ACCELERATING CAVITIES WITH AMORPHOUS IRON

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Abstract

In present paper some peculiarities of amorphous iron application in RF cavities for proton synchrotrons are observed. The construction of broadband RF cavity with amorphous iron is presented.

INTRODUCTION

More than fifty years in accelerating proton synchrotron devices for fast frequency tuning, mainly, the ferrites were used. However, in latter years, abroad, in newly developed and modified heavy ion and proton synchrotrons operating in frequency range up to 5.0 Hz and more, in accelerating cavities the ferrites are successfully replaced by amorphous alloy. This is explained by the fact that amorphous iron application enables to qualitatively and quantitatively change those devices and, first of all, to reduce the sizes, to simplify the construction and to considerably decrease the development and manufacture costs.

Modern under construction accelerator complexes require very high accelerating voltage. For example, in 3 GeV booster of JHF (Japanese Hadron Facility) project the necessary accelerating voltage is more than 800 kV [1], and accelerating device unit of length voltage increase is a natural aspiration. It is important task to reduce the sizes of RF cavities when also developing compact proton and ion synchrotrons for cancer therapy [2]. The radius of these devices is less than one meter; and placing of large accelerating station becomes problematic. As a result, the requirements to newly developed accelerating devices are sufficiently increased. The accelerating voltage and frequency tuning range support only is found to be not enough. The task to optimize the RF cavities, i.e. to get electrical parameter at small dimensions, is important.

SOME CHARACTERISTIC OF AMORPHOUS IRON

The use of amorphous iron enables to sufficiently move up the solution of this task. It is explained by the fact that amorphous iron assumes high levels of rf flux density, which are several times higher than the values for ferrites. If for amorphous iron the 0,05-0,1 T rf flux density levels are operative, 0,015 T levels for ferrites, as it is known, are already limiting. Hence, the change of ferrites by amorphous iron enables to reduce the dimensions of accelerating cavities.

The efficiency of amorphous iron application instead of ferrites for size reduction is estimated by overall index that is often shown in a frequency tuning accelerating device literature. Such an index is a rate of accelerating voltage amplitude to linear cavity length. The level achieved in the cavity with ferrites of more than 10 times tuning ratio and average loss power of 1,3W/cm^3 fits the value of 15 kV/m [3].Amorphous matter application enables to get 100 kV/m value at 4 W/cm^3 loss density [1].

To estimate the economy of amorphous iron application it is possible, on the analogy of ferrites, to use the index μQf, where: μ–permeability, Q–quality factor and f is frequency in Hz.

For amorphous iron Finemet FT-3M the index μQF is equal to 0,4E+10 up to 0,2T rf flux density, while for Ni-Zn ferrites this value fits 0,006T rf flux density and sharply decreases due to further rf flux density growth [1].

Amorphous iron application enables to produce broadband accelerating devices without traditional biasing systems, which, usually, are required in ferrites RF cavities for frequency tuning. These devices, especially those for providing fast frequency tuning of, for example, 5000-10000 MHz/sec, with repetition rate up to 50 Hz, become comparable by equipment volume and power consumption with RF power amplifiers supplying the RF cavities [3]. That is why, an abolition of biasing systems strongly simplifies accelerating device and increase its reliability.

As it was shown [4] a frequency range of amorphous iron RF cavities depends on a choice of initial frequency tuning, which is close to a frequency value on which the amplitude of response characteristic is maximum.

To estimate a possibly frequent range, one can use simple ratio between maximum amplitude response characteristic frequency and boundary frequency achieved after approximation of experimental response characteristics measured at a prototype of RF cavity with amorphous iron FT-3M [4].

$$f_{up.} = 2{,}35\, f_{max.} \quad (1)$$
$$f_{low.} = 0{,}2\, f_{max.} \quad (2)$$

where:

$f_{max.}$ is the RF cavity frequency tuning in MHz, at which response characteristic is maximum

$f_{up.}$ is the upper boundary frequency of the RF cavity transmission band in MHz.

$f_{low.}$ is the lower boundary frequency of the RF cavity transmission band in MHz.

Boundary values $f_{low.}$ and $f_{up.}$ are calculated by the frequency at 0.7 level from maximum value of amplitude response characteristic.

The received ratios allow writing down the expression for value of the transmission band of the RF cavity–fb. MHz.

f b.=2,15 f мах. (3)

It follows that the higher initial frequency tuning, the RF cavity transmission band is wider.

Amorphous iron is industrially produced in the form of ready-made rings with a big set of standard sizes. The quantity of standard sizes produced in Russia runs up to 150 [5]. Japanese company Hitachi Metals produces the amorphous iron with the dimensions that is ordered by a customer.

The amorphous iron may be produced with more than 250 mm ring external dimensions. Ferrites of such dimensions in Russia are made from separate segments only and their further utilization in accelerating devices involves laborious process of mechanical treatment and gluing.

RF CAVITY DESIGN

As a model of RF cavity, the construction proposed in paper [6] is offered.

The main idea consist in that, the accelerating system is made in form of a few of coaxial RF cavity sections corresponding to the number of amorphous iron rings. Each ring is glued with the heat conducting glue into the section housing which serves simultaneously functions of the RF cavity and heat removal, as is shown in Fig .1.

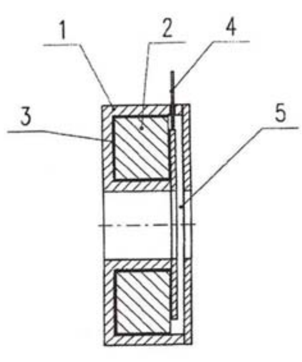

Figure 1: Design of accelerating section: 1-housing, 2-amorphous iron, 3-glue, 4- RF power input, 5- accelerating gap.

The RF power extraction in an amorphous iron is removed to the section housing through the end surface of the ring in the direction of the maximum conductivity. The thickness of glue layer is no more than 0.5–1 mm. The glue provides also the electric insulation between the amorphous iron and the housing.

The silicon organic compound “Elastoseal” with high dielectric and heat conductivity is used as a glue.

Each section can be coold either with air or water. In the case of water cooling, pipes are soldered to the outer surface of the section.

The overlapping of few functions in each section functional element allows to simplify the resonator as much as possible, to exclude a significant amount of additional devices and by that to reduce dimensions, laboriousness of development and manufacturing

In such a design of accelerating system the losses of high-frequency capacity appear to be minimally possible as they are defined only by losses in amorphous iron.

Each section has accelerating gap, whose voltage is lover than the total accelerating voltage by a factor equal to the number of sections form the accelerating system.

A feature of the design is an absence of high voltage at all the units of the accelerating device at a high total accelerating volltage.

Each or few sections connected in parallel to RF power source, forming the separate module.

Modules are established sequentially one after another, are electrically and mechanically pieced together and are drawn together by bolts, forming a uniform design of accelerating system.

CONCLUSION

On the basis of this offer the accelerating system for proton synchrotron was developed in Japan. On this system the 1.7-15 MHz tuning range and the parameter of accelerating voltage/length of 25 kV/m was achieved [7].

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