MACSE SUPERCONDUCTING CAVITY RF DRIVE SYSTEM

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Introduction

The five superconducting cavities, one for the capture section and four in the standard cryomodule, of the MACSE electron accelerator [1] are driven by five individual RF chains. The cryostat will contain 5-cell structures in a first stage and 3-cell structures in a second stage. The rf power delivered by the 5 kw klystron is transmitted after the circulator to the cavity through a coaxial dismountable coupling line. The tuning system is carried out by a precise mechanical system driven by a stepping motor lying in the LHe bath and the tuning resolution is so fine that the additional magnetostrictive system made of a Ni bar which was developed will not be necessary. Like the CEBAF control system [2] the classical regulation system with the heterodyne scheme is used for the feedback loops, which have to meet the stability requirements of 0.1° for the phase and of 10^{-4} for the amplitude.

The cavities and HOM-coupleurs

The purpose of the MACSE electron accelerator is to test different configurations of accelerating structures and to compare the performances and costs.

Figure 1 shows the 5-cell structure and its associated HOM coupler that will be mounted first in the cryomodule. The HOM coupler is just a 2-cell superconducting filter which was optimised for simultaneous high rejection of the fundamental mode and minimal reflection of the higher order modes.

Figure 2 shows the 3-cell structure and its associated HOM coupler that will be tested just after.The HOM coupler is here a simplified design where the coupling loop is used as a part of the LC rejection filter and is fully dismountable. In both cases the output signal is used as the probe signal for the control system, thus avoiding an additional rf port on the cavity. The main advantages of the last structure are summarized below [3] :

- statistical increase of the accelerating field in a cavity with a lower number of cells since the maximum value is given by the worst cell.
- higher shunt impedance reducing the helium consumption.
- lower peak / effective electric field ratio, thereby delaying to higher fields the onset of field emission.
- lower sensitivity to the multicell "trapped modes".

Parameters	5-cell cavity	3-cell cavity
Frequency (Mhz)	1497	1497
Active length (m)	0.5	0.3
Iris diam / Wavelength	0.35	0.25
Shunt imp r/Q (Ω/m)	960	1300
Ep/Eacc	2.5	1.75
Hp/Eacc(gauss/Mv/m)	45	39
Coupling factor (%)	3.6	0.9
Nearest mode (Mhz)	5.0	3.4

Table 1 : Main parameters for the 5-cell and 3-cell cavities

Although the parasite modes are harmless for the MACSE beam dynamics, these modes will be carefully studied on the machine with beam in order to know their effective damping in a real environment.

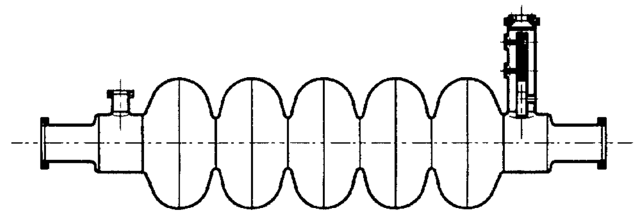

Figure 1 : The 5-cell cavity and the HOM coupler.

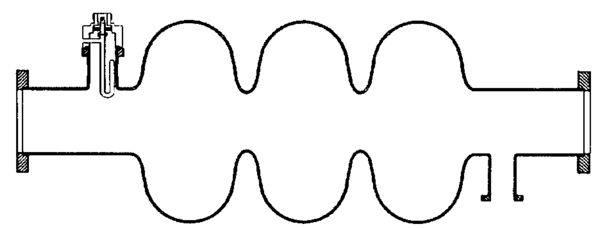

Figure 2 : The 3-cell cavity and the HOM coupler.

The fundamental power coupler

RF power from a 5 kW - 1497 MHz klystron is fed to the superconducting accelerating cavity through a fundamental power coupler. The design of this coupler is optimized to have a high RF transmission coefficient and to dissipate in the superfluid LHe bath a heat amount as low as possible. As the maximum transferred RF power is not too high, the thermal intercept principle has been chosen.

Although the waveguide coupler is easier to cool, its larger rectangular section makes it difficult for the use inside a cryostat. Therefore, the coupler used is of coaxial type (1 5/8" - 50 Ohms), ended with an antenna which protrudes 1.5 mm deep into the beam tube for the required coupling (Qex = 5.10^6).

There are two sapphire vacuum tight windows, a cold one close to the cavity and a room temperature one, both windows take over the cooling of the inner conductor. An other window, connected to the LN_2-shield, settles the 77K-point on the inner conductor. These windows are located at minimum voltage points which are independant of the rf working parameters. Because of the good thermal properties of sapphire, the Nb part of the coupler can be maintained in a superconducting state.

In case of leakiness or failure of one sapphire window, the upper coupling line can be easily dismounted for repair without opening the LHe-tank. The cold window is located between the beam vacuum and the isolation vacuum so that a small leak occuring during operation is harmless.

Figure 3 shows a schematic drawing of the coupling line. For the purpose of reducing the heat dissipation in the LHe-bath, we use between the warm part and the 77K-point, thin copper plated stainless steel conductors. The location and length of this thermal intercept are optimized for minimal heat load of the LHe-bath. In addition, a perfect thermal insulation between the 77K-point and the cold end of the line is insured by a choke coupling.

The total LHe bath heat load is expected to be less than 200mW for a RF power flow of 3kW.

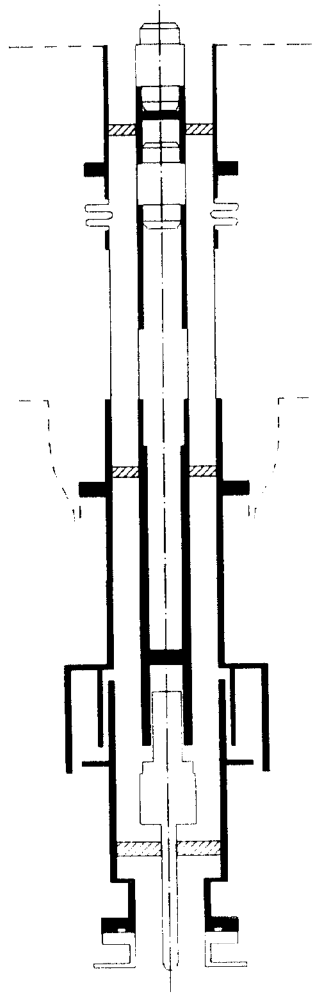

Figure 3 : The fundamental power coupler.

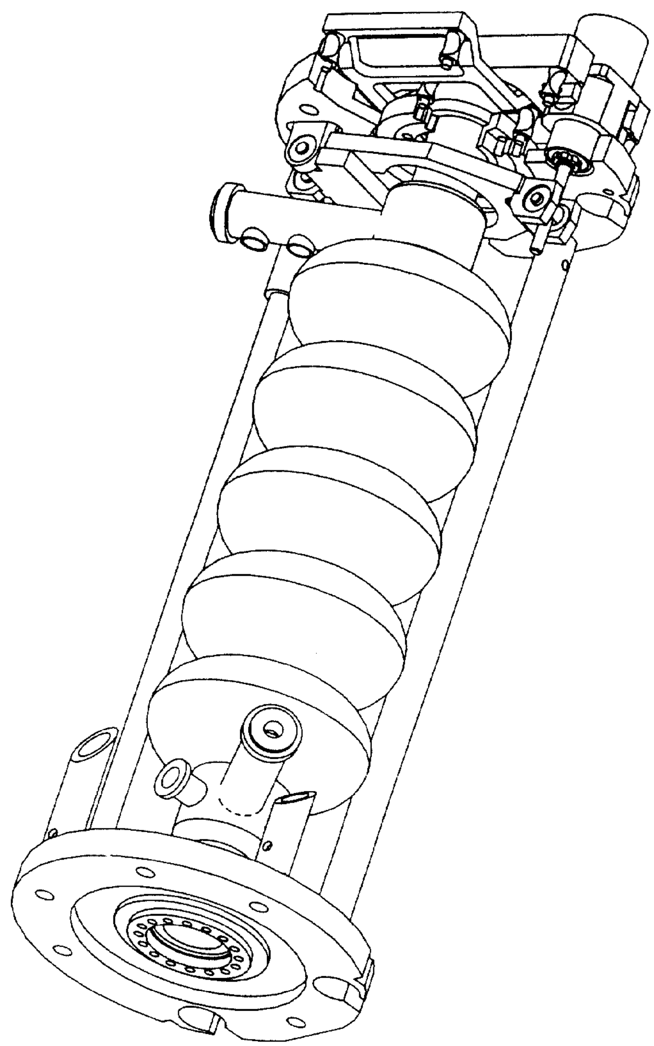

Figure 4 : The tuning system.

The tuning system

The principles

We request the tuning system to be able to correct the extrapolation error with a large range and to have an excellent accuracy because the cavity bandwidth is only 300 Hz. The elastic deformation (frequency shift of 500 kHz for a change of 1 mm in total length) is performed by means of a stepping motor - the coarse tuner - and a magnetostrictive Ni bar - the fine tuner - lying beside the cavity and of same length. All the system, mechanical and magnetostrictive, is immersed in the LHe bath.

As a fast device can excite the mechanical modes of the cavity and make therefore the control loop unstable, the response speed was willfully limited with a cut off frequency of 1 Hz. The phase and amplitude feedback loops will have to compensate the fast cavity frequency shifts due to microphonics. Antivibrationnal systems like damping wedges are however presently developed in order to push the mechanical resonance frequencies up and to reduce the magnitude of vibrations if necessary.

The mechanical design

Figure 4 shows a sketch of the overall system. The cavity is mounted in a rigid frame with a 3 mm elastic stretching to eliminate backlash. The total length can vary ± 1.5 mm leading to a maximum tuning range of ± 750 kHz. During the cold tests in the cryostat, the system performed accurately providing a tuning of 0.71 Hz per motor step without perceptible hysteresis and a tuning accuracy of about 1 Hz, corresponding to a final cavity length adjustment of only a few nanometers. Although an additionnal fine tuner seems superfluous, a magnetostrictive rod with a superconducting coil has been designed and will be installed if the stepping motors have to be exercised too frequently. The main advantage of the magnetostrictive device is its natural tuning accuracy but the drawbacks are a remanent magnetic field which can be eliminated only by a magnetic shield between the bar and the cavity and obviously the risk of trapped flux in case of cavity quench.

The control system

Like the CEBAF control system [2] the classical regulation system with the heterodyne scheme is used for the feedback loops. At the IF frequency of 60Mhz, the rf components are cheaper and present better features needed for meeting the stability requirements of 0.1° for the phase and of 10^{-4} for the amplitude.

The frequency loop

As we restrict the frequency loop to compensate for only slow fluctuations, this task is performed by the computer which actuates the mechanical tuner after reading the phase shift through the cavity. The finest frequency stabilization is given by the frequency resolution of the tuner. During the tests the frequency error threshold was settled to 10 Hz.

The phase and amplitude loops

Numerical simulations including the intrinsic phase amplitude coupling showed that amplitude gain of 10^4 and phase gain of 10^3 are needed up to about 500 Hz to meet the stringent requirements for stability in case of resonance frequency fluctuations as large as one half cavity bandwidth. The open loop transfer functions of the total rf chain were independently measured for phase and amplitude gains. The loop filters were then optimised for reaching the maximum gain up to a few hundred of Hz with a sufficient phase margin. The phase loop succeeded without any problem in meeting the 60 dB gain up to the cavity frequency corner while the present amplitude modulator prevented the amplitude loop gain from going beyond 70 dB. Another amplitude modulator version with a larger bandwidth is now under study.

Figures 5 shows the noise spectrum of the phase error signal just after the phase detector without control system during recent tests while some compressors, located very close to the test hall, were running. Figure 6 shows the same phase noise spectrum but after the loop amplifier (80 dB gain) and with control system on, pointing out the expected 60 dB phase loop gain.

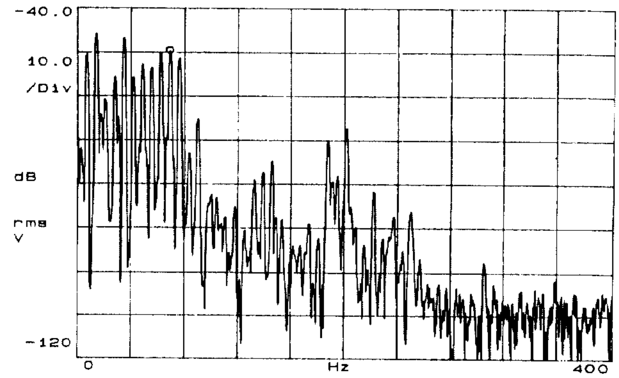

Figure 5 : Spectrum of the phase error before the amplifier loop without control system.

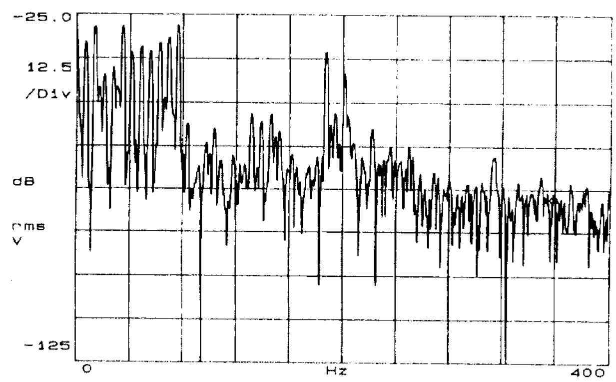

Figure 6 : Spectrum of the phase error after the amplifier loop with control system on.

References

[1] P. Leconte et al "MACSE :A super-conducting accelerator module", this conference.

[2] S. Simrock et al "RF control system development at CEBAF",PAC Chicago, 1989.

[3] A. Mosnier et al "Damping of the HOM's in a multicell SC cavity",EPAC Rome,1988.