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Cold tuning system

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Abstract

The cold tuning system of the Tesla cavities is described. An detailed analysis is given of the process required to get a cavity at the required frequency at liquid helium temperature, starting from an industry-delivered cavity. Most of the specifications on the cold tuning system are derived from this analysis.

1. DESCRIPTION OF THE COLD TUNING SYSTEM

The goal of the cold tuning system is to put the cavity at the frequency of the accelerator within an accuracy of about 1/20 of the width of the resonance curve of the cavity.

The loaded quality factor will be about 5×10^6 so that the width of the resonance curve (FWHM) will be about 260 Hz. Hence, the resolution of the CTS must be less than 260/20 = 13 Hz.

The CTS must operate without failure at liquid helium temperature because it is not possible to tune it at room temperature with such an accuracy : the resonance curve is then too wide. The CTS must also act during accelerator operation for detuning of an unused cavity and for small adjustments due to random frequency shifts caused by mechanical and pressure instabilities.

The cavity is tuned by changing its total length, thus acting on all the cells. As the cavity is enclosed in the helium tank, the latter must also accept the length variation. The subsequent change in volume of the cavity and of the helium tank should be comparable in order to reduce the sensitivity of the cavity RF frequency to helium pressure variations.

The length of the cavity, hence its RF frequency, are controlled by an electromechanical system acting differentially on one end of the cavity and a part of the helium tank. The other end of the cavity is rigidly fixed to the helium tank.

As the body of the helium tank is used as a mechanical reference for tuning the cavity, it should be a stable structure within the accuracy required by the resolution of the CTS (10 nanometer).

The CTS is made of a stepping motor + a harmonic drive (as a gear box) + a screw and nut system + a double lever system with leaf shaped articulation. The latter acts symmetrically on the cavity. Its thrust is transmitted on the same diameter as the stiffening rings.

The CTS are operating at 2K under vacuum. These conditions require a special surface treatment on the moving parts and a qualification procedure which has been thoroughly done at Saclay (See report to be published as a Tesla report).

No electrical switch will be required to tell the limits of the range of the CTS. Informations on the tuner position will always be given by the cavity frequency reading. A mechanical stop will be provided at each end of the tuning range. This stops will support the full torque and full speed of the motor for one hour and be able to go back in the other direction without trouble.

2. TUNING A CAVITY TO THE ACCELERATOR FREQUENCY

a) Cavity as delivered

An ideal cavity as produced by industry would have the right field flatness, the right frequency and the right length. However, a dispersion in frequency is generally observed due to deep drawing and welding inaccuracies and to chemical etching variations. For this reason, the cavities are first field-flattened and frequency tuned by acting on individual cell length. As a result, the total length of the cavity cannot be specified too sharply. The helium tank and the CTS must support this dispersion in length. A conservative figure is given as :

$$\Delta Z_1 = \pm 5 \text{ mm}$$

b) Cavity as adjusted

The cavity is then at frequency :

$$F1 \pm 100 \text{ kHz}$$

c) Cavity as surface treated

The cavity is now heat treated and surface treated. This process should not affect the field flatness (particular care has to be taken for this purpose). But, chemical etching will necessarily lower the frequency in a way which should be well mastered. The resulting new frequency is then about :

$$F2 = F1 - 300 \text{ kHz} \pm 150 \text{ kHz}$$

d) Cavity as harnessed and warm tuned

The cavity is then introduced into the helium tank and welded. A part of the lever system of the CTS is immediately assembled and blocked in order to fix mechanically the length of the cavity and helium tank before vacuum tests. Thus, inelastic deformation of the cavity will be avoided. The parts which are now assembled, should be simple enough to allow thorough cleaning as they will be on the cavity during class 100 clean room operations.

After tests and final surface treatment, the full CTS is installed. The stepping motor is set at the center of its range and extra adjusting screw allow a final room temperature setting at frequency :

$$F3 \pm 100 \text{ kHz}$$

At this point we should note that F3 must be lower than F2 for any cavity so that they must always be set in a state of compression (reduced length). The reason of this specification will appear later.

The deformation of the cavity must be here in the range :

$$\Delta Z2 = 0, -0.5 \text{ mm}$$

The corresponding resolution of this warm tuning operation is :

$$\delta Z1 = \pm 0.1 \text{ mm}$$

d) Cavity as cooled

After cooling, the frequency of the cavity (if it were free) would increase by about 2 MHz. However, the CTS and the helium tank are made of stainless steel which has twice the thermal expansion coefficient of the niobium, (niobium : 1.5 mm/m). As a result the cavity is compressed by its stainless steel harness. The frequency is then :

$$F4 \approx F3 + 1250 \text{ kHz}$$

The uncertainty on this shift is estimated at ± 500 kHz.

It could be better controlled after some experience. But, in order to avoid the risk of missing the target frequency, the tuning range of the remote controlled CTS is fixed at :

$$\Delta F4 = \pm 750 \text{ kHz}$$

Knowing that the tuning sensitivity is about 500 kHz/mm, the tuning range is set to :

$$\Delta Z3 = \pm 1.5 \text{ mm}$$

A resolution as required of 10 Hz of the CTS means a smallest step lower than : 20 nm. The present design derived from the MACSE CTS allows :

$$\delta Z2 = 1.5 \text{ nm}$$

f) Cavity mechanical neutral point

It is required that the relation between frequency and motor steps be as linear as possible for simple programming. This is generally easily obtained but in one case, when a backlash shows off if the tuning range crosses an equilibrium point between pushing and pulling.

This must be avoided.

As it is cooling, the cavity contracts by 1.5 mm whereas the helium tank contracts by 3 mm. This causes the cavity to be compressed. As the maximum elongation allowed by the CTS is not larger than 1.5 mm, we just have to make sure that the cavity is in a state of compression and not of elongation before cooling.

Frequency F1 and F2 must then be chosen so that this condition is fulfilled.

One has also to make sure that the mechanical neutral point will not change during the preparation of the cavity. This can happen if the stress in niobium overpasses the elastic limit. This must be avoided.

e) Tuning force

The maximum possible deformation after this total process is 3 mm due to the tuning range to which we must add the maximum possible stress which is imposed at the

final warm temperature tuning. The latter is of the order of 250 kHz representing about 0.5 mm.

The deformation force as calculated by DESY and SACLAY is 3000 N/mm. The maximum force applied by the CTS must then be :

$$f < 10^4 \text{ N}$$

As the CTS cannot be infinitely rigid, we must also specify its rigidity. The cavity must move by at least 75 % of the total deformation provided by the screw and nut system. This imposes a rigidity larger than 3×10^4 N/mm. Note that this reduces by a large amount ($\div 2$) the very conservative tuning range that has been specified previously.