THE MYRRHA SPOKE CRYOMODULE

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Abstract

In the framework of the MAX project, dedicated to the detailed study of the MYRRHA facility LINAC, the engineering study of the 'Spoke' cavities cryomodule, situated in the low energy superconducting section, has been achieved. The beam optics study, highly constrained by strong reliability requirements, leads to a modular cryomodule composed of two beta=0.37, 352 MHz, single bar 'Spoke' cavity cooled at 2K. The power coupler design, not studied in detail under the MAX project, is directly taken from a 20 kW continuous wave 352 MHz coupler designed and successfully tested in the framework of the previous EUROTRANS and EURISOL projects. The cold tuning system is identical to the one designed for the ESS 'Spoke' cavities. We present in this paper, the RF, the mechanical and the thermal design of the complete cryomodule as well as the optimization and simulations of its individual components (Cavity, Cryostat, Tuning System...).

INTRODUCTION

The proton superconducting LINAC for MYRRHA [1] (600 MeV, 5 mA) consists in 4 sections [2]. The low beta (0.37) section from ~17 MeV to ~100 MeV is comprised of cryomodules housing two single Spoke cavities cooled at 2K [6]. A beta = 0.47, from ~ 100 MeV to ~ 200 MeV, and a beta = 0.65 from ~ 200 MeV to ~ 600 MeV, sections are comprised of cryomodules housing 4 elliptical Cavities. The detailed study of the complete spoke cryomodule and its constituting components (Cavities, Cold Tuning System, Power Coupler, Cryostat...), achieved in the framework of the European MAX [3] project is described below.

SPOKE CAVITY DESIGN

Two Spoke cavities designed for the MYRRHA Cryomodule are currently under manufacturing. We describe below the studies done for the RF and mechanical optimizations.

RF Design

The RF design [7] was conducted taking into account the feedback experience on the manufacture and the tests results of two spoke cavities designed at IPNO. The main manufacturing issue concerns the spoke-bar geometry.

In a first single spoke cavity prototype a cylindrical shape at the magnetic field area was chosen to simplify the manufacture. It leads to high peak magnetic field not acceptable for the specifications for the MHYRRA LINAC. On a second triple spoke prototype a racetrack shape at the spoke bar cavity body connection leading to good theoretical RF parameters was manufactured. The 3D welding for this connection is difficult to manage and because of a lack of experience for this kind of manufacturing we conservatively avoid to choose this solution for the MAX Spoke Design.

A conical shape at the spoke bar/cavity body connection was chosen. It leads to acceptable RF parameters according to the MAX specifications and reduce the manufacturing difficulties. At the E field area (cavity central part) a racetrack shape giving good theoretical RF performances and easy to manufacture is chosen.

The electro-magnetic optimization leads, keeping Beta = 0.37 and the frequency of the first TM_{010} at 352 MHz, to minimize the peak surface electric field over accelerating gradient ratio (E_{pk}/E_{acc}) and the peak surface magnetic field over the accelerating gradient ratio (B_{pk}/E_{acc}). The goal is $E_{pk}/E_{acc} < 4.4$ and B_{pk}/E_{acc} (mT/MV/m) < 8.3. The accelerating gradient values for the Spoke section of MHYRRA are $E_{acc\ max\ nominal}$ = 6.2 MV/m for nominal operation and $E_{acc\ max\ fault\ tolerance}$ = 8.2 MV/m when the cavity is used in fault recovery mode [4]. It leads to a maximal surface magnetic field of 68 mT, and a maximal surface electrical field of 36 MV, which for spoke cavities, gives a sufficient margin and fulfill the reliability constrains of the MHYRRA accelerator.

Table 1: RF Parameters

Parameters	**Value**
Optimal beta	0.37
Vo.T [MV/m] @ 1 Joule & optimal beta	0.693
E_{pk}/E_{acc}	4.29
B_{pk}/E_{acc} [mT/MV/m]	7.32
G [Ohm]	109
r/Q [Ohm]	217
Q_o @ 2K for R_{res}=20 nΩ	$5.2\ 10^{9}$
P_{cav} for $Q_o=2\ 10^{9}$ & 6.4 MV/m [W]	9.35
L_{acc}= beta $_{optimal}$. c . f [m]	0.315m

The Electro-Magnetic design was performed using the 'CST Micro Wave Studio 2012' numerical code (see Table 1). A quarter of the cavity was simulated using border conditions on the magnetic planes with tetrahedral mesh elements (10 000 Tetrahedrons were used). Only the first mode (TM010) was calculated for the optimization that was performed by playing on a dozen of geometrical parameters.

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The distribution of the Magnetic field around the spoke-bar and electrical fields in the cavity axis volume are given in Figure 1.

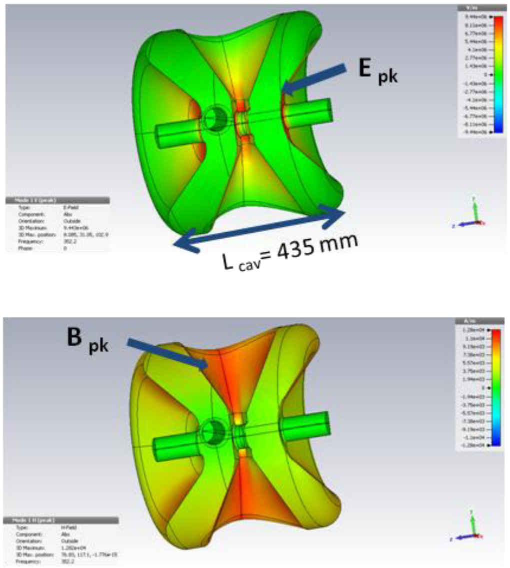

Figure 1: Fields Distribution

Mechanical Design

The main mechanical optimization goals were to avoid exceeding the material elastic limit for any load case during the manufacturing and the operation of the cavity, while lowering the RF frequency sensitivity to mechanical loads. To keep the cavity walls thickness to 3 mm, for cost reduction reasons, several stiffening parts were added to the cavity body as well as a welded connection between the Titanium Helium tank and the cavity walls (see Fig. 2). The coupled Electromagnetical/Mechanical simulations [7] were done on ANSYS. The main mechanical characteristics are summarized in Table 2.

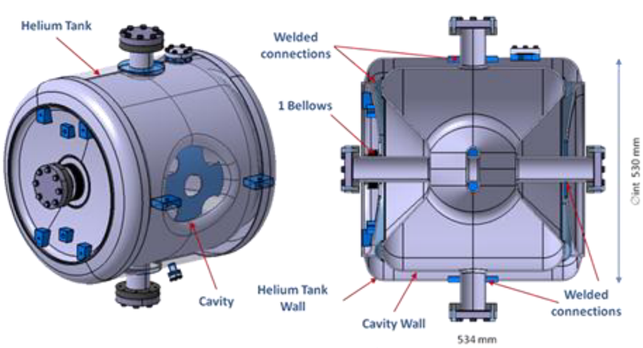

Figure 2: Cavity Mechanical Design

Table 2: Cavity/Helium Tank mechanical parameters

Parameters	Value
Max V.M. Stress @ 300K	35 MPa
Max. V.M. Stress @ 2K	52 MPa
First Eigen Mode	232 Hz
Tuning Sensitivity	180 kHz/mm
Cavity/Tank Stiffness	14,5 kN/mm
Tuning V.M. Stress	370 MPa/mm
Sensitivity to Pressure (Hz/mbar)	< 14
L.F. Factor [Hz/(MV/m)^2]	$-6 < K_L < -5{,}2$

RF POWER COUPLER

The Power Coupler, featuring only one warm Window (SNS Type) is designed for 20 kW CW and 50 Ohm. The specifications for the Spoke section of the MYHRRA LINAC are 10 kW average with a maximum of 16 kW for fault tolerance recovery (adjacent cavities operating at higher power to compensate cavity failure). The external conductor is fitted to the cavity bottom with a CF 63 flange. The distance between 2K and 300 K is around 300 mm. Two heat intercepts respectively at 50 K and 5 K are sufficient to reach the thermal losses specifications. A barometric compensating system, placed outside the Cryomodule, reduces the pressure forces induced to the cavity when evacuating the vacuum vessel. A first prototype, manufactured in the framework of the EURSOLD project has been successfully tested with a maximum RF power of 8kW CW (amplifier limitation), in a cryomodule configuration. It is then decided to keep as it the design of the window block for the MHYRRA spoke cryomodule.

COLD TUNING SYSTEM

We use the CTS, Cold Tuning System (see Fig. 3) designed for the ESS Spoke cavities [5]. The CTS features a cold stepping motor and gear box to compensate slow cavity frequency shifts. The bandwidth for the spoke section is around 160 Hz and assuming a bath pressure stability of around +/- 2 mbar at 2K and a cavity sensitivity to pressure fluctuations of less than 14 Hz/mbar, it would be possible to avoid operating the stepping motor during operation at 2K for pressure variation compensation. This would increase the life time of the system which responds to the reliability improvement. Piezoelectrical actuators are inserted in the CTS to compensate the fast perturbations on the cavity frequency.

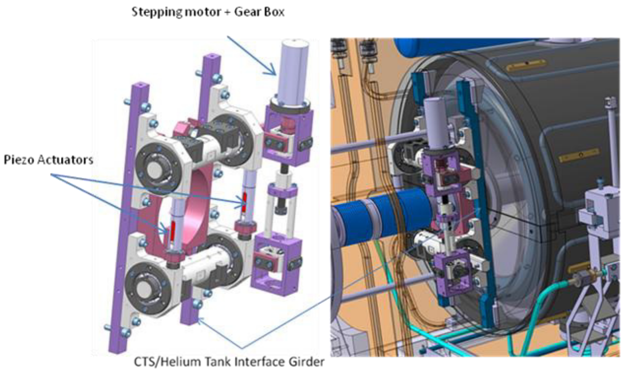

Figure 3: Cold Tuning System

CRYOSTAT

For the MYHHRA LINAC a fine Cryomodule segmentation was chosen in order to be able to apply fault tolerance scenarios in case of the failure, for any reasons (RF, Vacuum, Cryogenics...) of a single Spoke Cryomodule. Hence there will be only one separate valves box per Cryomodule.

The cryostat (see Fig. 4) will have a single thermal shield cooled with gaseous helium at 4 bars, from 40K to 80 K. Multi Layers Insulation (30 Layers on Thermal shield, 10 on Cavity) will provide additional thermal radiation insulation. Thermal intercepts (between 5K and 10 K), for the power couplers and for the cavity supporting frame, will be performed by a circuitry fed by Supercritical Helium at 3 bars. The Cavities and the magnetic shields will be cooled down from 300K to 5 K using a dedicated loop with Liquid Helium at 1.2 bars. A phase separator of around 5 litres, placed on the top of the cavity string, allows maintaining the cavities at 2K [6] with small pressure fluctuations. Preliminary evaluations of the cryogenic static losses, below 3 W at 2K, below 10 W at around 7K, and below 90 W at around 60K, suit the cryoplant specifications.

The two cavities' string is maintained on a simple frame put on two adjustable posts fixed to the cryostat vacuum vessel. The cavities are able to slide on the frame which can slide itself on one of the posts. An invar rod fixed to the fix part of the frame limits and controls the longitudinal displacement of the two cavities, to, respectively, 0,1 mm and 0,4 mm. The cavities will vertically go down from less than 1 mm during cool down. This possible misalignment can be adjusted by anticipating this displacement during warm temperature assembly or, as the posts can be adjusted, by performing a new alignment after cool down. The vacuum vessel diameter is 1200 mm and the length between the cryostat warm valves is 2200 mm. The cryogenic connection line is situated at the top of the vacuum vessel. All the cryogenic valves and sub cooling heat exchanger are implemented inside a dedicated valve box fixed on the LINAC tunnel close to the Cryomodule.

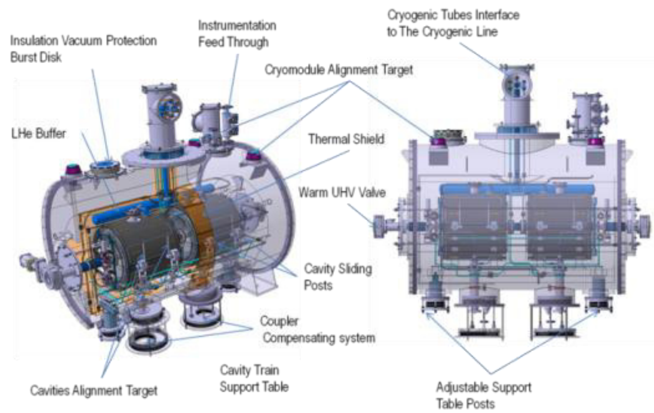

Figure 4: Cryostat

FUTURE WORK

Two prototypes of cavity are currently under manufacturing. They are planed to be achieved at the middle of 2015 and fully tested in cryogenic configuration at IPN Orsay. A first version of the technical drawings of the complete cryostat and its auxiliary components has been performed to launch a call for tender as soon as a budget will be available.

ACKNOWLEDGMENT

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REFERENCES

[1] MYRRHA website: http://myrrha.sckcen.be/
[2] J-L. Biarrotte et al., "Design of the MYRRHA 17-600 MeV superconducting linac", Proc. SRF 2013, Paris, France, September 2013.
[3] MAX project website: http://ipnweb.in2p3.fr/MAX/
[4] J.-L. Biarrotte et al., "Beam operation aspects for the MYRRHA linear accelerator", Proc. TC-ADS-2, Nantes, France, May 2013.
[5] N. Gandolfo et al., "Deformation tuner design for double Spoke cavity", Proc. SRF 2013, Paris, France, September 2013.
[6] ACS," Analysis of the optimal temperature of the MYRRHA superconducting linac", Deliverable 4.1 of the MAX project, January 2012.
[7] H. Saugnac et al.," Spoke cryomodule design", Deliverable 3.3 of the MAX project, July 2014.

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