ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP006

CRYOGENIC TESTS OF THE SPIRAL2 LINAC SYSTEMS

A. Ghribi*, P-E. Bernaudin, R. Ferdinand, A. Vassal[1], GANIL, Caen, France
[1]also at Univ. Grenoble Alpes, INAC-SBT, F-38000 Grenoble, France
[1]also at CEA/DRF/IRIG d-SBT, F-38000 Grenoble, France

Abstract

Two full cool-down of the SPIRAL2 superconducting LINAC have been performed in 2017 and 2018 respectively, followed by a total of around 5 months of tests at 4 K. Several cool-down strategies were tested, in order to minimize 100 K effect on the SC cavities. Helium bath regulations (level and pressure) have been tested and optimized. Effects of pressure instabilities and coupling with the cryogenic plant have also been observed. Cryogenic performances of each cryomodule have been measured. Low-level RF measurements were also performed on all cavities and showed unidentified modulations at frequencies around 5Hz. These turned out to be thermoacoustic oscillations (TAO) on the cryogenic lines, which generate important pressure instabilities. Several solutions to remove TAO and cure these instabilities have been tested and one has been successfully deployed.

INTRODUCTION

The GANIL SPIRAL 2 Project [1] aims at delivering high intensities of rare isotope beams. It consists of high performance ECR sources, a RFQ, and the superconducting light/heavy ion LINAC, accelerating protons, deuterons and heavy ions. The SPIRAL 2 LINAC is based on superconducting, independently phased resonating QWR cavities. There are two types of cavities: 12 low beta cavities housed in 12 cryomodules type A, and 14 high beta cavities in 7 cryomodules type B (2 cavities per cryomodule) [2].

The cryogenic system is crucial to insure stable operation of these cavities. Working at 4.4 K around 1.2 bar, it is composed of a dedicated cryoplant, centered around a HELIAL LF Air Liquide cold box and two Kaeser cycle compressors. The 5000 L main Dewar feeds the 19 cryomodules, located 9.5 m below in the LINAC tunnel. There, 19 valves box (one per cryomodule) regulate the cryogenic fluids distribution (4.4K liquid helium and thermal screen 50K, 15 bar gas helium) through 5 cryogenic valves (one for the input and the output of each circuit, plus one dedicated to the liquid helium cooldown input). The valves boxes are connected one to the next, their assembly forming the cryogenic lines in the LINAC tunnel. The vertical connection to the main Dewar is located in the physical center of this line, hence of the first type B cryomodule. For more details on the cryogenic system of SPIRAL 2, please refer to [3].

COOL-DOWN AND THERMALISATION

SPIRAL 2 superconducting cavities are made of unbaked bulk niobium and are therefore sensitive to the so called Q disease effect : If, during cool down, a cavity spends too much time (more than 60 minutes) at a temperature between 50 K and 150 K, the risk of trapping hydrogen and forming niobium hydrides at the surface increases. This, in turn, can significantly degrade the cavities performances [4]. Therefore, temperature drop slope has to be taken into account in order to avoid this effect. The cool down procedure that has been considered so far prioritise the two end cryomodules (CMA12 and CMB07) in order to thermalize the return line. Then, cryomodules are cooled down from the end to the center of the return line in groups that respect the symmetry of the heat load distribution in the LINAC. Figure 1 shows the time that cryomodules spent within the accepted limit during 2017 and 2018 cool down. This shows the difficulty of controlling the cool down during the commissioning phase where automation and control process is still being tested and optimized. Due to the lack of cold bypass at the ends of the LINAC, the first cryomodules are slow to cool and usually hit the time limit. Once the return line is thermalized and the rest of the LINAC is cold, one has to warm up these cryomodules (room temperature regeneration) and cools them down again to stay within the specifications and avoid the Q disease effect. For the rest of the LINAC and after careful optimisation of the process, the specifications are reached.

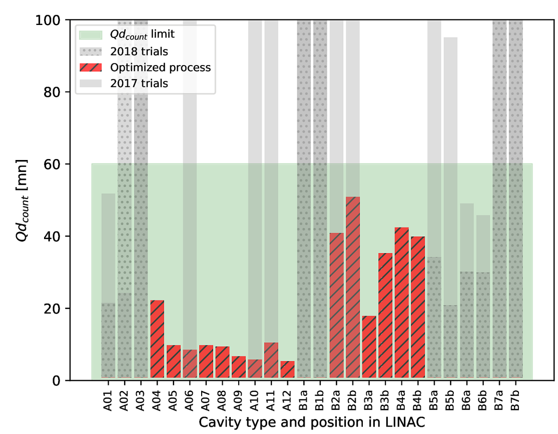

Figure 1: Q disease counter distribution across the LINAC for 2017 and 2018 cool down. The x axis shows both positions (1,2,..) and type (A and B) of the cavities.

REGULATIONS AND OPERATION

SPIRAL 2 cryogenic operation is ensured by a dedicated cryogenic system [3]. The latter ensures the required stabilities in both temperature and pressure as well as the temperature drop requirement during cool down. Temperature is

* adnan.ghribi@ganil.fr

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP006

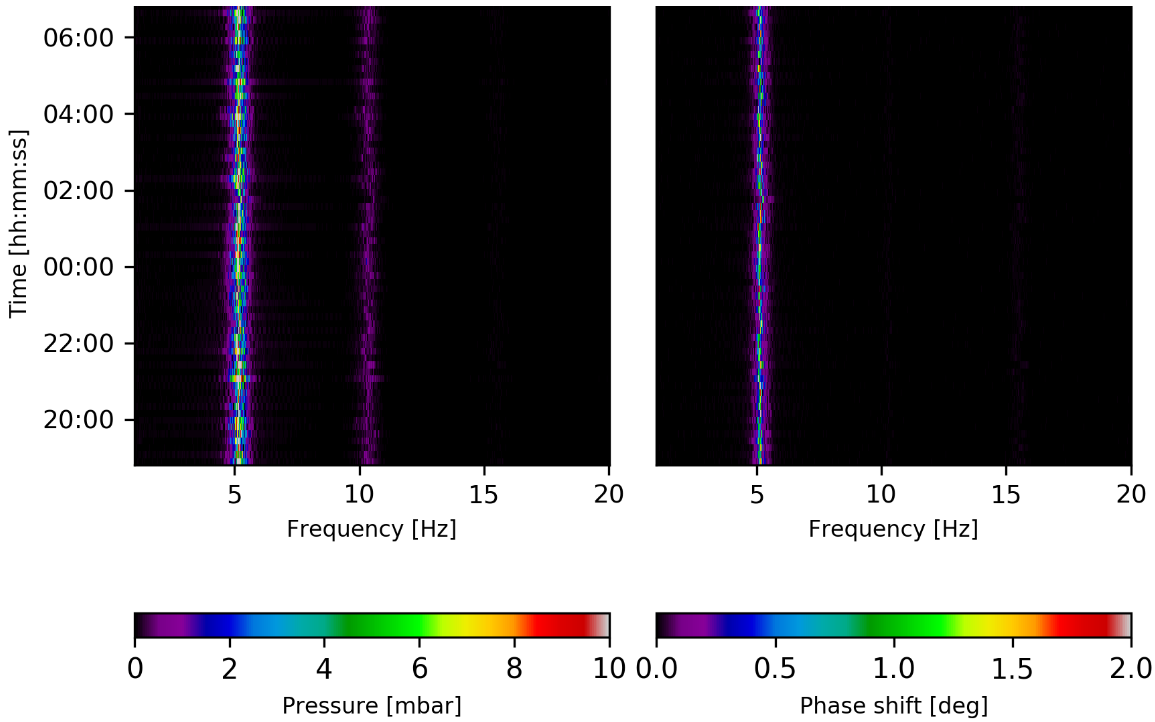

Figure 2: Simultaneous measurements of liquid helium bath resonance frequencies (left) and RF phase shift modulation frequencies (right) for cryomodule A01. The two figures show a strong correlation between liquid helium bath pressure and RF phase shift.

kept stable by ensuring that all cavities are in completely submerged by liquid helium at all times. Pressure in the cavities liquid helium baths applies on the cavities surface and can induce small changes in their shape. However small, this slight dynamic deformation translates into a dynamic change of characteristic impedance and thus the detuning of the cavities with respect to the frequency of operation. At some detuning level, low level RF correction and embedded frequency tuning systems correction [5] can not compensate, leaving the cryogenic system as the last resort to ensure stable RF operation (if instabilities are due to pressure). For the cryogenic system, there are two levels of pressure regulation. The first one is made possible by the cryoplant and translates in a stable pressure of the common liquid helium Dewar and the common cold helium return line to the cold box. The second one is located at each cryomodule (the cryostats where cavities are located) and is ensured by dedicated valves boxes (one for every cryomodule). For every cryomodule, liquid Helium (LHe) level regulation is made by a valve located at the LHe bath top feeding line while pressure regulation is ensured by a valve located at the output return line of the LHe bath. These two valves behaviour can be linked and their tuning has to be made such as this coupling is reduced.

Liquid Helium Level Control

Once the clowdown is finished, the level regulation has to stay within the acceptable range of ± 5% around its nominal value of 90%. As long as liquid level is sufficiently high to fully immerse the superconducting cavities, there is no need of any highly accurate regulation. Consequently, we chose to tune the PID responsible for the level regulation so that it acts smoothly on the input valve. This setting was chosen in order to reduce the pressure variation due to valve inlet opening.

Cavities Liquid Helium Bath Pressure Control

Figure 3 shows a 12 hours acquisition of cavities bath pressure fluctuations in the LINAC during 2017th cool down. The optimized PID did not allow at that time to correct periodic bumps in the pressure. We also noticed that the return line (supposedly saturated helium) showed non uniform high temperatures compared to the temperature of saturated helium at atmospheric pressure. This translates in unusually hight temperature of the common helium return line to the cold box. Low level RF measurements showed a 6 Hz modulation of the phase shift between input and output signal. Altogether, this suggested the presence of a phenomena that we couldn’t see and that would have effects on all cavities.

During Sep. 2018th cool-down, we began a hunt for fast fluctuations thanks to an accelerometer, two fast relative pressure transmitters and one absolute pressure transmitter that we moved in every cavity location in the LINAC. These measurements were done simultaneously with RF measurements using the same National Instrument Compact DAQ in order to have the same clock.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP006

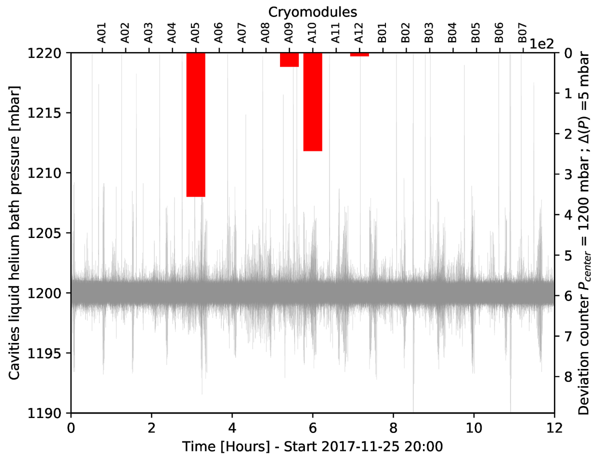

Figure 3: Measured pressure stability of cavities helium baths during 2017 cool down. Data have been acquired from 2017-11-25 20:00 to 2017-11-26 08:00 with a sampling rate of 300ms. The upper plot shows a counter for pressure going beyond the limit of ±5 mbar. The top x axis shows the counter for every cryomodule.

Different accelerometer measurements at different locations did not show any correlation with RF measurements nor did they show any resonance with a significant amplitude at any of the critical mechanical mode frequencies of the cavities. On the opposite and as it can be seen in Figure 2, relative pressure measurements showed clear correlations with RF measurements. These measurements have been repeated at every location and for every cryomodule. This showed that pressure fluctuation resonance frequencies vary between 4 and 6 Hz.

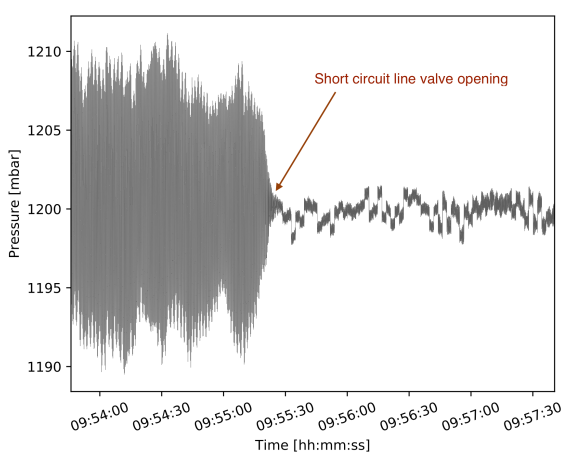

Figure 4: CMA05 liquid helium bath pressure stability before and after short-circuit line correction.

This behaviour has been identified as thermoacoustic oscillations in the LINAC. This phenomenon occured mainly at a room temperature tapping of the return line of every valves box. This tapping is used to bypass the cold box for certain cases. Since then, different strategies have been tested to correct this effect :

- Piston correction : introducing a piston in the line to change its effective inductance.
- Buffer correction : adding different volumes in parallel to the line in order to change its effective capacitance.
- Line correction : adding a short circuit between the return line tapping and the phase separator of the cryomodule. The purpose here is to balance the pressure between the LHe bath outlet and the warm line.

These solutions have been tested for different operation conditions (liquid helium level, bath pressure, heat load). So far, only the line correction proved to be efficient in all cases. Figure 4 shows an example of thermoacoustic oscillations damping when activating a line short circuit correction. This solution has been successfully deployed on all cryomodules.

CONCLUSION

Thanks to two full cooldown of the SP2 SC LINAC, strong thermoacoustic oscillations on the cryogenic valves boxes feeding the cryomodules have been discovered and suppressed. The cryogenic system is now operational and ready for RF commissioning of the cavities (planned for the second half of year 2019).

Optimization of the cryogenic system remain nevertheless mandatory, as the SC cavities are highly sensitive to helium pressure sensitivities. Optimization of the cryoplant (and espacially of the compression station), as well as fine tuning of the helium bath pressure regulation, will be going on as soon as the LINAC is coold down again. These optimizations are supported by simulation of the cryo system; this simulation work is the subject of a PhD and is performed in the frame of the GRAAL collaboration [6].

ACKNOWLEDGEMENTS

This work has been funded by Region Normandie as well as the city of Caen, CNRS and CEA. We would like to thank all contributors from CEA-IRFU, CNRS- IPNO, IFJ-PAN (Krakow) and GANIL without whom fabrication/approval of the cryomodules and the valves boxes and integration in the SPIRAL 2 LINAC beam line would not have been possible. We also would like to thank F. Bonne and P. Bonnay (dSBT/CEA) for the Simcryogenics library that has been used for modelling the cryogenic system of SPIRAL 2.

REFERENCES

[1] S. Gales, "GANIL-SPIRAL2: a new era", *Journal Of Physics: Conference Series*, vol. 267, pp. 012009–8, 2011.

[2] C. Marchand *et al.*, "Performances of Spiral2 Low and High Beta Cryomodules", in *Proc. 17th Int. Conf. RF Superconductivity (SRF'15)*, Whistler, Canada, Sep. 2015, paper WEBA04, pp. 967–972.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPMP006

[3] A. Ghribi, P-E. Bernaudin, A. Vassal, and F. Bonne, "Status of the SPIRAL 2 LINAC cryogenic system", *Cryogenics*, vol. 85, pp. 44–5, 2017.

[4] J. Vogt, O. Kugeler, and J. Knobloch, "Impact of cool-down conditions at Tcon the superconducting rf cavity quality factor", *Phys. Rev. Spec. Top. Accel. Beams*, vol. 16, pp. 102002–8, 2013.

[5] P. De Antoni *et al.*, "The architecture of the low level RF electronics for Spiral2", in *LLRF Workshop*, Knoxville, TN, USA, October 22-25, 2007.

[6] A. Vassal *et al.*, "Dynamic modeling and control of the SPIRAL2 cryomodules", *IOP Conference Series: Materials Science and Engineering*, Vol. 502, 2019.