ACTIVE MAGNETIC BEARINGS SYSTEM UPGRADE FOR LHC CRYOGENIC COLD COMPRESSOR, RADIATIONS MITIGATION PROJECT (R2E)

P. Arpaia, University of Napoli Federico II, Naples, Italy; CERN, Geneva, Switzerland
M. Girone, University of Sannio, Benevento, Italy; CERN, Geneva, Switzerland
M. Hubatka, MECOS AG, Winterthur, Switzerland
M. Pezzetti, CERN, Geneva, Switzerland

Abstract

During the normal operations of the Large Hadron Collider (LHC), the high hadrons flux level induced several Single Event Errors (failure caused by a particle passing through a sensitive device) to the standard electronics installed underground. Such events perturbed LHC normal operation. As a consequence, a mitigation plan to minimise radiation-induced failures and optimise LHC operation was started: Radiation to Electronics (R2E) mitigation project. The full paper will deal with the mitigation problem for LHC/Point 8 equipment and the main improvements for the equipment in LHC/Point 4, with special focus on the controllers for the Active Magnetic Bearings (AMB) used in the IHI-LINDE cold compressors. A proven approach based on frequency response analysis to assess the cold compressor mechanical quality will be presented. The hardware and software design, implemented to increase the global reliability of the system, will be highlighted. A corresponding experiment protocol was developed at CERN in collaboration with the Swiss Company MECOS and the Italian Universities of Sannio and Napoli Federico II. Preliminary experimental results showing the performance of the proposed approach on a case study for the cold compressor stage 1 in Point 4 will be finally reported.

INTRODUCTION

The level of the flux of hadrons with energy in the multi MeV range expected from the collisions at the interaction Points 4 and 8, which are not in the center on the cavern, unlike Point 1,2 or 5, (Fig. 1) will induce Single Event Errors (SEEs) in the standard electronics present in much of the control equipment. Furthermore, a risk of SEEs induced by thermal neutrons cannot be excluded. In the long-term, such events could perturb the LHC operation, possibly leading to critical situations for the machine elements and subsequent important downtime [1].

In particular this paper is focused on the impact on the electronics of MECOS Active Magnetic Bearing controllers. The high-performance bearing are applied in the LHC cryogenic cold compressor equipment in order to satisfy the need of covering vibration, stability and robustness in nominal operation and transition phases. In fact, magnetic bearing-equipped machines are suitable for unlimited, reliable and safe operation even in the presence of "large" residual unbalance levels [2]. Those high performances requires deeper user understanding of the magnetic bearing technology and a commissioned system cannot be modify so easily. The R2E Mitigation Project foresees shielding or relocating the equipment sensitive to radiation, which is presently installed in these critical areas, into safer areas. The majority of these mitigation activities were performed, in three phases, between (date) in Point 4 and between (date) in point 8. This document reports on these mitigation activities and their associated improvements. It presents the strategy applied, the enhancements on the modification for the new version of AMB used in the IHI-LINDE cold compressors which were needed to be replaced within a longer distance (from 20 m to 45 m).

STRATEGY APPLIED

The first LHC run took place from 2010 to 2013, on 14th February 2013 the Long Shutdown 1 (LS1) started. During the LS1 preventive maintenance, upgrade and necessary repairs were performed.

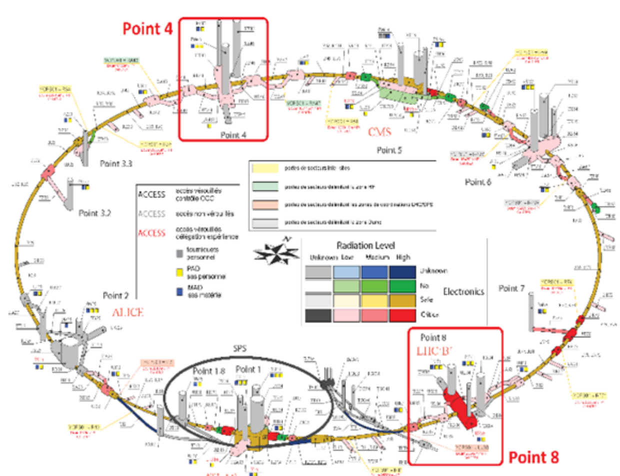


Figure 1: LHC critical areas considered by the R2E Mitigation Project.

A project called Radiation to Electronics (R2E) has been created in 2009 to mitigate the risk of failures due to single events upset (SEU) of the equipment installed in the tunnel and shielded areas. In 2011-2012, due to beam parameters increasing, SEUs had a significant

ISBN 978-3-95450-148-9

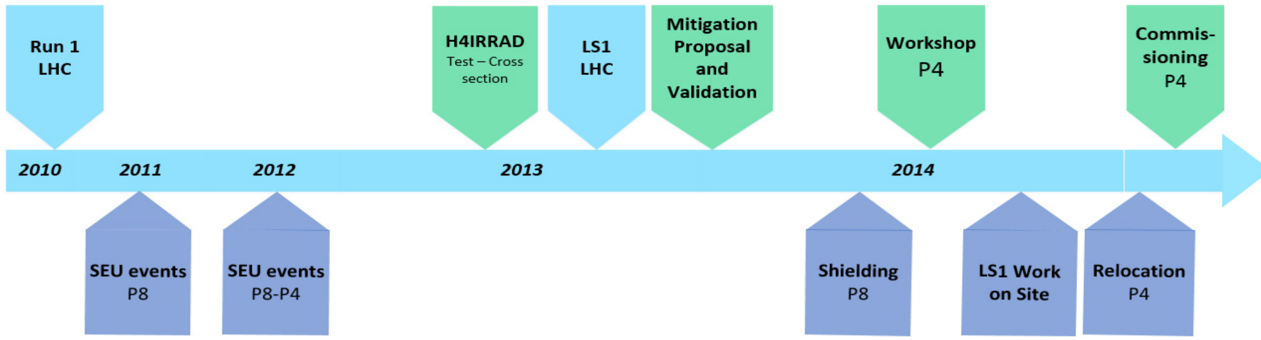


Figure 2: Actions strategy timeline.

impact in P8 and P4. These events caused several equipment failures. On October 2012, in order to determine the failure cross-section due to radiation of specific bulk equipment, a new test area was setup in the H4-beamline of the North Area: H4IRRAD. In this area several tests were conducted and they proved that industrial or commercial equipment are not qualified for radiation and they had to be removed from exposed areas. As a consequence the sensitive equipment located in these areas was relocated to safer areas and protected by new shielding walls (for P8). These mitigation activities were performed mainly during the LS1. Even though the commissioning had very tight constraints it was successfully accomplished.

AMB R&D

In this section, the enhancements on the controlling system for the Active Magnetic Bearings (AMB) used in the IHI-LINDE cold compressors are presented. All the hardware and software improvements were first tested in the CERN control and electricity laboratory, and after several validation tests were implemented in the cold compressor systems in LHC/Point 4. The hardware and the software improvements will be first discussed. At the end the proposed fault detection protocol for the cold compressors will be presented.

Hardware Improvements

Before the installation in the LHC cavern in P4, several tests and measurements on IHI-LINDE spare cold compressors systems (CCS) were performed together with MECOS Company.

Due to the electrical cabinets' relocation, as previously described for R2E project, longer cables (from 20 to 45 m) to connect the cold compressors and the magnetic bearings controllers were needed. Thanks to this project the cabling know-how has been transferred to CERN and the new cables were produced in situ and improved.

In Fig.3 an active magnetic bearing system architecture is schematized and it is possible to notice that two different type of cables are needed for an AMB control system: a cable for position sensors (*blue arrow*) and another cable (*red arrow*) for the levitation magnets (actuators).

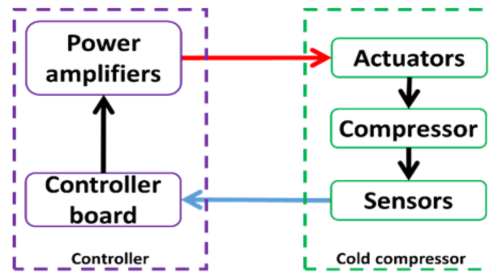
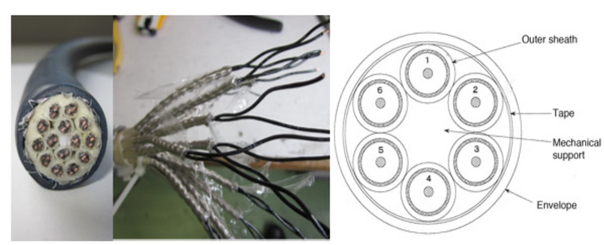


Figure 3: Active magnetic bearing system architecture.

Major attentions were put on sensors cables, because all the processor calculations are based on the position sensors measurements, and high noise levels could lead to system instabilities. In Fig.4.b a section of the existing sensors cable is showed.



a) b)

Figure 4: a) New sensors cables; b) Old sensors cables section.

A different configuration was adopted, and in particular, the following cables were chosen (Fig.4.a): IGUS Chainflex CF12 TPE-14 x 2 x 0.5. In these cables the wirings are twisted per pairs and they have a double shield: one shield per pair and a global shield for the entire cable.

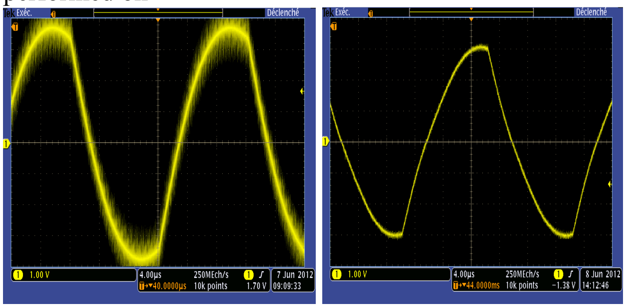
In Fig.5.a and 5.b, position sensor test measurements, performed in CERN control and electricity laboratory, are showed. The measurements were carried out with the old controller (MBC150) and with the old and the new cable respectively, both 20 m long.

It is possible to notice that the overall noise level, with the new cable, is decreased. After these encouraging results, several measurements were performed on the new

ISBN 978-3-95450-148-9

cables and in particular several lengths were tested: from 25 up to 60 m.

The power supply cables for actuators were also changed (CERN NG18-9 x 2 x 1.0) but no tests were performed on



a) b)

Figure 5: a) Position measurement with the old cable: b) with the new cable.

them because, as mentioned, they are not as critical as the sensors cables for compressors controls.

Together with the new cables, new connectors (Amphenol MS4102E), for power supply and sensors, were installed on both the cables extremities and on the new MECOS controller to improve the connections robustness.

Several hardware modifications were also implemented inside the AMB controller (MBC–170A). The internal power supply was removed in order to enhance the system reliability. Instead of 4 different power supplies, one per unit, CERN adopted a redundant system: the 4 controllers were supplied by two independent electrical power systems circuits.

In more, the previous MBC generation needed two different software configurations for the four stages: one type could be used only for stage 1-2 and another type for stage 3-4. CERN, together with MECOS, decided to implement the same configurations for all the controllers, thus helping reduce the down-time of the LHC machine by simplifying the maintenance procedure. Moreover it improves the handling of the spare parts by reducing the number of controllers to be kept in stock.

Software Improvements

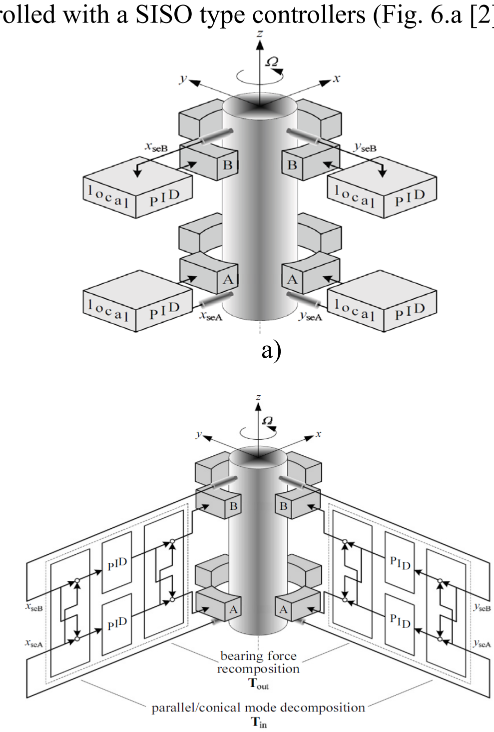
Together with the hardware enhancements, some software modifications were implemented in the supervision and control system for the cold compressors system in P4.

In case of cold compressors failures, on electrical/electronic or mechanical equipment, the entire 1.8 K cold box, and consequently the entire LHC machine is stopped. To restart the system an operator was required to go to the caver and reset the system manually in the electrical cabinet. In order to reduce the operation time a remote controller RESET was implemented on MBC–170A. Thanks to that the operators in P4 cryogenics control room can easily restart the entire cold box.

Together with the remote RESET, a monitoring interface, integrated in the LHC supervision and control panels, was implemented. In particular the axial rotor position and the radial bearings unbalance levels are monitored. The operators, monitoring the abovementioned trends, can avoid potential failures in a reactive manner.

Another enhancement, aimed to facilitate the control and the supervision system is the implementation of a customized analog output (4-20 mA) to monitor the compressor rotational speed. The maximum current (20 mA) is set according to the maximum compressor speed: 240, 500, 833, and 833 Hz respectively for compressor stages from 1 to 4.

In conclusion, a different control strategy on cold compressor stage 1 (CCS1) was adopted. All the cold compressors installed in the 1.8 K cold boxes are controlled with a SISO type controllers (Fig. 6.a [2]).



a)

b)

Figure 6: a) AMB controller architecture SISO; b) Parallel/conical modes control.

Due to the CCS1 intrinsic physical properties (higher gyroscopic effects due to impeller dimensions, first bending modes close to nominal operational frequency), during the controller parametrization, some difficulties in tuning the different SISO controllers independently were found. For this reason a MIMO strategy was applied (Fig. 6.b [2]). Such a controller, controls the *parallel* (centre of gravity motion on x and y planes) and *conical* (centre of gravity tilting motion on α and β angles) modes.

Cold Compressors Fault Detection

To evaluate the cold compressor mechanical quality a proven technique based on frequency response function analysis (FRF) has been used. A corresponding

ISBN 978-3-95450-148-9

experiment protocol was developed at CERN in collaboration with the Swiss Company MECOS and the Italian Universities of Sannio and Napoli Federico II. The proposed method will allow, during the LHC ordinary maintenance stops, to evaluate the mechanical quality of the cold compressors through a proactive fault detection.

Thanks to the nature of the active magnetic bearings, the system FRF $H = {}^{Y}\!/_{X}$ can be measured without additional sensors or measurement devices (Fig.7).

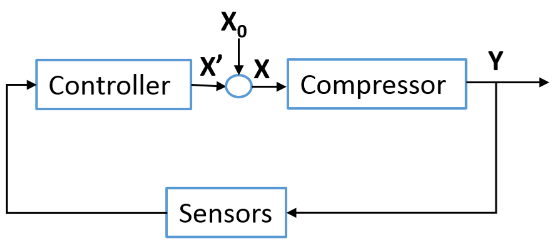


Figure 7: Measurement system architecture.

In particular, the system outputs Y are the rotor position measurements, while the inputs X are the sum of the controller signals (X') and an excitation signal X_0. In Fig.8 a FRF measurement for CCS1, performed in the lab, with the impeller in a vacuum case and in standstill conditions, is reported.

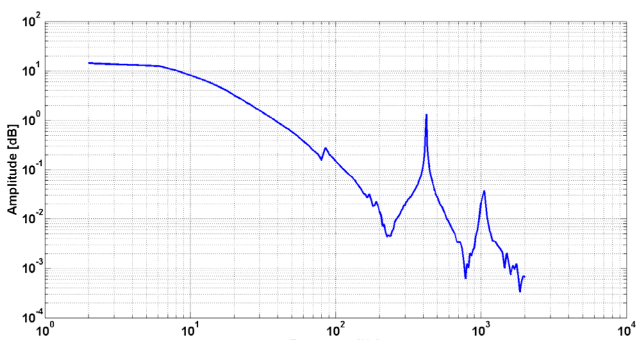


Figure 8: Cold compressor system 1 frequency response function.

During the P4 commissioning phase, FRF measurements were performed on all the cold box stages for both the installations: QURCA and QURCB. In particular, several test campaigns were conducted: a first measurements campaign was conducted for fixed rotational speeds (15, 22, 35 and 45 Hz for CCS1 to CCS4 respectively) at 300 K. Consequently, other measurements were conducted with the same rotational speeds but with the helium temperature was equal to 30 K. Finally a last test campaign was conducted on QURCB speeding up the compressors up to their nominal speed: 240, 500, 833, and 833 Hz respectively for compressors stages from 1 to 4.

During the first two measurements campaign on QURCA, a strange behaviour on CCS1 was detected. A special focus was addressed to the first resonance frequency peaks because from 300 to 30 K, they moved to lower frequencies (Fig.9).

Since the rotor is considered as rigid body, for lower temperatures, and especially for such a temperature gradient, the peaks were expected to move to higher frequencies. In more the CCS1 FRF presented some unexpected peaks at low frequencies, as it is possible to notice in Fig.9.Based on that, the compressor was replaced and sent back to the manufacturer.

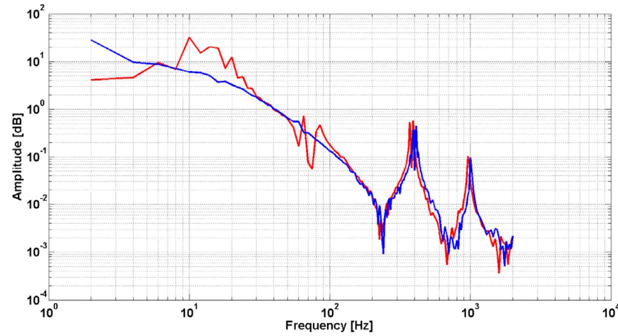


Figure 9: CCS1 installed in P4: frequency response function at 300 K–*blue*– and 30 K –*red*–.

The IHI-LINDE confirmed that some mechanical small problems were present. The same test campaign at 300 and 30 K was then performed on the new compressor (Fig.10). As it is possible to notice the behaviour is completely different from the previous compressor.

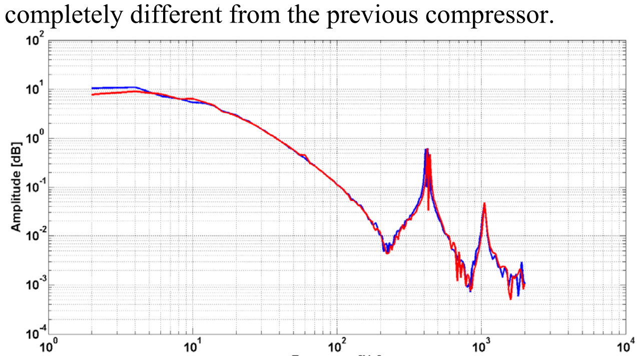


Figure 10: New CCS1 installed in P4: frequency response function at 300 K–*blue*– and 30 K –*red*–.

Thanks to this technique, in a preventive way, a mechanical compressor fault was detected and consequently a potential breakdown was avoided.

CONCLUSION

The work described has enhanced a deep knowledge of the cold compressor process control equipment. Moreover a new improved preventive maintenance plan has been set up based on the cold compressors mechanical quality evaluated by on-line measurement (done through AMB) compared with old one.

ISBN 978-3-95450-148-9

REFERENCES

[1] L. Perrot, "R2E strategy and activities during LS1", CERN Chamonix, 2012.
[2] Gerhard Schweitzer, Eric H. Maslen, "Magnetic Bearings Theory, Design and Application to Rotating Machinery", Springer, Berlin, 2009.

ISBN 978-3-95450-148-9