6%	6%
Operational Cost - Net Present Value @ 20 Years (USD)	**566,592,918**	**570,868,458**	**555,131,379**
Additional Operating Cost - Net Present Value @ 20 Years (USD)	**11,461,539**	**15,737,079**	**REFERENCE**

which means there is no contact between the rotor and the stator. As a result, the bearings can reach very high circumferential speeds. Often, system designs are only restricted by the mechanical strength of the rotor parts (up to 180 m/s). In traditional fluid film bearing systems, the circumferential speed is usually limited to speeds of about 80 m/s.

- **OIL-FREE** AMBs do not require oil for lubrication and can thus be implemented in environmentally sensitive applications. This is in contrast to fluid film bearings, which require special measures to be put in place to protect against oil leakage. AMBs also eliminate the possibility of fouling due to oil migration into the process, making them ideally suited for a range of applications, such as cryogenic expanders and subsea compression.
- **FRICTIONLESS AND RESISTANT TO WEAR** Because they are non-contacting, there is no abrasion or wear, and practically no maintenance requirements for magnetic bearing actuators. Being frictionless also minimizes energy losses, which can be significant in the case of large axial fluid-film bearings.
- **NO LUBE OIL SYSTEM REQUIRED** Fluid film bearings require dedicated lube oil systems and extensive maintenance to sustain optimal performance. This includes changing and disposing of the lube oil and cleaning the oil system with potentially hazardous chemicals. Additionally, oil pumps and coolers in the lube oil system increase energy costs. In contrast, AMB systems do not require a lube oil system, which reduces OPEX and eliminates chemical disposal costs. Elimination of the lube oil system also results in a reduction of the number of compression train auxiliary systems, which may become single points of failure, leading to machine shutdown.
- **ELIMINATION OF GEARBOX** In a drive train where the motor and compressor have the same power rating, the shaft diameter of the motor will usually be larger than that of the compressor. Since the circumferential speed of the fluid film bearings at the compressor is typically already at its limit, a gearbox is required to ensure that circumferential speed of the motor's fluid film bearings is not exceeded. Magnetic bearings have a higher maximum allowable circumferential speed. Therefore, the motor and compressor can rotate at the same speed, which eliminates the need for a gearbox, as well as physical space requirements.
- **ACTIVE DAMPING** Like other types of bearings, AMBs provide stiffness and damping to the rotor system; however, unlike other bearings, the AMBs allow the stiffness and damping to be adjusted (by the AMB controller). The controller in the AMB can, therefore, be used to introduce

significant damping into the system at critical speeds, allowing for the design of API-compliant machines with a very wide speed range (typically being able to run continuously between 10 and 105% speed).

- **DIGITALIZATION** Magnetic bearings enable improved health monitoring by delivering information about the rotor position and bearing forces. Therefore, the AMB system can determine the disturbance forces at the compressor and the motor rotor. As a result, even small variations in the process condition become detectable by the bearing without additional equipment. This enables operators to implement condition-based maintenance strategies. With an approved connection to the AMB system, the client can even access data on the performance and health of the compressor train remotely.

Oil-free vs. fluid film bearing compression train comparison

Non-hermetically sealed oil-free compressor trains utilizing AMBs can provide numerous advantages compared to traditional fluid film compression systems, particularly when it comes to train power consumption, weight and footprint, and operating flexibility. Each of these is discussed in greater depth below.

Power consumption of motor-driven compressor trains is a critical variable that has significant implications for facility OPEX. Because of this, it should be carefully evaluated when selecting a compression solution.

Take, for example, a hypothetical compression facility consisting of four trains, each handling one-quarter of the total expected capacity (i.e., 4 x 25%). In this type of facility, operators have multiple options for driving centrifugal compressors. The table below provides a detailed breakdown of the power consumption of a 1) a traditional compression train using variable speed motors, 2) a traditional compression train using a constant speed motor, and 3) an oil-free compression train utilizing a high-speed motor.

In this scenario, the high-speed motor utilizes AMBs, while the variable and constant speed motor options utilize oil bearings and a speed increasing gearbox. The motor rating for this application is approximately 19-20 MW. Induction technology was selected for the high-speed motor, while synchronous technology was selected for the conventional driver configuration.

The table contains the average power consumption for each one of the train configurations considering six different expected operating points defined for a specific field, which represented the changes in the inlet and discharge pressures and the associated flows for that field during its 20-year life. The average compressor power consumption was taken into account for this calculation, assuming that the compressor is operating at each one of the process conditions for the same amount of time within the 20-year period.

As seen in table 1 on page 43, when the compressor power is considered, along with the train mechanical losses and the power consumption of the auxiliary systems, the oil-free compression solution provides OPEX cost savings of ≈US$19.8 million over the traditional variable speed compression solution and ≈US$27.2 million over constant speed compression train over the 20-year period. Considering a discount rate of 6%, the net present value of the above referenced savings over the 20-year period are US$11.5 million and US$15.7 million respectively.

As mentioned previously, the OPEX calculations are affected by the cost of the electricity, so special care must be taken to evaluate with the correct rate. One factor that is not accounted for in the data shown on the table is the removal of the need to store, transport, maintain, and dispose of the oil that is required for the conventional solution. The costs associated with these activities may become large when the compression facilities are located in remote locations.

Weight and footprint

Footprint and weight are other key factors that need to be taken into account when evaluating compression solutions. For brownfield projects, footprint is especially critical because limited space is often available. The load capacity of existing cranes could also be a limiting factor in terms of skid weight. For greenfield projects, the use of compact trains will help to reduce the overall plot plan of the facility and lead to a reduction in the mechanical completion efforts.

To illustrate the footprint and weight savings offered by an oil-free train solution, we will examine two compression trains with a nominal power rating of 19-20 MW: 1) an oil-free train (High-speed induction motor+compressor) and 2) a traditional compression train (variable speed synchronous motor+gearbox+compressor). The figure below shows a 3D representation of both options.

Overall, with auxiliary systems included, the oil-free compression train has a reduced footprint of 657 sq.ft. (61 m^2) and a lower weight by 52.9 tons (48 tonnes). For the previously mentioned compression facility

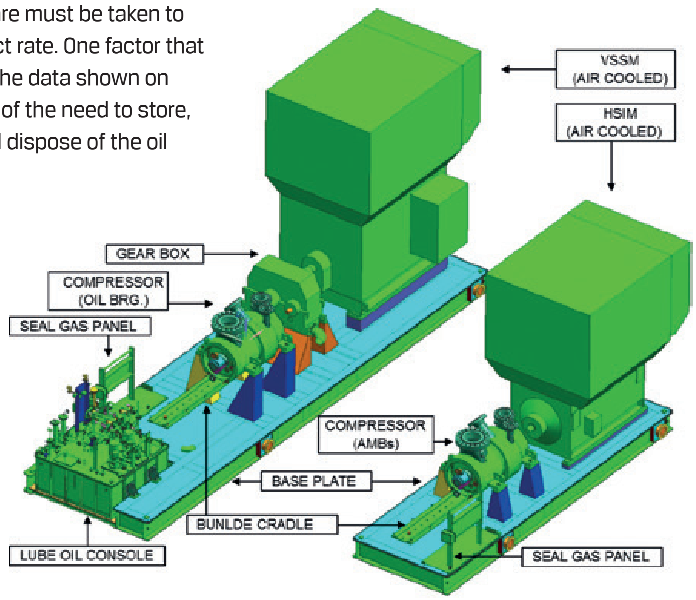

FIGURE 1
Typical arrangement of an oil-free compression train.

TABLE 2 FOOTPRINT AND WEIGHT COMPARISON

LOCATION	EQUIPMENTS	HSIM+COMPRESSOR		VSSM+GEAR+COMPRESSOR	
		Footprint (m^2)	Weight(kg)	Footprint (m^2)	Weight(kg)
Motor-Compressor Skid	Electric Motor	Included	Included	Included	Included
	Speed Increasing Gearbox	N/A	N/A	Included	Included
	Compressor	Included	Included	Included	Included
	Seal Gas Panel & Piping	Included	Included	Included	Included
	Lube Oil Console & Piping	N/A	N/A	Included	Included
	Train Base Plate	Included	Included	Included	Included
Compressor Train		**39**	**100923**	**77**	**141756**
Local Electrical Room	Transformer	Included	Included	Included	Included
Local Electrical Room	VFD Cabinet	Included	Included	Included	Included
Local Electrical Room	Braking Resistor Bank	Included	Included	N/A	N/A
Not Required	Main Grid Filter	N/A	N/A	N/A	N/A
Not Required	Harmonic Filter	N/A	N/A	N/A	N/A
Local Electrical Room	Exciter Panel	N/A	N/A	Included	Included
Electrical Auxiliary System		**49**	**72850**	**45**	**71400**
Field	Lube Oil - Air Cooler	N/A	N/A	Included	Included
Field	VFD Cooler	Included	Included	Included	Included
Main Skid/Field	Gas Seal Conditioning Skid	Included	Included	Included	Included
Field Auxiliary Equipments		**17**	**9000**	**47**	**19144**
Safe Zone	Unit Control Panel	Included	Included	Included	Included
	AMS Panels	Included	Included	N/A	N/A
Control Room Equipment		**4**	**2900**	**1**	**1500**
TOTAL FOOTPRINT (m^2) & WEIGHT (mTons)		**109**	**186**	**170**	**234**
SAVINGS / Train		**(61)**	**(48)**		

with four compression trains, the equivalent footprint, and weight savings would be roughly 2626 sq.ft. (244 m^2) and 212 tons (192 tonnes), respectively.

Operating flexibility

Oil-free compression trains are also beneficial in that they offer wide operating ranges in terms of speed variation. Much of this is due to the use of AMBs, which provide the capability to adapt the stiffness and damping characteristics of the rotor system, leading to improved rotordynamic behavior. The AMBs allow the trains to operate continuously at very low speeds, extending their speed range well below the typical 70% minimum speed limit that applies to most compression trains using oil lubricated bearings.

Running at very low speed is often challenging for oil bearings due to breakage of the oil film between the journal and bearing pads. Furthermore, because the stiffness and damping characteristics of the oil bearings cannot be adjusted, the machine has to run with sufficient separation margins from potential rotor critical speeds.

The work of Kümmlee et al. provides a detailed example of the benefits of the application of high-powered, oil-free compression to a gas field which has shifted from a free flow state to a compression state over several years of operation of the depleting field. The introduction of the oil-free compression solution to the field development provided significant energy savings, as it could support the lower compression ratio phase by running at very low speeds utilizing low power levels during the initial phase of the field.

As the natural pressure of the field decreased over time, and the pressure ratio increased, the rotational speed of the compression trains was also increased. When the compression needs approached the maximum speed limits of the initial compression train configurations, re-bundling of the existing compressor allowed the field operator to continue to produce from the field even though the pressure ratio had increased.

In highly dynamic applications like this, wide compression rotational speed ranges are necessary. Such large variations (between 20 - 105%) are typically only possible if the compressor and the motor driver utilize magnetic bearings.

Conclusion

While oil-free compression systems have been around for many years, the technology is still not understood or widely accepted by many throughout the industry. Much of this is due to the issues that were experienced when magnetic bearings were originally introduced into O&G turbomachinery applications in the1980s. However, advances in AMBs and other components now enable these systems to reach very high levels of availability and reliability, making them ideally suited for critical rotating machinery applications. These types of systems are a key enabler for the development of unmanned or normally unmanned installations due to a drastic reduction in maintenance requirements and the availability of predictive maintenance capability built into the magnetic bearings. The systems are also well suited for applications in hostile environmental conditions like deserts and extremely cold regions. CT2