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ACCELERATED LIFETIME TEST OF SPOKE CAVITY COLD TUNING SYSTEMS FOR MYRRHA

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Abstract

Within the framework of MINERVA, the first Phase of MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications) project, IN2P3 labs are in charge of the developments of several accelerator elements. Among those, a fully equipped Spoke cryomodule prototype was constructed, it integrates two superconducting single spoke cavities operating at 2K, the RF power couplers and the associated cold tuning systems. The extreme reliability specified for this project motivated to conduct accelerated lifetime tests (ALT) on two cold tuning systems in a cryomodule-like environment. By gathering experimental data, many critical aspects can be enhanced like maintenance plan consolidation, determination of aging indicators and design optimization of the whole system and its sub components. This paper describes the complete ALT process from the studying elements and the test environment design, to the experimental findings.

INTRODUCTION

MYRRHA [1] is the combination of a subcritical nuclear reactor driven by a proton accelerator. One of its goals is to provide answers to the feasibility of nuclear waste transmutation at a massive level. Because the accelerator is coupled to the reactor, its reliability requirement is significantly higher than for any other operational high power proton beam accelerator. This key parameter encouraged to build the accelerator components conservatively but also to design and operate dedicated tools to assess the reliability of systems that are considered the most critical for the beam acceleration, either because of the low accessibility or the high risk to provoke a loss of beam scenario.

The early stage of the superconducting linac will bring the beam energy up from 16.6 MeV to 100 MeV [2] thanks to 30 cryomodules [3], which contains each two single-spoke cavities (β = 0.37, 352 MHz). Each cavity is equipped with a cold tuning system [4], which allows a fine control of the resonant frequency required to operate at the nominal accelerator field. Four tuners were built, two for the prototype cryomodule development purpose, and two dedicated for the ALT campaign.

TUNER DESCRIPTION

The MINERVA cavity cold tuning systems is a double-lever class tuner (see Fig. 1) based on the design of ESS double-spoke cavity tuner [5]. The tuner is actuated using a low temperature stepper motor (VSS57.200) with a 6.25:1 planetary gearhead from Phytron [6] and two piezo actuators (NAC2022-H72) from Noliac [7] for coarse and fine tuning respectively. The motor is mechanically coupled to a full stainless steel satellite roller screw coated with MoS2 dry lubricant built by Elitec [8]. The lever arms are guided by a set of four stainless steel hybrid ball bearings built by JESA [9]. All of those components are considered critical in terms of reliability due to the combination of small motions, high forces, and material fatigue in vacuum environment at cryogenic temperatures.

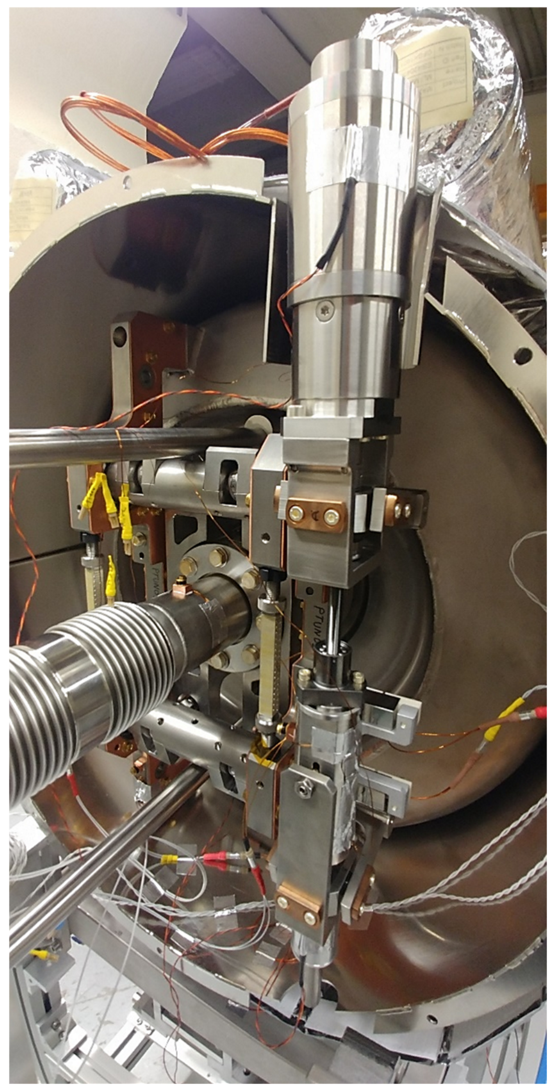

Figure 1: Prototype tuner assembled on a single-spoke cavity during cryomodule integration.

TEST ENVIRONEMENT

In order to mimic the cryomodule environment, a dedicated tuner test cryostat has been designed and built

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(see Fig. 2). To reduce cryogenic costs while maintaining a high flexibility of operation, the tuner is cooled (by conduction) using liquid nitrogen fluid instead of liquid helium, assuming differential shrinks between 77K and 4K would have low impact on the mechanical behavior. Also, to keep operation cost and labor low, this cryostat does not require the tuner to be attached to a cavity. Instead, an aluminum plate is used as a "dummy cavity" is designed with an equivalent stiffness and mechanical interface. A set of strain gages is glued on this plate to measure the force applied by the tuner, which serves as the main feedback indicator during the tests. It reflects an equivalent response as if the tuner was tested attached to a cavity during a vertical cryostat test. Moreover, the cryostat provides enough space to allow up to four simultaneous tuners tests.

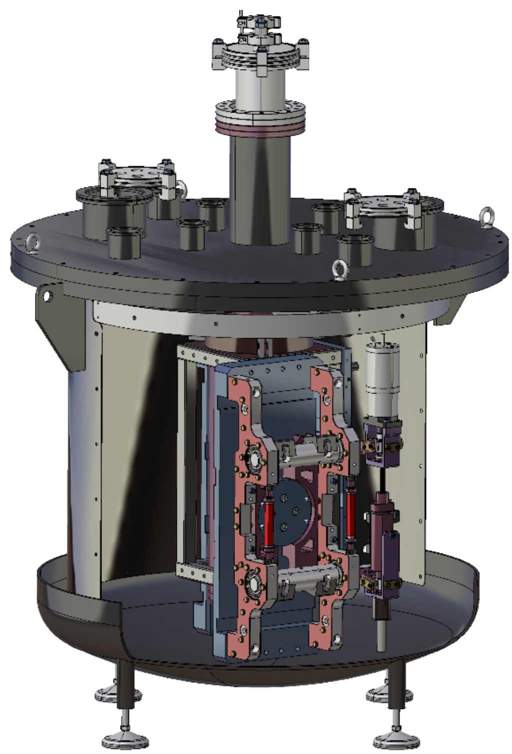

Figure 2: CAD view of the tuner test cryostat.

TEST PLANS DEFINITION

Initially, the ALT campaign was organized as sequence of different phases: endurance, regulation and standstill. An endurance run consists of high amount of large cycles applied to the actuators to periodically stress the entire system and provoke wear and fatigue symptoms. The regulation phase intends to provoke micro grinding, and the standstill phase was imagined to characterize the resistance to galling and cold welding. Due to rapid and unexpected loss of the system performance, the ALT focused on the endurance phase only by using the motor.

In order to balance working time, test safety and representability of the tuner in a real operational environment, a sequence of 50 full nominal range round trips has been defined, which is equivalent to 10.000 motor revolutions or 1.600 gearhead shaft revolutions. This sequence can be performed within four hours, which allows to perform both cycles and a full characterization (motor, piezos) the tuner on one working day. The characterization permits to track any performance variation between each sequence. Four sequences a week have been scheduled in order to cover a total of 200 round trips. The LabVIEW software code programmed on a computer, which is connected to a CompactRIO controller. It handles the automatized process, which includes eight pauses during each round trip to periodically measure the dummy cavity deformation thus recording valuable information of the test progress.

Two tuners labelled as PTUN03 and PTUN04 were driven in parallel. The motor speed was configured at 1.5 revolution per second and its current was applied only during motion at 1.0 A.

RESULTS

Before running the sequence of cycles, a characterization test has been made in order to record the initial tuner performance.

Characterization Test

During this test, which consist to do a full round trip with the motor (see Fig. 3), additional measurements are made at 40, 90 and 140 motor revolution positions which represents the start, mid and end of the tuning range respectively. During cool down, the tuner is moved to zero position, i.e. where it has nearly no mechanical contact with the dummy cavity. 40 motor revolutions are required to pass the initial non-linear region.

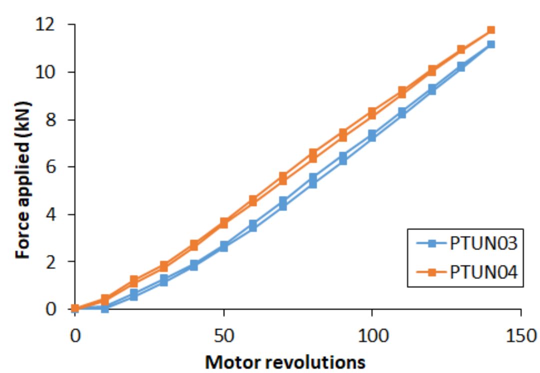

Figure 3: Strain gage response to full round trip of the tuner from zero (no mechanical contact) to maximum allowable position.

Endurance Test

Day 1, day 2 and day 3 endurance curves are shown in Fig. 4. On the first day, 50 motor cycles carried out without observing any lack of performance. On the second day, one tuner (PTUN03) started to fail after 13800 revolutions, and much frequently again later. This tuner was then discarded from the rest of this test. On the third day, the second tuner (PTUN04) also failed after 27800 motor revolutions. The initial temperature of both motors was recorded and was in the range of 120 K before each sequence of cycles, and

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raised to 150 K after four hours of operations, then cooled down to 120 K before the next ALT cycle.

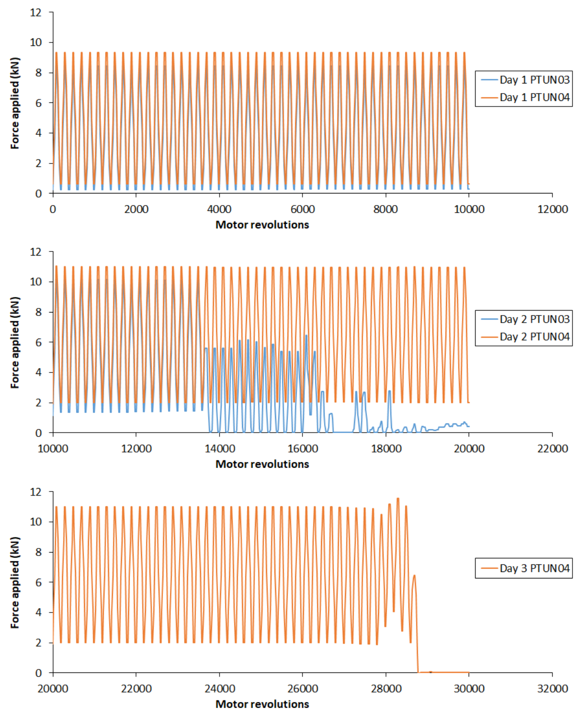

Figure 4: Force variation applied by the tuner over cumulated motor travel distance.

Additional tests have been performed to identify the reason of the failures. For instance, a rise of the motor current from 1.0 A to 2.0 A has been tried to recover normal operation, but it did not succeed at all, which indicates that the issue observed is not directly torque related. Thus, it is due to a strong mechanical failure rather than a slight performance degradation of the system over time.

Room Temperature Check

After warming-up the system and performing a visual inspection, no sign of surface degradation has been observed, especially concerning the MoS2 coating of the satellite roller screw (see Fig. 5) which is one of the main critical components vulnerable against wearing.

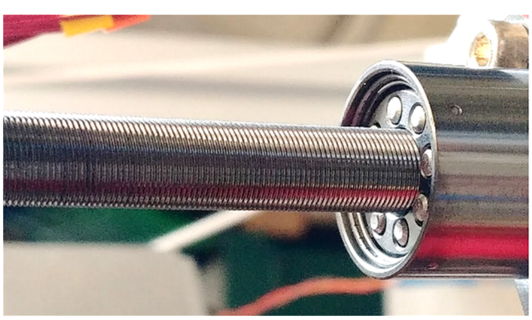

Figure 5: Close view of satellite roller screw.

A room temperature test of the tuner motors has been carried out afterwards. A temporary loss of steps has been observed periodically on PTUN03 motor, whereas the PTUN04 motor stalled, even while it was disconnected from the tuner. This motor recovered however by itself, unexpectedly after a few minutes of continuous excitation.

Motor Gearhead Internal Inspection

Due to the abnormal operation of the PTUN04 motor and its gearhead - while disconnected from the tuner - an internal inspection of the gearhead has been performed.

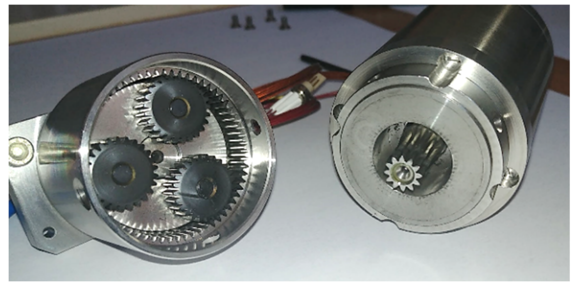

Figure 6: Gearhead (on the left) disassembled from the motor (on the right) after ALT.

Some black powder has been found on most of the surfaces (see Fig. 6), and significant non regular friction torque could be noticed while running by hands the planetary gearhead. Further investigations ascertained that the satellite gears are coated with Diamond Like Carbon (DLC) that quickly wore out for a reason that remains unclear. This coating is known to be used for space applications since a few decades as an alternative to MoS2 as it avoids risks from relative humidity at room temperature, i.e., when the motor operates (or is stored) in ambient air [10]. Note that friction performances are very dependent of the deposition method and environment parameters such as the vacuum level, hydrogen content and mechanical pressure [11-12].

CONCLUSION

An ALT campaign has been carried out for two prototype tuners designed for the MINERVA single-spoke cavities. The experiments have revealed a motor lifetime of about 50 round trips, which is equivalents to only a few months of lifetime in the linac. From the MINERVA project point of view, requiring much higher reliability and availability, this is not acceptable. Further investigations on the gearhead with additional ALT campaigns are foreseen trying to solve this issue with the involvement of Phytron.

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