DEVELOPMENTS AND TESTS OF A 700 MHz PROTOTYPICAL CRYO-MODULE FOR THE MYRRHA ADS PROTON LINEAR ACCELERATOR

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Abstract

It is foreseen to build an ADS demonstrator (MYRRHA) in Mol (Belgium). Such a device will be piloted by a 600 MeV / 4mA superconducting Linac. A prototypical cryomodule, for the high energy section of the accelerator, equipped with a 5-cell superconducting cavity and its tuning system was realised. Developed at INFN Milano, this RF cryogenic accelerating device is tested for the first time at IPN Orsay. The status of the R&D activities regarding the main elements of this device are described in this paper.

INTRODUCTION

Accelerator Driven system (ADS) is one solution to enable the reduction of nuclear waste radio-toxicity before their deep ground storage. Based on the transmutation process, such a device allows to decrease the radioactive waste life time and consequently to relax the constraints on the geological disposals.[1]

Towards this goal, The MYRRHA experimental facility which is planned to be built in Mol (Belgium) wishes to demonstrate the technical feasibility of Transmutation. [2]

An ADS transmuter typically requires a 600MeV to 1GeV accelerator delivering a beam intensity of a few milliamps. Because of the induced thermal stress to the subcritical core, the high-power proton LINAC will have to fulfil stringent reliability requirements.[3]

The high energy section of the MYRRHA Linac will be composed of 5 cells elliptical cavities. A prototypical cryomodule, equipped with a β=0.47 superconducting cavity and its tuning system, developed by INFN Milano is tested at IPN Orsay. This experiment aims to evaluate the cavity performances but above all the cryomodule reliability to fulfill ADS needs. We report here the RF and cryogenics developments of this module as well as preliminary tests and considerations in view of performance and reliability studies.

SUPERCONDUCTING ACCELERATING MODULE

The development of an accelerating superconducting cavity requires the prototyping of all the auxiliary systems needed for its operation in a real environment. In this context, R&D activities involve INFN and CNRS resulting in the design and fabrication of a cryogenic real scale module dedicated to be tested in new experimental area. INFN contributed in the development of the cryomodule and made available its beta 0.47 TRASCO cavity equipped with a cold tuning system. IPN Orsay (CNRS/IN2P3) participated in the development of the cryogenic valve-box, of the power couplers and makes available its new facility SUPRATech dedicated to the preparation (chemistry, clean room) and cavity tests (experimental area set up in progress) with an 80 kW RF power supply.

The Cryomodule

The Cryomodule design (see Figure 1) has been performed by considering reliable aspects for the assembly, and the cavity handling, derived from the experience accumulated by the TESLA Test Facility (TTF) and the Spallation Neutron Source (SNS).

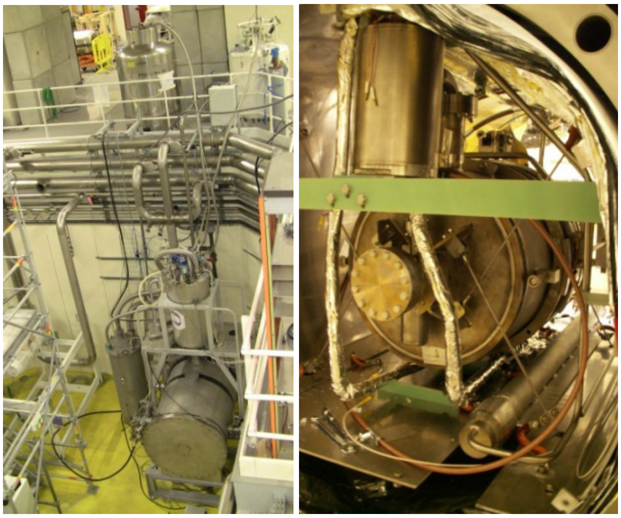

Figure 1: The prototypal 700MHz cryomodule, installed in the experimental pit and an inside view during instrumentation.

The module is 1.5 m long, for a diameter of about 1.4 m with the cold box assembled on top of it. The module was designed to operate at 2K for a nominal accelerating gradient of 8.5 MV/m and an assumed conservative quality factor value of $Q_0=5.10^9$ for computations. At 2K, the dynamic heat load has been estimated to 25W and 4W in static conditions. More details concerning the thermal design are given in Reference [4].

Static losses are kept in the module by minimizing the heat flow toward the 2K helium bath. Therefore, the thermal radiation, flowing from surfaces at room temperature, is intercepted by a thermal shield at intermediate temperature (Nitrogen at *77 K*) and minimized by using multilayer insulating blanket

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(35layers of single aluminized Mylar® sheets separated by a low thermal conducting spacer net).

The cryogenic cold valve box, derived from the IPN Orsay EURISOL design, has a nominal cooling capacity of 50W at 2K. A 20 liters helium buffer is placed inside the box to prevent from pressure perturbations in the cavity Tank. The cold box thermal shield, made of copper and covered with multilayer insulation, is able to evacuate 60W at around 80K.

The Dressed Cavity

The cryogenic module is equipped with one of the two TRASCO cavities (geometrical β=0.47) fully “dressed”. A magnetic shield made of 1 mm Cryoperm10® sheets encloses the cavity and is located inside the helium Tank [5]. Magnetic shield measurements showed that the contribution to the surface resistance by trapped magnetic field is estimated to be below 10 nΩ which guarantee a quality factor higher than 5.10^9.

The cavity and its shield are placed in a titanium helium tank which provides the low pressure He bath for 2K operations.

A coaxial blade tuner derived from the one successfully tested at TTF [6] has been developed and fabricated (see Figure 2) within the EU FP6 CARE-HIPPI program. This device, mounted on the tank, will allow slow and fast tuning compensation. A rotation torque provided by a stepper motor is transferred into a longitudinal displacement by means of bending blades and enables the control of the cavity resonance frequency and the static compensation of Lorentz forces detuning. This coaxial device is also assisted by piezoelectric actuators which allow dynamic cavity frequency adjustments.

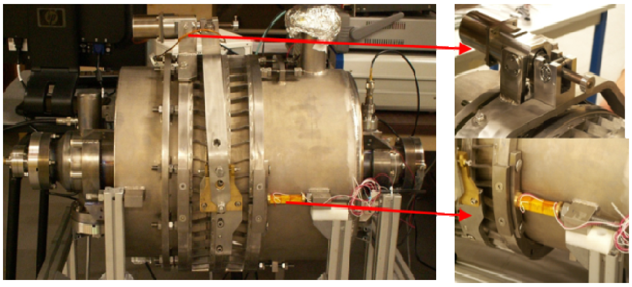

Figure 2: The Z501 TRASCO cavity fully dressed with its stepper motors and the piezoelectric actuators.

FIRST EXPERIMENTAL RESULTS

Experiment Installation & First Cold Test

The cryomodule fabricated by SIMIC Company in Camerana (Italy), was delivered in spring 2010 at IPNO. It was then assembled and instrumented with its dressed cavity. At the same time the former naked AGOR cyclotron pit was renovated as an experimental area dedicated to RF superconducting cavities and cryomodules. A piping network was also built in order to save helium going out of the cryogenic device. This He is then stored and re-liquefied, in situ, to re-supply the cryogenics experiments of the SUPRATech area. Pumping systems to obtain a 2K super-fluid He bath in the cavity tank are currently being installed and processed.

In view of RF tests the internal surfaces of the cavity were prepared by applying a chemical surface treatment. The BCP (Buffered Chemical Polishing) was applied for 30 min to remove an average Niobium thickness of 25 µm. Such value was estimated sufficient since the cavity had already been treated and tested in vertical cryostat [7]. Finally the resonator was High Pressure Rinsed in clean room and the cavity was closed without its power coupler but with an antenna which enables a critical coupling.

It was chosen to first proceed to low power tests, with an antenna providing a critical coupling, i.e without the power couplers. Those tests will enable to measure any evolution of the quality factor [7] since its assembly within the helium tank and the magnetic shield. It will be carried out at 4K and 2K, and it will be, above all, an experiment for testing the new building facility as well as the performance of the cryogenic cooling system.

A first preliminary cryogenic test was achieved in July 2010 giving conclusive results in the cooling capabilities of the thermal screen and the cavity tank. The good functioning of the entire RF Phase Lock Loop (PLL) was checked and cavity modes were identified. However a significant leak was detected at 4 K on the helium circuitry and the experiment had to be stopped to investigate on its cause.

The entire power supply chain has been installed, tested and is now fully operational. A Thales® IOT was successfully tuned, and an expected average gain of 21 dB was measured (The gain is slightly changing as function of the output power, maximum: 21.5dB for 60kW).

Once the Power Couplers conditioned, the high power tests will be a second evaluation of the module cryogenic efficiency. But, above all it is the capability of the piezo-based tuning system coupled with the prototypical digital LLRF I/Q feedback loop which will be evaluated. The reliability of the entire installation and its response time for fast set points update of the entire installation will be tested.

Tuning System Characterisation

The low power tests will also enable to evaluate the static and dynamic capabilities of the slow (motor) and fast cold tuning system (FCTS) (piezoelectric actuators), already measured at room temperature. Those firsts measurements aimed to evaluate the vibrating mechanical modes of the cavity and to model the transfer function of the FCTS acting on the cavity resonance frequency, in view of reliability analysis and RF cavity control simulations.[8]

In this purpose, the experimental setup is described by Figure 3. A low power RF signal at the resonating frequency (π-mode) of the cavity is introduced. In this way, the detuning is deduced by measuring the phase between the input and the output signal. At the same time, this phase oscillation is compared to the piezos driving signal by using a lock-in amplifier which provides a good noise rejection [9]. The Bode diagram of the tuning system (Gain in Hz/V and phase) can be deduced from the harmonic response of the discrete frequency sweep.

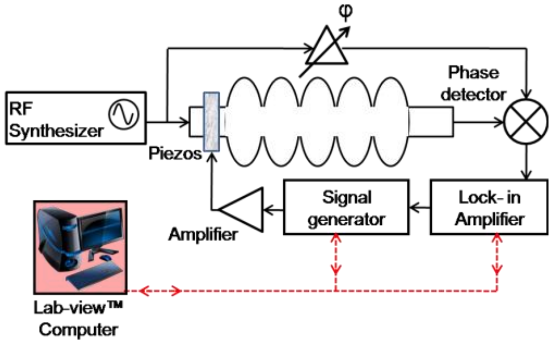

Figure 3: Experimental setup for measuring the TF of the fast tuning system.

Several measurements were carried by applying different voltage amplitude (0.5 to 20 V) to the piezos terminals. The main tendencies of the FCTS behaviour have been assessed, and main microphonics vibrations identified are between 50Hz to 200Hz (possible excitation from the pumping systems). The detuning was measured for a frequency sweep from 0 to 1 kHz, as well as the phase between the piezos driving signal and the detuning oscillations.

To anticipate on the best solutions for the control and feedback system of the tuner, one can extrapolate, from the previous measurements, a model of the transfer function. On Figure 4, the blue curves are the gain (in Hz/V) and the phase deduced from the measurements. The green curve is the result of sum of first order and second order transfer functions. The first order transfer function enables to adjust the gain at low frequency whereas the second orders imitate the resonances [9].

$$H(s) = H_1(s) + \sum_{i=1}^{n} H_{2i}(s)$$

$$H_1(s) = \frac{K}{1+\tau s} \quad \textit{and} \quad H_{2i}(s) = \frac{K_i\ \omega_i}{s^2 + 2\,\delta\omega_i s + \omega_i^2}$$

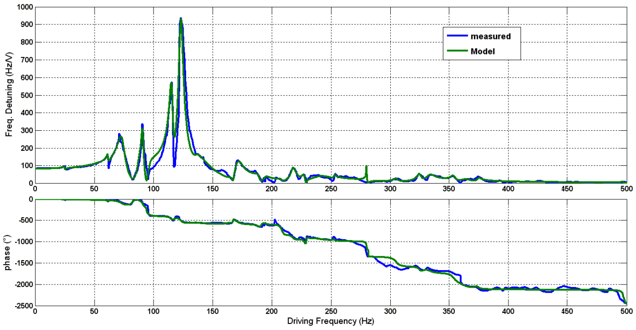

Figure 4: Measurements and model of the FCTS transfer function at room temperature.

The model was realised by adjusting the half bandwidth $\delta\omega_i$ of the resonances and their pulsations ω_i as well the detuning amplitudes coefficients K_i. This model is used to complete a preliminary theoretical study of the cavity behaviour with its LLRF control feedback loop system. This computer program using Matlab simulink™ allows to study reliable aspect of the control system and to propose solutions for the development of a reliable FCTS feedback loop system.[8]

CONCLUSION

The experimental campaign on the 700MHz full scale Cryomodule started in July 2010 with preliminary cryogenic tests. In the long run, the experiment will be able to provide a testing bench for specific sequences of the MYRRHA fault tolerant Linac. The aims of reliability tests will be to recover and complement computations results for the set points updating and fast cavity detuning to validate an efficient and safe "fast fault-recovery" procedure [8].

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REFERENCES

[1] European Technical Working Group, "The European Roadmap for Developing ADS for nuclear waste incineration", ISBN 88-8286-008-6, ENEA 2001.

[2] H. A. Abderrahim et al, "MYRRHA: A multipurpose accelerator driven system for R&D", Nucl. Instr. and Meth. in Phys. Res. A 463 (2001), pp. 487-494.

[3] J-L. Biarrotte et al, "Accelerator reference design for the MYRRHA European ADS demonstrator", LINAC10, Tsukuba, September 2010,

[4] S. Barbanotti et al, "Design of the prototypical cryomodule for the Eurotrans superconducting linac", EPAC'08, Genoa, June 2008,MOPP114, p.826.

[5] P. Pierini et al, "Design of the magnetic shield for Trasco low beta elliptical cavities", SRF 2007, Beijing, September 2007, WEP61, p.651.

[6] P. Pierini et al, "Report on Tuner Design", CARE Note-2006-003-HIPPI.

[7] A. Bosotti et al, "RF tests of the beta=0.5 Trasco cavities", EPAC'04, Lucerne July 2004, TUPKF026, p.1024.

[8] J-L. Biarrotte, F.Bouly,C. Joly, "LLRF developments toward a fault tolerant Linac scheme for ADS", LINAC10, Tsukuba, September 2010, MOP083, These proceedings.

[9] M. Luong et al, "Analysis of microphonics disturbances and simulation for feedback compensation", EPAC'06, Edinburgh, June 2006, THPCH159, p. 3167.