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Operational Experience With A Cryogenic Axial-Centrifugal Compressor

L. Decker[1], A. Kündig[1], K. Löhlein[1], W. Purtschert[1], B. Ziegler[1],
Ph. Lebrun[2], L. Tavian[2], I. Brunovsky[3], and L. Tucek[3]

Abstract

The Large Hadron Collider (LHC), presently under construction at CERN, requires large refrigeration capacity at 1.8 K. Compression of gaseous helium at cryogenic temperatures is therefore inevitable. Together with subcontractors, Linde Kryotechnik has developed a prototype machine. This unit is based on a cryogenic axial-centrifugal compressor, running on ceramic ball bearings and driven by a variable-frequency electrical motor operating at ambient temperature. Integrated in a test facility for superconducting magnets, the machine has been commissioned without major problems and successfully gone through the acceptance test in autumn 1995. Subsequent steps were initiated to improve efficiency of this prototype. This paper describes operating experience gained so far and reports on measured performance prior to and after constructional modifications.

1 Linde Kryotechnik AG - 6422 Pfungen, Switzerland
2 CERN LHC Division
3 PBS - 59512 Velka Bites, Czech Republic

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Administrative Secretariat
LHC Division
CERN
CH - 1211 Geneva 23
Switzerland

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COLD COMPRESSOR DRIVE

Design Approach

Within the last decade, ball bearing technology has improved significantly thanks to the introduction of new materials like ceramics, beside metals, to form mixed material systems, so-called hybrids. Hybrid ball bearings offer longer service life at considerably higher operational speeds than conventional types. In addition they are extremely well suited for permanent grease lubrication. Applications are found in grinding spindles and, closer to cryogenics, vacuum machinery, specifically turbo-molecular pumps. In contrast to cryogenics, these industries produce huge numbers of pieces with corresponding investment potential, highly developed products and excellent knowledge of components in terms of behavior and service life supported by statistics.

When Linde Kryotechnik resumed cold compressor development in 1994, it was decided to make use of this potential rather than develop specific technology. The decision to use ball bearing technology was taken on the grounds that they show low costs comparably to all other alternatives, are impressively simple and reliable, and feature extremely small clearance thanks to pre-stressed bearing arrangement.

Therefore a partnership with an industrial supplier for high-speed spindles with excellent reputation was established. The basic approach was based on the following concepts:

- technological transfer from a branch with high repetition to a one with low repetition,
- design of a machine with standard components as far as possible with the advantage of detailed knowledge of the applied components’ operating limits in advance,
- low manufacturing costs for a special application,
- establishing a number of standard frame sizes in order to cover multiple stage applications like CERN-LHC, DESY-TESLA, NIFS-LHD
- service friendliness by using standard components.

Key features

The compressor is driven by an asynchronous electrical motor with frequency converter for variable speed, up to 700 r.p.s. working at ambient temperature. The voltage at defined maximum load was selected to be 130 V in order to minimize the risk of motor damage due to reduced dielectric strength of gaseous helium at low operating pressure. In addition special isolation material was chosen.

The axial and radial hybrid ball bearings operate at ambient temperature with the fixed point of the axial bearing next to the compressor wheel. They are life lubricated with grease, in order to minimize the risk of process contamination. The total amount of grease is only a few grams. The hybrid ball bearings have demonstrated their excellent suitability to this application. Unlike oil, gas or magnetic bearings during transients, they are characterized by a high stiffness and extremely precise radial and axial positioning. This results in a fixed positioning of the compressor wheel, whether off duty or in operation. Moreover, they require neither emergency bearings nor complex utilities as bearing gas or uninterrupted power supply.

The control system requirements are as for standard machinery. Therefore all functionality can easily be integrated into a high-level control system („open“ system).

The total speed range is clearly below the whipping speed of the rotor including shaft and compressor wheel.

Protection from air in-leakage is secured by a vacuum guard integrated in the housing so as to provide easy access for maintenance.

The number of electrical feedthroughs has been kept to a minimum of 11 (4 for electrical power, 4 for temperature sensors, 3 for speed pick-up), i.e. much fewer than for magnetic bearing systems.

The housing, which features all-welded water cooling passages, is compact, with an outer diameter of 200 mm., and a height of 400m.

Ambient-temperature

Prior to “cold“ operation, short- and long-term tests were performed at Linde’s premises with the following aims:

- Measurement of vibrations and imbalance of dummy wheel and vibrations of housing,
- Verification of calculated first resonance frequency (nondestructive testing),
- Check of strength at low operating pressures,
- Suitability of lubrication with grease at low operating pressures,
- Verification of predicted ball bearings’ service life of more than 8'000 hours.

For this purpose, a test stand with low pressure vessels and the necessary instrumentation was specially built. The complete assembly showed extremely low vibrations, which are in accordance with highest class of precision standards. The maximum speed was checked to be far below the first resonance frequency. No disruptive electrical breakdowns were observed. After more than 8'000 operating hours the condition of bearings and grease was analyzed with excellent results.

These tests also enabled to identify potential for further improvements.

COLD STAGE

Design Approach

The unit realized is based on CERN’s specification. The main design data are:

Flow rate	18	g/s
Suction pressure	10	mbar
Discharge pressure	30	mbar
Pressure ratio	3	
Suction temperature	3.5 to 4.4	K
Isentropic efficiency	$\geq$ 60	%

Thermodynamic, aerodynamic and mechanical design, as well as manufacture of the cold stage, were performed by PBS, Velká Bites, Czech Republic, a company which has been collaborating with Linde for years.

The characteristics of the cold stage are:

Wheel diameter :	118 mm
Wheel shape :	backswept
Diffus :	bladed
Thermal intercept :	None

The machine was designed to have a comfortable working field in view of multistage application for the LHC. Emphasis therefore was put on operational flexibility rather than efficiency alone.

Tests at CERN

In autumn 1995, the system was installed and successfully commissioned and tested at CERN. As reported in [1] the efficiency at design conditions was 57 %, i.e. 3 % lower than predicted. The operating field is wider than expected.

One main problem occurred during commissioning, namely electrical breakdown in the motor housing at the feadthroughs, which was easily corrected.

Based on the results of these tests, it was obvious, that the efficiency of the machine could be improved by reducing the heat inleak through the housing below the measured 51 W, as well as by optimizing the geometry of the bladed diffuser.

Consequently another series of tests were performed in the spring of 1997 with modified housing and diffuser. The reduction of heat inleak from 51 to 41 W resulted in an increase of efficiency by 2 %, while the better adapted diffuser's contribution was 5. In total the machine as it is now shows an efficiency of 64 %. The working field is somewhat reduced but still very comfortable.

Due to competing tests of other cold compressor prototypes, and main usage of the facility for magnet tests, the number of operating hours achieved is still small.

CONCLUSION

The cryogenic helium compressor supplied by Linde, based on an axial-centrifugal impeller and hybrid ball bearings operating at ambient temperature, has confirmed -after optimization of housing and diffuser, and life-time service testing of the bearings- its good performance and technological suitability for large capacity 1.8 K refrigeration.

REFERENCE

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