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WIDEBAND RF-CAVITIES WITH AMORPHOUS IRON

Budker INP 2001-67

Novosibirsk
2001

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with amorphous iron

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Abstract

In the work presented here some results of the study of the amorphous iron Finemet FT-3 are given for the frequency range up to 35 MHz for operation in wideband RF-cavities.

Аннотация

В работе приведены некоторые результаты исследования аморного железа Finemet FT-3 в диапазоне частот до 35 МГц для работы в широкополосных ускоряющих устройствах.

Last years in RF- cavities of proton synchrotrons the amorphous iron is often used instead of conventional ferrites for frequency tuning. It is caused by the fact that the use of the amorphous material enables one to make such devices wideband without biasing systems, which are usually required in RF-cavities with ferrites for frequency tuning.

Obtaining very wide frequency ranges more then ten times seems to be not a complicated problem, than those in RF-cavities with ferrites.

In addition to the simpler and therefore cheaper design, the wideband RF- cavities have no limits in the tuning speed, it allows to design accelerators with low accelerating time $1-2$ msec and one can increase the repetition rate to increase the intensity.

One more indisputable advantage of the wideband RF-cavities is a possibility of superposition of the 2nd and 3rd harmonics to increase beam capture efficiency with no use of additional cavities [1].

At present the upper frequency of the wideband RF-cavities with an amorphous materials achieves 20 MHz [1]. However, in the literature there are no enough investigations on the peculiarity of using of the amorphous materials in this and in the higher range of frequencies. Therefore, we have to carry out some additional studies of amorphous materials within the frequency range up to 35 MHz. It is worth to mention that the expansion of the frequency range with the use of amorphous materials to the higher frequencies enables one to reduce the dimensions of new developed accelerators. The interest to the studies is related to the discussions about the development of the COMPACT PROTON AND HEAVY ION SYNCHROTRON FOR CANCER THERAPY AND BIO-SCIENCE, which requires development of a small-dimensional wideband RF-cavity operating within the frequency range of $1.7-15$ MHz with the maximum amplitude of the RF voltage of 13 kV [2].

FINEMET FT-3 of 20 mkm thick made by Hitachi Metals was taken as a test specimen.

In the process of the investigations the quality factor and permeability of the material FT-3 were measured as well as the frequency characteristics of the resonant circuit, whose inductance was made with an FT-3 core.

It is known, that permeability of the amorphous iron does not remain constant with the change of frequency. It decreases with its growth. Therefore, for calculations of the resonant circuit we had to measure its value at some frequency values within the range was studied. The results of measurements are given in Fig.1. As it follows from this characteristic, within the frequency range from 1 MHz to 7 MHz, the permeability varies from 6700 to 1500.

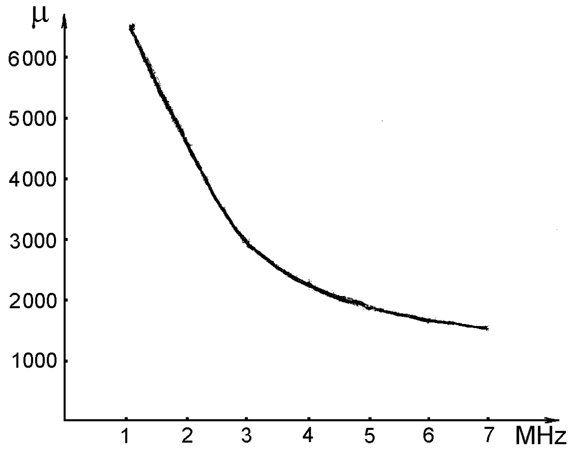

Figure 1: Permeability vs. of frequency.

To estimate losses in the resonant circuit with an amorphous iron we have measured the quality factor at some frequencies of resonant tuning. The circuit quality factor, whose inductance was made with an FT-3, for some frequencies and values RF flux density is given in Fig.2. As it is seen from the characteristic, within the frequency range 0.8 – 5.0 MHz the quality factor remains to be less than unit.

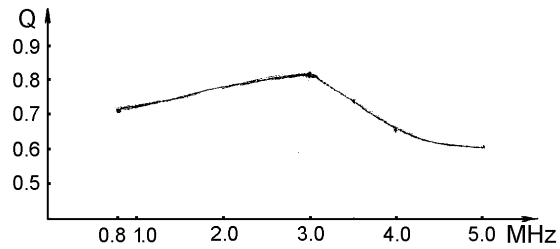

Figure 2: Quality factor vs. of frequency.

During measurements of the quality factor, the RF flux density in an amorphous material was 190 Gs at a frequency of 0.8 MHz and $50-40$ Gs at frequencies $3-5$ MHz.

Taking into account that the frequency characteristic of the resonant circuit with an unductance with amorphous core is asymmetric because of the permeability frequency dependence, it is interesting to determine the frequency limit dependence for various frequencies of the resonant tuning. In this connection, the frequency characteristics were measured for several frequencies of the resonant tuning to the resonance of 2.3, 3.5, 5.0, 7 and 9 MHz. Measurement results are given in Fig.3.

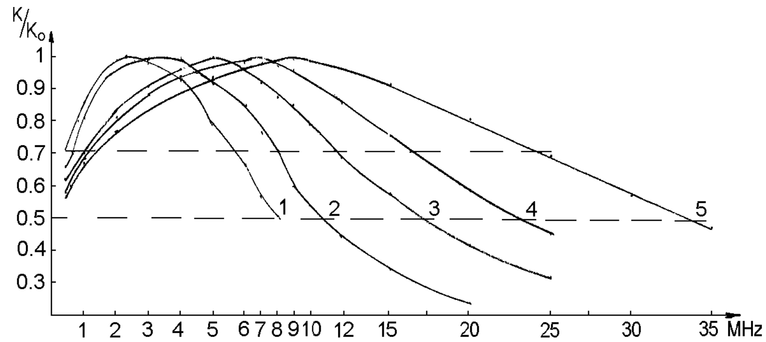

Figure 3: Frequency characteristic vs.of the resonant frequency: 1 - resonant frequency 2.3 MHz; 2 - resonant frequency 3.5 MHz; 3 - resonant frequency 5.0 MHz; 4 - resonant frequency 7.0 MHz; 5 - resonant frequency 9.0 MHz.

As is seen from these characteristics, the frequency characteristics are compressed from the side of low frequencies and expanded to the side of high frequencies to the right with respect to the resonance. Within the measured frequency range, the variation of the circuit resonant frequency leads mainly to the change of only upper frequency limit where the coefficient of voltage transfer ratio decreases down the level of 0.707 from the value at the resonant frequency. The lower frequency limit changes from 0.4 MHz to 1.4 MHz.

As a result of studies it was found out that the resonant frequency change from 2.3 MHz to 9.0 MHz leads to change of the bandwidth from 5.0 MHz to 24 MHz, i.e. almost a 4 times change of the resonant frequency leads to the increase in the bandwidth more than 4.5 times. On average, we can take that the resonant frequency change by 1.0 MHz leads to the change of the upper frequency limit by a considerably larger value of $2.5 - 3$ MHz. Such a strong dependence of the upper frequency limit of the resonant circuit with an inductance comprising an amorphous iron on the resonant frequency makes reasonable its graphic representation as shown in Fig.4 (1). By using the characteristic obtained, without special measurements, knowing only the resonant frequency, one can determine the upper frequency limit of the RF-cavity with an amorphous iron or , as mentioned above, taking into account that in practice, the lower frequency limit changes slightly within the wide range of resonant tuning remaining to be about 0.9 ± 0.5 MHz and the bandwidth.

The characteristics obtained enable us to come to the following conclusion: the wider is the required frequency range, the higher should be the cavity resonant frequency.

As one can see from the characteristic, if the resonant frequency is 6.5 MHz, one can obtain the upper frequency limit of 15 MHz, which is required for the accelerating system considered. In this case, at a lower frequency of the operation range of 1.7 MHz the coefficient of voltage transfer ratio is 0.8.

In some cases of RF- systems operation, the large drop of the coefficient of voltage transfer ratio on the upper frequency is admissible, for example, down to the level of 0,5. In this case, the bandwidth can

As is follows from the characteristic, an increase in the initial resonant frequency, for example, up to 9.0 MHz leads to an increase in the upper frequency limit up to 24 MHz and at the level of 0.5 up to 34 MHz.

It is worth to mention that these studies of frequency characteristics were carried out with the use of low power high frequency transistor at low levels of power, at which the RF flux density in an amorphous iron did not exceed several Gausses. In the RF-cavities the RF flux density can reach $200 - 500$ Gs and higher. Therefore, in the real designs of RF-cavities, one should expect even larger bandwidth. In addition, the circuit parameters during measurements, in particular, the circuit capacitance can be chosen arbitrarily with the only limit from the transistor output capacity and measuring circuit, the total value of which does not exceed 25 pF. Under the real conditions, RF-cavities are powered with powerful tubes with substantial output capacity. Therefore, the total capacity including the mains capacity and that of the cavity accelerating gap can not apparently made lower than $80 - 100$ pF. Natural wish to decrease the high frequency power for powering the RF system requires an increase also in the cavity inductance. All this leads to that the cavity resonant frequency has to be selected lower than $5.0 - 6.0$ MHz.

Because of these restrictions, the wideband RF-cavities with an amorphous iron for the operation in a wide range of frequencies with the upper frequency limit higher than 15 MHz should inevitably have the non-homogeneous frequency characteristic with the non-homogeneity lower than 0.707.

The given restrictions on the selection of the resonant frequency and non-homogeneity of the frequency characteristics are only related to accelerating devices powered by the powerful resonant amplifiers. When feeding cavities from power amplifiers with the distributed amplification, the resonant frequency can be selected substantially higher than mentioned above, since in this case, the output capacity of the terminal circuit is included into the anode delay line and thus, it turns out to be neutralized, and the resonant frequency at a given inductance is mainly determined by the capacitance of the accelerator gap,

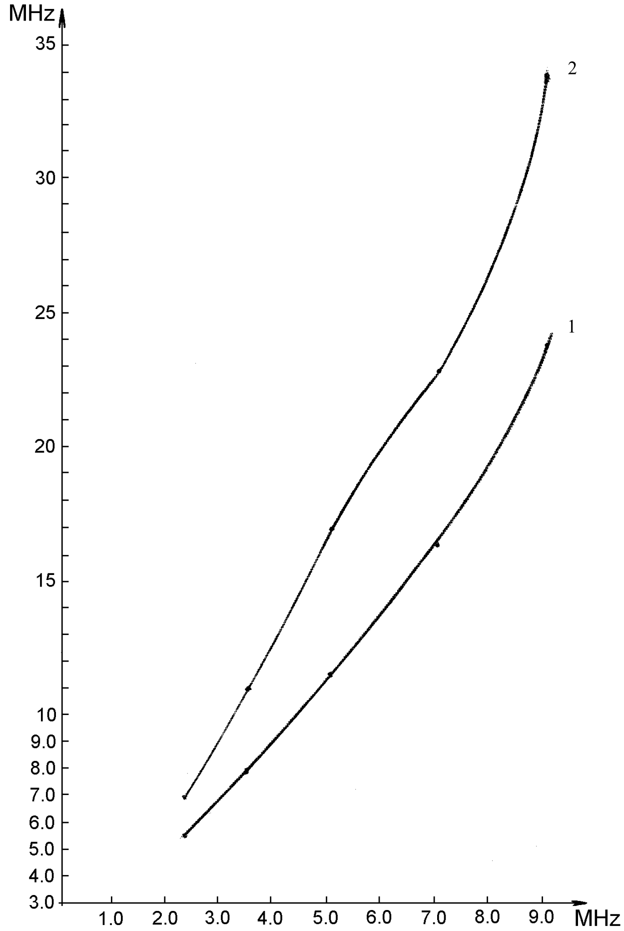

Figure 4: Upper frequency vs. resonant frequency: 1 - upper frequency limit, 2 - upper frequency on the level of 0.5.

be substantially increased to the side of high frequencies. For comparison, Fig.4 (2) shows the dependence of the upper frequency with the coefficient of voltage transfer ratio of 0.5 on the resonant frequency.

which can be made sufficiently small. However, one should take into account that when feeding RF-cavities from distributed amplifiers, the required RF power increases because of the resistors of the compensating network. In some cases, this power increase achieves 30% [1] and can not always be admissible especially for the development of compact accelerators with corresponding small RF-cavities and adequate RF power supply.

The author is thankful for Dr. G.I. Silvestrov for the support and constant attention to this work. Special thanks for S. Ninomiya.

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ИЯФ 2001-67

Ответственный за выпуск А.М. Кудрявцев
Работа поступила 25.10.2001 г.

Сдано в набор 26.10.2001 г.
Подписано в печать 26.10.2001 г.
Формат бумаги 60×90 1/16 Объем 0.6 печ.л., 0.4 уч.-изд.л.
Тираж 90 экз. Бесплатно. Заказ № 67

Обработано на IBM PC и отпечатано на
ротапринте ИЯФ им. Г.И. Будкера СО РАН
Новосибирск, 630090, пр. академика Лаврентьева, 11.