TOWARDS THE CONSTRUCTION OF AN ULTRA SHORT CAVITY FOR HEAVY IONS SYNCHROTRON

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Abstract

Heavy ion need radiofrequency cavities that can be tuned over a wide frequency range, such as that of our MIMAS injector synchrotron ranging from 150 kHz to 2500 kHz.

We carried out a series of experiments on a reduced sized cavity (length = 120 mm, diameter = 80 mm) that had been filled with a high permeability material. In the light of the experiments it turns out that the frequency can range from 130 kHz to 3 MHz. The maximum power levels we could reach are mentioned in the paper.

The outcome of the experiments makes it possible to contemplate building a cavity for a heavy ion synchrotron whose length would be about half the size of a traditional one with equal electrical characteristics.

I - Introduction

Low energy heavy ion synchrotrons use accelerating cavities whose frequency can be tuned over a wide range with a very low starting frequency. For instance the "SATURNE II" synchrotron (3 GeV protons) uses two identical cavities (1) whose frequency ranges down from 850 kHz up to 9 MHz. In order to build our new injector synchrotron MIMAS (2) which started performing at the end of 1987, we had to design and make two cavities working on an even lower frequency range (150 kHz-2.5 MHz) that can yield a 4 kVpp maximum voltage on the accelerating gap (3).

A 2 x $\lambda/4$ (SATURNE II) or $\lambda/4$ (MIMAS) coaxial resonator loaded with high permeability ferrite (for low frequencies operation) has provided the basic element for the building of this type of cavity. Usually, for all low energy synchrotrons, the cavity's length should be as short as possible (4).

After running the accelerator MIMAS for three years, we could say that we had almost reached the maximum ratings we could expect from this type of ferrite-cavity, mainly its frequency swing, and the accelerating gap's maximum voltage possible. That's why we carried out experiments on other types of materials that could allow better ratings at low frequencies.

II - Nature of selected materials

It is known that the resonance frequency of a cavity loaded with a $\mu_0\,\mu_r$ magnetic permeability and a $\epsilon_0\,\epsilon_r$ dielectric permittivity material is proportionnal to $(\epsilon_0\epsilon_r\mu_0\mu_r)^{-\frac{1}{2}}$ with $c = (\epsilon_0\mu_0)^{-\frac{1}{2}}$. For a given length of a cavity, one has to select a high magnetic permeability material so as to reach a low resonance frequency. At the same time electric and magnetic losses of the material should be as low as possible to maintain a high enough impedance (few hundred Ohm). To this effect we decided to use an amorphous magnetic alloy (on a Co-basis) such as "VITROVAC" which was provided by the VACUUMSCHMELZE firm. For instance its relative magnetic permeability reaches 80000 at 10 kHz. These materials are available in the shape of toroïdal cores and are therefore very well suited to the building of a coaxial resonator. They are made of an about 25μm strip-wound toroïdal core. Each turn is electrically insulated from the next one by a 0.2μm -thick insulating coat. As we had done for MIMAS we took measurements on a model size coaxial cavity (fig. 1) loaded with four "VITROVAC" tores. Dimensions are following :

outer diameter = 80 mm
inner diameter = 50 mm
thickness = 25 mm

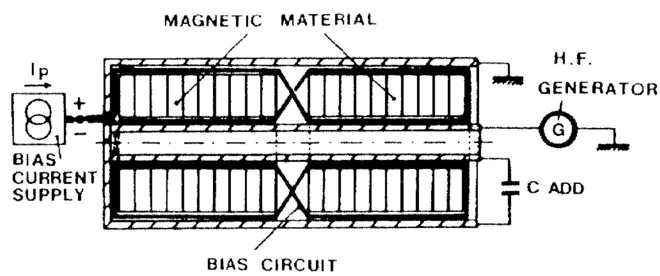

fig. 1 : coaxial test cavity scheme

Our interest was mainly focused on cavity impedance value, obtainable frequency swing and maximum possible voltage level.

III - Electric and magnetic characteristics of the VITROVAC

We compared the results to those we got on the same cavity loaded with a kind of ferrite (TDK) particulary well suited to low frequencies on which tests were carried out before the building of MIMAS (μ_r = 1600, quality factor = 6 at 150 kHz).

"VITROVAC"'s electric resistivity is 1.3Ωmm^2/m. Its relative magnetic permeability curve is schown on diagram 2. The usual ferrites loading the RF cavities have a constant permeability in the required frequency range. This VITROVAC material on the opposite, has a relative permeability that decreases with frequency from 10 kHz on. Nevertheless the relative magnetic permeability of VITROVAC is 5000 at 1 MHz whereas that of ferrite is 1500 at the same frequency.

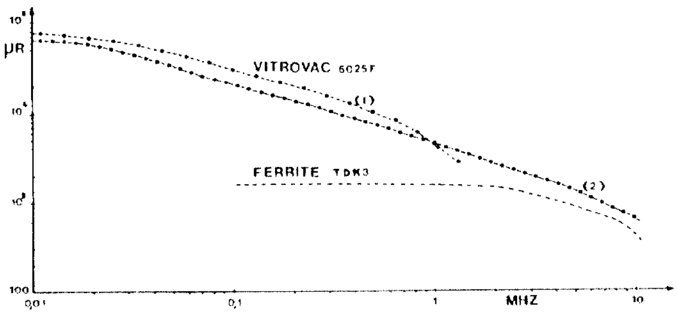

fig. 2 :
. (1) VITROVAC relative magnetic permeability (VACCUMSCHMELZE Data)
. (2) VITROVAC relative magnetic permeability (measured)
. ferrite TDK relative magnetic permeability (measured)

Dielectric transverse permittivities are comparable, with a value of $\epsilon r = 9$. It comes out from these first measurements that the wavelenght in this type of material ranges from 4.5 m at 150 kHz down to 1 m at 2 MHz according to the permeability decrease with frequency. Therefore a one meter long cavity (the usual size in accelerator building technology) could provide an ideal $\lambda/4$ resonator at 150 kHz.

IV - Model size cavity impedance

Still within the MIMAS cavities possibilities, we have tuned our cavity to a starting frequency of 150 kHz. Our biasing circuit is made of four turn copper wire around the material to be studied. In order to get this resonance frequency, one has to set a 3700 pF tuning capacitor on the "VITROVAC" cavity, as compared to 80000 pF on a ferrite loaded cavity. The impedances that have been measured are plotted on diagram 4.

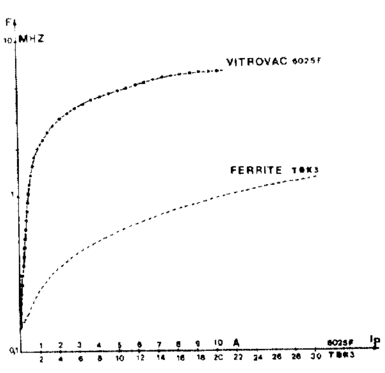

fig. 3 : cavity frequency range

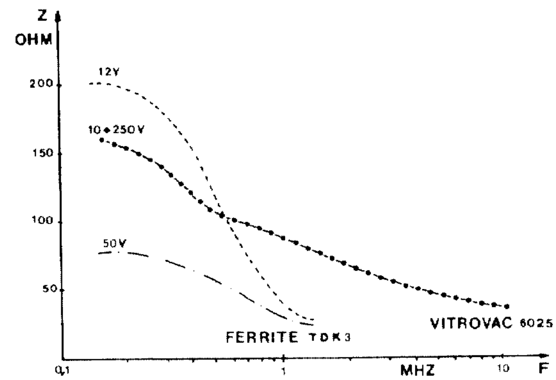

fig. 4 : cavities impedance for different voltage levels

Their values are roughly similar (higher for ferrite at low frequencies, lower at higher frequencies) at low level voltage. But the possible swing in frequency is far wider with the VITROVAC material. In fact a 1.5 A current is enough in our biasing circuit to go over the frequency range from 150 kHz to 2.5 MHz with the VITROVAC cavity while with ferrite 30A are needed to reach a maximum frequency of 1.3 MHz.

Besides, our measurement devices have not so far allowed us to test the capacities of our VITROVAC loaded cavity beyond the level of 250V. Nevertheless further tests have been made at 300 V in continuous wave without therebeing any amplitude distorsion or particular losses in frequency range 150 kHz - 3 MHz. In fact we don't exactly know the maximum voltage limits.

In ferrite-cavity impedances decrease very much with the RF voltage applied. It was only possible to obtain 50V in the range of 300 kHz-1.5MHz (220V from 150 kHz to 300 kHz). A hard Q loss effect is detected about 1 MHz.

V - Further tests on large diameter toroïdal cores

We asked "VACUUMSCHMELZE" to make for us two cores of the following dimensions (MIMAS dimensions) :

outer diameter : 510 mm
inner diameter : 355 mm
thickness : 25 mm

We set them into a model size cavity (L = 30 cm). Unfortunatly our "filling ratio" was not quite satisfactory. Yet we carried out the previous tests on our large size cavity. The impedance and frequency swing measurements at a lower frequency of 150 kHz (tuning capacitor = 10000pF) are shown on fig. 5 and fig. 6. As a comparison the same cavity loaded with ferrite has a 50Ω impedance at fo = 150 kHz (tuning capacitor : 100 nF)

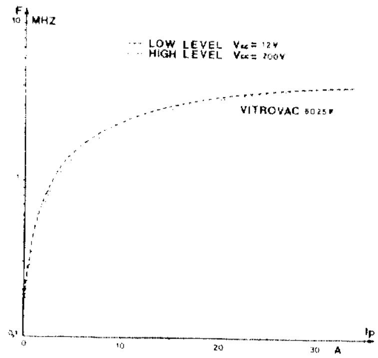

fig. 5 : frequency range (large toroïdal core)

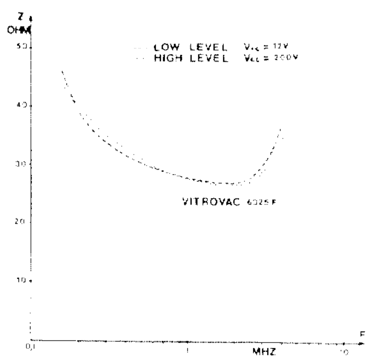

fig. 6 : cavity impedance (large toroïdal core)

Conclusion

The experiments we have carried out on amorphous materials are therefore most promising as to the building of low frequency accelerating cavities. In fact :

- because of the high value of magnetic permeability we can contemplate building short length (1m) accelerating cavities with a very low starting frequency (150 kHz or less),

- the maximum posible RF voltage applied is much higher for amorphous material (more than five times in our model size cavity).

- we can reach a much higher frequency swing than on ferrite cavities (fmax/fmin = 25 or more),

- at high voltage level, impedance will be higher in amorphous cavity (twice as high after our measurements).

The characteristics of amorphous materials are then well suited to the building of accelerating cavities for low energy synchrotron. Our purpose is to replace our two MIMAS accelerating cavities with a single one loaded with amorphous material. To achieve this goal, we are making further experiments meant to precisily detect the maximum voltage levels that can be reached on the accelerating gap.

Lastly we are aiming at better measuring the electric and magnetic losses occuring at high frequency (1 MHz - 10 MHz) in order to know if we can change SATURNE cavities.

Aknowledgements

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