MAGNETIC BEARING IMPROVEMENT PROGRAM AT NOVA

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ABSTRACT

Nova Gas Transmission Ltd., located in Alberta, Canada, has lead the way in the application of dry gas seals and magnetic bearings to centrifugal compressors in gas pipeline service. The introduction of magnetic bearings in the NGTL system started in 1986 and to date some 34 units were installed. There are presently 31 units running with magnetic bearings due to some units being retired.

It was part of NGTL vision to pursue the application of technologies holding promise of increased efficiencies for the pipeline. The installation of units with magnetic bearings had coincided with a period of rapid expansion of the pipeline in which there were limited resources and time available to assess equipment performance. Well into the magnetic bearing program, challenges associated with the magnetic bearing systems started to accumulate to a point where a serious study was warranted. These were in essence, the incidence of unit shutdowns, failure of components, and ultimately some instances of internal rubs of the rotating elements of the compressors.

A complete technical audit of the magnetic bearing installed base at NGTL was conducted to evaluate potential improvements to the system, improve the knowledge of NGTL personnel in the relevant technical aspects, and set the foundation for on-going management of the technology.

This audit effort pointed out several areas for improvement and a number of remedies were selected for implementation; mostly changes in the control system design, auxiliary bearing layout, and quality control of the installation.

The changes proposed have been implemented in 18 units during 1995, with some other 6 planned for 1996. The results were excellent with the reliability of the upgraded units reaching virtually 100%. It should be pointed out that these 18 units have now accumulated 22,000 hours in service throughout the year.

The most important part of this program is however, the Quality Control of the installations. We can say most of our problems in the past could certainly be attributed to poor quality control and should not be seen as an indictment of the magnetic bearings.

There is optimism about the magnetic bearing performance and the long term benefits of using this technology.

PROBLEMS OVERVIEW

A number of nuisance shutdowns occurred which can be attributed to inconsistency in the tuning procedure of the control system. A less than robust control system was not able to retain control when operating conditions changed. Several tuning exercises on each unit eventually lead to damage of the electronic card traces, making the system even less reliable.

Electrical noise in the control cabinet also eroded the available dynamic capacity for most units. In some extreme cases, over 50% of the capacity of the system was taken up to deal with noise.

For some units, which operated at higher speeds, nuisance shutdowns translated into severe damage to the internals of the compressor due to shaft whirl on the auxiliary bearings during coast down. This forced the operation of these units under speed
restriction in several cases. Also, it was clear that the dynamic capacity of the bearings for these high speed units was running close to its limit. This was because an unforeseen problem of shaft thermal growth forced the tuning of the units in class B, further reducing the dynamic capacity.

Several amplifier failures also plagued the system. It was determined that the amplifier efficiency was low with consequent excessive heating of components. Poor choice of components also resulted in several failures of capacitors.

THE AUDIT PROCESS

The process started with an assessment of the problem with the help of an independent engineering firm, A.D. Little. The report from this work suggested further analysis of several potential improvements to the system. A decision was made to do a complete technical audit of the installed base of magnetic bearings.

The audit was conducted by NGTL Engineering and Performance Testing personnel and supported by representatives from University of Virginia, Magnetic Bearings International (MBI), Societe Mechanique Magnetique (S2M) and Cooper Bessemer Rotating Equipment. A detailed report on the as-found condition of the units was submitted by UVA.

S2M submitted an independent report on their recommendations for improvements which became the core of the upgrade program, which is now in the implementation phase.

The audit results attempted to "distinguish between problems that are characteristic of an emerging technology and those which are somehow fundamental to magnetic bearings specifically." The audit "did not uncover any glaring design shortcomings in the bearings except, perhaps, for the dynamic performance of the thrust bearing. Instead, it was found that the rotor dynamic design of the compressor in conjunction with the non-linearities inherent in magnetic bearings presents a fundamental sensitivity to surge and other sudden, transient overloads and that the existing bearing design represents a fairly good effort at mitigating this sensitivity. The recommended changes each provide incremental improvements in bearing performance which, when taken together, should lead to sufficient advances in availability to meet or exceed that attained with oil film bearings."

SOLUTIONS AND THE UPDATES PROGRAM

The following upgrades were selected for their expected impact on magnetic bearing system reliability and were supported by a cost/benefit analysis. They are grouped in two phases. Phase 1 consists primarily of controls and dynamic capacity improvements. Phase 2 consists of mechanical protection improvements. These improvements are all consistent with standard production features routinely applied by S2M.

Phase 1 Improvements (not in any particular order)
1. Electrical Noise Assessment and Action
2. Power Amplifier Upgrade Or Replacement
3. Class A Control On All Axes
4. Purge and Cooling Air Capacity Improvement (where necessary)
5. Implement Gain Limit with Phase Lead
6. Notch Filter Adjustment Re-range
7. Flux Feedback Reconfiguration
8. Tilt and Translate (TNT) Control Implementation (where required)
9. Quality Control and Assurance Measures
10. Dynamic Testing (vibration, balance, consumed and reserve capacity) and Thermal Growth Verification

Phase 2 Improvements (not in any particular order)
1. Implement 4 Ball Bearing Protection Design
2. Dampening Ribbon Mounting For All Ball Bearings
3. Preload System Improvement On Outboard Angular Contact Ball Bearings
4. Implement Increased Capacity Outboard Ball Bearing
5. Bearing Cable Upgrades

DETAILS: PHASE 1 IMPROVEMENTS

1. Electrical Noise Assessment and Action

Assess the electrical noise level and impact on available dynamic capacity represented by consumption of available PWM duty cycle on the amplifiers when the shaft is statically levitated. Identify root causes and take corrective action. The benefit is restoration of wasted dynamic capacity.

2. Power Amplifier Upgrade

The requirement to complete and provide long term support for the installed base of amplifiers prompted NGTL to continue the program with a replacement amplifier of a more recent design. It required repackaging in order to have the same footprint as its predecessor.

The benefits of the replacement amplifier in comparison to its predecessor are lower electrical noise levels, higher accuracy current sensor with offset compensation for temperature variation, reduced switching delay, lower voltage overshoot, lower internal losses, load short circuit protection and total command/power stage isolation. The amplifier hardware also provides a 4 to 1 cost reduction ratio in spare parts carrying costs. This results from combining all of the bearing and air gap specific circuits on a single flux measurement piggyback board, which attaches to the main amplifier circuit board.
In addition, the replacement amplifier circuitry linearizes the force/current relationship. The tangible benefit is that Class A control bias currents are lower than in the non-linearized condition.

3. **Class A Control On All Axes**

Implement Class A control on all axes, including the thrust bearings. The benefit of Class A control is approximately 2 times increase in dynamic capacity compared to Class B control, as well as elimination of the Class B linearization boards and their associated electrical noise. This increase in dynamic capacity is key to removing performance restrictions and reducing nuisance shutdowns.

4. **Purge and Cooling Air Capacity Improvement**

On units that are sensitive to thermal expansion in the rotor, modify purge air delivery capability in order to contain thermal growth within acceptable limits. The benefit is the allowance of Class A control while accommodating higher thermal losses in the rotor.

5. **Gain Limit with Phase Lead Implementation**

Implement gain limit with phase lead circuits on all axes. The benefit is the handling of excessive loads without loss of control.

6. **Notch Filter Adjustment Rerange**

Rework notch filter boards to reduce the adjustment range of the potentiometers and use more consistent component values. The benefit is reduced sensitivity to calibration drift.

7. **Flux Feedback Reconfiguration**

On units retaining the original power amplifiers, replace flux feedback adjustment potentiometers on the amplifier command boards, with fixed resistors. The component values are pre-calculated and are the same for a given bearing size and air gap. The benefit is elimination of the flux measurement circuit as a source of calibration drift.

8. **Tilt and Translate Control Implementation**

Install Tilt and Translate (TNT) control on the radial bearings. This allows decoupling of the first two rigid body modes in the controller. The gain applied to the translation and tilting modes can then be independently adjusted. The benefit is better utilization of available dynamic capacity with overall conservation if the gain on the less prominent mode can be reduced.

9. **Quality Assurance Checks and Measures**

Verify accuracy of vendor documentation and complete detailed documentation of unit baseline parameters. Thoroughly clean all PC boards with solder flux remover and conformal coat the solder side.

10. **Dynamic Tests**

Run the unit and assess vibration performance, trim balance if necessary and document dynamic capacity usage. Verify thermal growth after adequate heat soaking.

**DETAILS: PHASE 2 IMPROVEMENTS**

1. **Implement 4 Ball Bearing Protection Design**

A single deep groove ball bearing is added between the radial bearing and the dry gas seal at each end of the shaft. This will limit shaft deflection under extreme loading conditions.

2. **Dampening Ribbon Mounting For All Ball Bearings**

The deep groove inner ball bearing carriers are fabricated to include dampening ribbon mounting for the ball bearings. The outer ball bearing carriers are machined to accept dampening ribbon mounted ball bearings.

3. **Preload System Improvement On Angular Contact Ball Bearings**

Install a spring activated preload system for the existing, outer, angular contact ball bearings. The benefit is that the preload force is dependent on the spring constant, which is made consistent through spring selection.

4. **Implement Higher Capacity, Full Complement Ball Bearing Design**

Increase the load bearing capacity of the existing, outer, angular contact ball bearings by removing the cage and adding a full complement of balls. The benefit is greater load bearing capacity.

5. **Bearing Cable Upgrades**

Bearing cables, including magnet, sensor and RTD wires, will be upgraded to replace stainless steel with fiberglass braided armor protection. The benefit is elimination of ground faults due to frayed stainless steel braid and easier handling.
RESULTS AND CONCLUSIONS

Since December of 1994, phase I improvements have been completed on 18 units, with 6 more scheduled for 1996. In the same period, 6 units have undergone Phase II upgrades.

Figures 1 & 2 show reliability data for both magnetic bearing and oil bearing units. It is clear that magnetic bearings have achieved and surpassed equivalent oil bearing reliability in similar applications. The results for the upgraded fleet show reliabilities reaching 99.9%. NGTL is very optimistic about the long term prospects for continuing reliability.

ACKNOWLEDGEMENTS

We would like to acknowledge the efforts of Mr. Greg Farris in compiling reliability data. Also the efforts of NGTL Magnetic Bearing Action Team for their input.

REFERENCES

Figure 1
Magnetic Bearing 12 Month Rolling Statistics

Figure 2
Oil Bearing 12 Month Rolling Statistics