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RF–CAVITY FOR COMPACT PROTON SYNCHROTRON

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НОВОСИБИРСК

RF-cavity for compact proton synchrotron

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Abstract

The results of the work on producing the accelerating system for compact proton synchrotron are given. Fast frequency tuning during 2.5 ms in 2.7 – 22 MHz range and high voltage on one accelerating gap are the main features of the accelerating system.

The RF cavity contains ferrites, for which the work regimes at uprated levels of RF flux density are investigated and factor quality is measured. The measurement results are given.

The estimation of ultimate voltages on one accelerating gap is made basing on performed investigations for the case of the constant level of RF power supply.

Аннотация

Приведенны результаты работы по созданию ускоряющей системы для малогабаритного протонного синхротрона. Отличительной особенностью ускоряющей системы являются быстрая (в течении 2.5 мс) перестройка частоты в диапазоне 2.7 – 22 МГц и высокое напряжение на единичном ускоряющем зазоре.

Ускоряющая система содержит ферриты, для которых исследованы режимы работы при повышенных уровнях высокочастотной индукции и измерена добротность. Приводятся результаты измерений.

На основе проведенных исследований сделана оценка предельных напряжений на единичном ускоряющем зазоре для случая постоянного уровня высокочастотной питающей мощности.

The work on making compact proton synchrotron [1] is being fulfilled in BINP during a number of years for proton therapy purposes. During last years physicists in Italy, in collaboration with whom STAC [2] project (synchrotron technology advantage and compact) has been designed, show interest to this project.

Creation of RF systems, which parameters are close in a principle plan, is one of the problems at the development of these synchrotrons.

In frame of the work on the STAC RF system development originally was developed the RF system for STAC prototype — compact proton synchrotron (CPS). It is explained by the fact, that the main CPS devices (magnetic vacuum system, injector, power supply system) are already made or are at the completing stage of production.

Produced RF system allows, firstly, to start designing and producing STAC RF system on a basis of found solutions and, secondly, being installed on existing synchrotron, allows to solve problems of capturing, tracing and extraction of particles in advance of STAC production and, besides, allows to use synchrotron as an independent accelerator.

The main CPS paramaters are given in Table 1.

Table 1

Maximum energy	MeV	70 – 200
Maximum dipole field	T	5
Dipole radius	m	0.43
Intensity per pulse		10^{10}
RF voltage	kV	14
Equilibrium phase SinF		0.5
Tuning range	MHz	2.7 – 33.3
Accelerating time	ms	2.5

Taking into account that the greatest difficulties are related to the getting of high voltage at the beginning of range and to the provision of a fast frequency tuning, it was decided to develop on the first stage an RF-cavity, that provides maximum possible RF voltage on one accelerating gap and is tuned in frequency range in less than 2.5 ms time. It was supposed with that to use the existing standard RF tubes and ferrite rings with the lowest allowable diametrical sizes.

Preliminarily investigations allowed to suppose that RF voltage, that is about 4 kV, can be obtained on accelerating gap in the cavity on 200 ВНП type ferrites with standard sizes of rings 180×110×20 mm and with 45 degrees electrical length, that can be located in the CPS lattice. As this quantity is less than the required 14 kV, so the frequency tuning range is limited in such way, that it will be possible to accelerate up to 70 MeV energy at 2 RF cavities installation with 4 kV RF voltage on each.

The main parameters of the RF-cavity are given in Table 2.

Table 2

RF voltage	kV	4
Frequency range	MHz	2.7 – 22
Accelerating time	ms	2.5

Produced cavity represents the coaxial short circuited line filled up with 200 ВНП type ferrite rings. Rings sizes are 180 × 110 × 20 mm. The height of a ferrites set is 180 mm. The electric line length is 39 degrees. Geometric length is 200 mm.

Ferrite cooling system is made on the principle, developed by us before and successfully used in previous designs [3]. Cavity tuning for frequency is executed with the help of electromagnetic bias device, that is supplied from the pulse bias amplifier, made on KT-872A transistors. The total number of transistors in the amplifier is 60 pieces.

Fig.1 shows resonance frequency at various bias amper turns. Fig.2 is time characteristics of the cavity with 200 ВНП ferrites. As it seen from these figures, the cavity tunes in a 2.7 – 23 MHz range during 1 ms. The maximum frequency tuning speed is 30000 MHz/s. The obtained time values of cavity tuning and the frequency tuning speed exceed in several times the analogous characteristics, supposing for STAC.

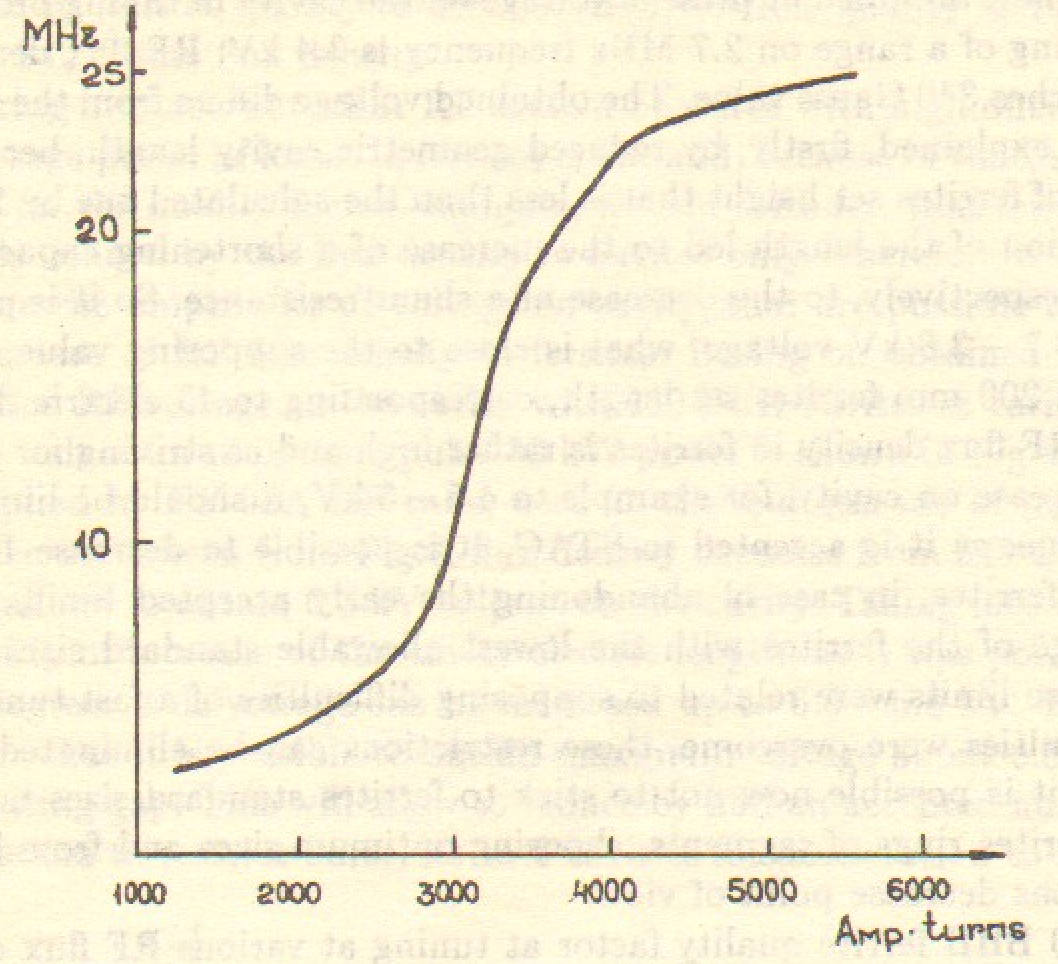

Fig. 1. Resonance frequency at various bias amper turns.

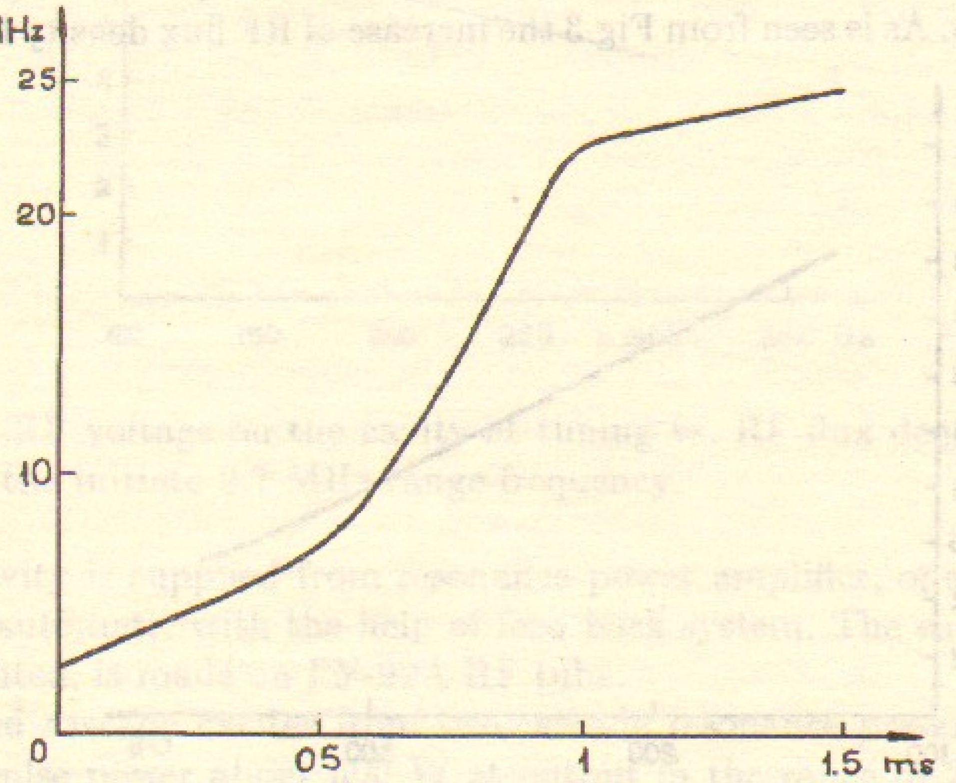

Fig. 2. Time characteristics of the RF-cavity with 200 ВНП ferrites.

The highest obtained at present voltage on the cavity in tuning process at the beginning of a range on 2.7 MHz frequency is 3.4 kV. RF flux density in ferrites reaches 340 Gauss value. The obtained voltage differs from the project value. It is explained, firstly, by reduced geometric cavity length, because of the choice of ferrites set height that is less than the calculated one by 20 mm. The reduction of the length led to the increase of a shortening capacitor by 10% and, respectively, to the decrease of a shunt resistance. So it is possible to obtain 3.7 – 3.8 kV voltage, what is close to the supposing value, on the cavity with 200 mm ferrites set length, corresponding to 43 electric degrees. Secondly, RF flux density in ferrites is rather high and as striving for further voltage increase on cavity, for example to 4.5 – 5 kV, it should be limited by a lower value, as it is accepted in STAC. It is possible to decrease RF flux density in ferrites, in case of abandoning the early accepted limit, related to the usage of the ferrites with the lowest allowable standard sizes in the cavity. These limits were related to supposing difficulties of a fast tuning. As these difficulties were overcome, these restrictions can be eliminated. More than that, it is possible now not to stick to ferrites standard sizes now and to bond ferrites rings of segments, choosing optimum sizes and from biasing consumptions decrease point of view.

The 200 ВНП ferrite quality factor at tuning at various RF flux density amplitude at the initial 2.7 MHz range frequency is measured to clear up the question of the expedient value of RF flux density. This dependence is given in Fig.3. As is seen from Fig.3 the increase of RF flux density leads to the

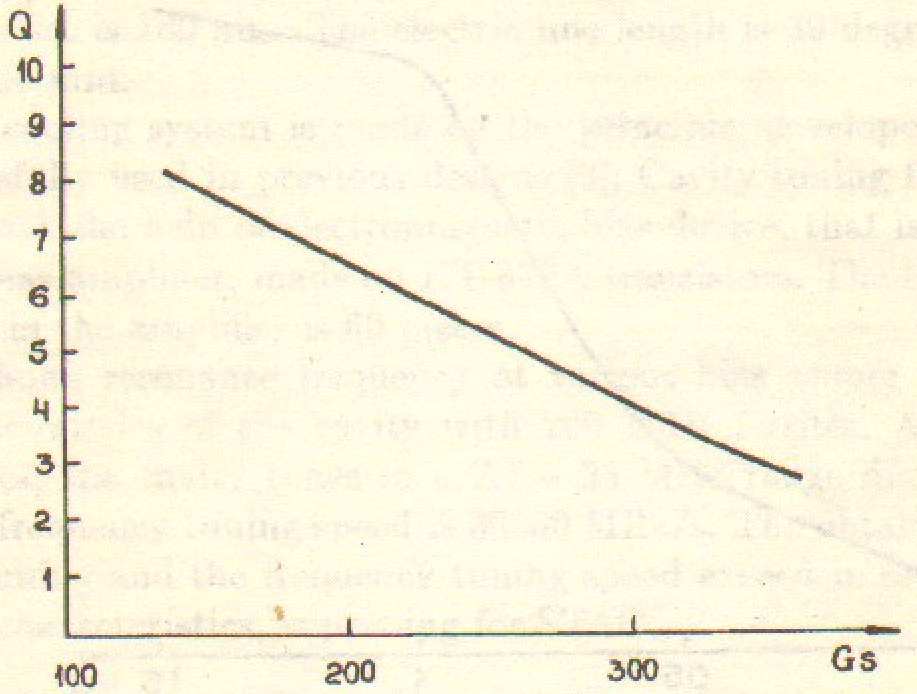

Fig. 3. The RF-cavity quality factor at tuning vs. the value of RF flux density in ferrite at the initiate 2.7 MHz range frequency.

decrease of ferrites quality factor. 200 ВНП ferrites quality factor decreases to 3 at 340 Gauss flux density.

Taking into account, that RF system operates with high duty factor and the average power of losses in ferrites is low and, because of that, it influences weakly on the quality factor changing, we can consider, that ferrites quality factor is defined by the flux density in ferrites only. Therefore it is expidient to define the amplitudes of voltage on cavity, that are possible to obtain at the decrease of RF flux density in ferrites. Basing on obtained results, the calculated RF voltage on the cavity with 200 ВНП ferrites at various RF flux density values for maximum pulse 30 kW power is shown in Fig.4, which can be supplied by ГУ-92А RF tube, used in the end cascade of power supply amplifier. As is seen from Fig.4, flux density decrease from 340 Gauss to 150 Gauss allows to obtain 6.3 kV voltage on the cavity. Taking into account the possibility of increase of the cavity electric length, as it was pointed earlier, to 45 degrees, this voltage can be increased up to 6.5 – 6.8 kV. Thus we can consider that it is possible to obtain maximum voltage about 6.5 kV on one accelerating gap. This will allow to reduce by half an accepted number of RF cavities and to restrict ourselves to 2 cavities for acceleration to 200 MeV.

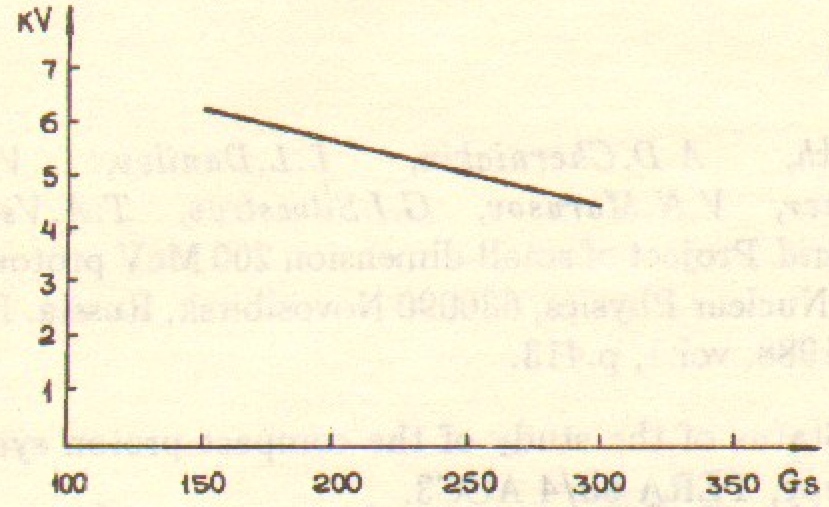

Fig. 4. RF voltage on the cavity at tuning vs. RF flux density values in ferrites at the initiate 2.7 MHz range frequency.

The cavity is supplied from resonance power amplifier, operating in the regime of automatic with the help of feed back system. The end cascade, as it was pointed, is made on ГУ-92А RF tube.

The end cascade excites from two-cascade resonance pre-amplifier, that provides pulse power about 500 W at output in the range of 2.7 – 32 MHz tuning frequencies.

It is expedient to compare the main principal parameters of developed

RF system with planned STAC project characteristics. For convenience these parameters are given in Table 3.

Table 3

Parameters		CPS RF system	STAC RF system
RF Voltage on one gap	kV	3.4	3.1
Rf flux density	Gauss	340	185
Tuning ratio		8.5	3.6
Tuning time	ms	1.0	3.5
Tuning speed	MHz/s	30000	8500

As it follows from Table 3, the developed RF system exceeds the characteristics of STAC system for all parameters.

The obtained experience allows to start RF development of STAC system.

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