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STAC ACCELERATING SYSTEM

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Abstract

The problems and the results of the work for creation an accelerating system are considered for compact proton synchrotron. Distinctive peculiarities of the accelerating system are a high RF voltage 12.4 kV and tuning speed 14000 MHz/s. The frequency range is 7.4 – 27 MHz. The constructive csheme of the accelerating system is given.

Ускоряющая система для синхротрона STAC

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Аннотация

Рассмотрены проблемы и результаты работы по созданию ускоряющей системы для малогабаритного протонного синхротрона. Отличительной особенностью ускоряющей системы являются высокие ускоряющее напряжение 12.4 кВ и скорость перстройки частоты 14000 МГц/с. Диапазон перестраиваемых частот 7.4 – 27 МГц. Приведена конструктивная схема ускоряющей системы.

The main problems of the creation of the STAC (synchrotron technology advantage and compact) accelerating system [1] are connected with the necessity of obtaining a rather high RF voltage of a rapid tunable cavity in a wide frequency range. The technical difficulties of obtaining high RF voltages are caused by ferrites which are used for frequency tuning. It is known that at the beginning of fast biasing the ferrite quality factor falls several times comparatively to the level of ferrites in not-magnetized state. That's why for obtaining a high quality factor it is necessary to choose ferrites with a high initial quality factor, but such ferrites have a small permeability and there are difficulties with a frequency range providing. Besides, the quality factor reduces with increasing of RF flux density in ferrites, it happens with the growth of RF cavity voltage. The ultimate values of RF flux density, when the quality factor is still satisfactory don't exceed $150 - 200$ Gs. Reducing of the RF flux density level by increasing of ferrite volume provokes difficulties with a fast tuning and with the accelerating system placing because of limited straight section which contains only 470 mm. The task of STAC is complicated by the fact that the highest RF voltage is necessary at the beginning of the accelerating cycle on the lowest frequency range, where the RF flux density of ferrites has the highest value, and their quality factor is minimum, because of a high RF flux density and the fall of the quality factor at the beginning of the process of fast biasing . The low quality factor of ferrites means the low shunt impedance, and as that's why the RF voltage of the cavity must be maximum, a necessary RF power supply is maximum for the accelerating system. Usially the final cascades of RF power supply amplifiers are made on tubes which are installed directly on the RF cavity. For high power creation powerful tubes with large dimensions are required. The anode of the tube and the construction which connects it with the RF cavity, form an additional not-tuning volume. At the case of large dimensions it can limit obtaining the required tuning range of the RF system and considerably increases the bias power supply. Besides that, if the straight section dimensions are limited, it's difficult to locate a large tube on the RF system.

The parameters of the STAC accelerating system at 12 Mev injection energy are given in Table 1.

Table 1

RF voltage	kV	12.4
Frequency range	MHz	7.4–26.6
Accelerating cycle duration	ms	3,5
Tuning speed	MHz/s	14000
Number of cycles per seconde		10

The elaboration of the STAC accelerating system is based on BINP's experience of the creation of compact rapid tuning accelerating devices with ferrites. Particular principal and constructive decisions allowing to accomplish technical requirements to STAC RF system were tested and realized at the operating accelerating systems of proton synchrotron B-5 [2], electron synchrotron B-4 [3] and RF system of compact proton synchrotron [4]. That's why it is possible to provide the STAC accelerating system parameters by using all these decisions during the development at the same time. The point of these decisions is next:

1. Accomplishment of the accelerating system as several resonance sections with several accelerating gaps, combined into the united accelerating device [5].
2. Minimum ferrite volume application in RF cavities.
3. Usage of the construction as RF cavity in wich all the housing is full of ferrites, and spaces which are not-occupied by ferrites, are so minimum as it is possible.
4. Accomplishment of a biasing winding as sectional with every section supply from a particular biasing amplifier.

As it was already pointed the idea obtaining of high voltages in RF cavities on ferrites consists in the fact that the full voltage is distributed uniformly between several cavity sections. Such a full voltage distribution allowes to reduce the RF flux density, the ferrite losses and also reduces the required RF power. This excludes the necessity of powerful tube application in the final cascades and removes the problem of their placing. Every section is made with such a minimum ferrite volume in which the operating regimes are provided with a high quality factor. Every section has an accelerating gap. The sections are connected in parallel and are placed at the same straight section.

Taking into account that the high RF voltage of the STAC accelerating system must be provided simultaniously with the rapid tuning of the frequency, for optimizing its volume and reducing the biasing power, preliminary it is necessary to define the most possible RF voltage of a cavity section made with the smallest ferrite volume. And it is supposed that all the section is full of ferrites. For this goal the cavity was made, it represents a short-circuited at one end coaxial line which is completly full of ferrite rings. For investigation ferrites of 60 BNP type were chosen with minimum standart dimensions which can be used at STAC. The ring dimensions are 180 × 110 × 20 mm. 100 mm of the ferrite set lenght were chosen with taking into account the possibility of placing of four sections in a lattice.

Ferrite biasing and cooling systems are completly taken away from the internal cavity volume into the external side of the housing and does not prevent to a full filling of lines by ferrites and consequently to obtaining the highest tuning.

A cavity tuning by the frequency was realized with help of electromagnetic biasing device. In the coordination with earlier indicated recommendations for reducing a reactive power, the biasing winding was made as several galvanicaly isolated sections, and every one is supplied by a particular semiconductor amplifier. Amplifiers are united only by an input signal. Every amplifier is intended for the amplification of a sawliked pulse current till 50 Amp. and a momentary overload by the voltage till 1 kV.

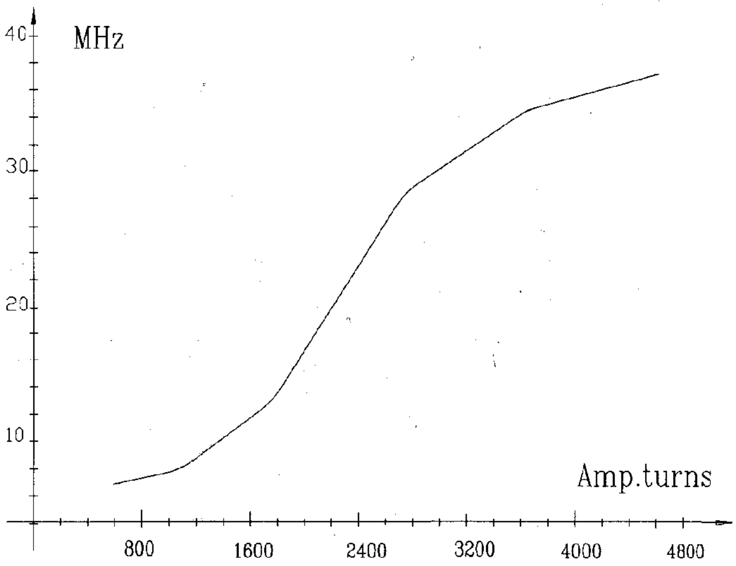

Figure 1: Resonance frequence vs. Bias Amp. turns.

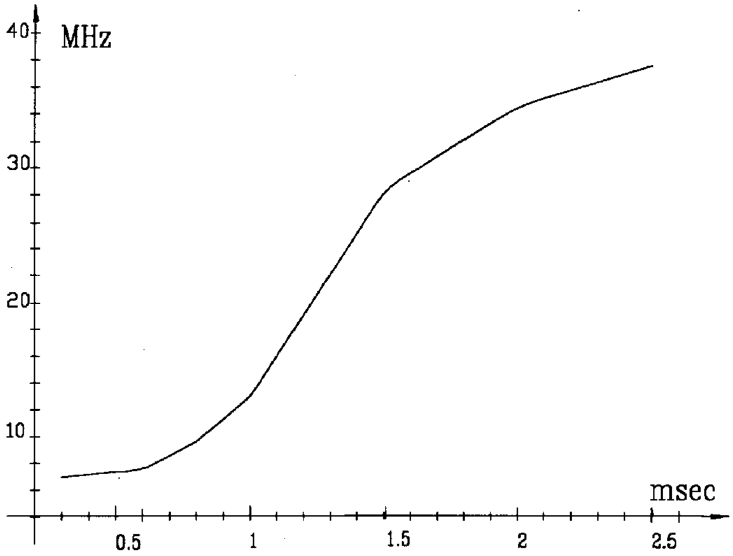

Figure 2: Frequence vs. Time.

The resonance frequency dependence on bias amper turns and time characteristic of the RF cavity are given in Fig.1 and Fig.2. As it is showen in Fig.1, the cavity is tuned

5.2 times at the frequency range of 7.2 – 37.5 MHz, that exceeds considerably the required tuning range for STAC accelerating system. A necessary range tunes in practice in 1 ms. The tuning speed at the beginning of the tuning range, where it must be maximum, achieves a desined value 14000 MHz/s.

The measurment of RF voltage of the cavity at the tuning process was carried out at the beginning of frequency range of 7.4 MHz, to which correspond the highest value of the operating regime, and consequently the highest RF flux density and losses of ferrites.

RF cavity was supplied by a specially fabricated tuning resonanse amplifier of the RF power, and its final cascade is made on GU-92A tube.

Figure 3 shows experimentally obtained dependence of the RF cavity voltage on voltage amplitude of the excitation at the control grid of the final tube. The maximum RF cavity voltage amplitude obtains the value of 3250 V., that corresponds to a ferrite RF flux density 215 Gs. A further excitation voltage increasing does not lead to a substantial voltage increasing of the cavity. It is probably explaned by a sharp fall of the quality factor at the process of obtaining ultimate values of RF flux density which are higher then 200 Gs for 60BNP ferrites.

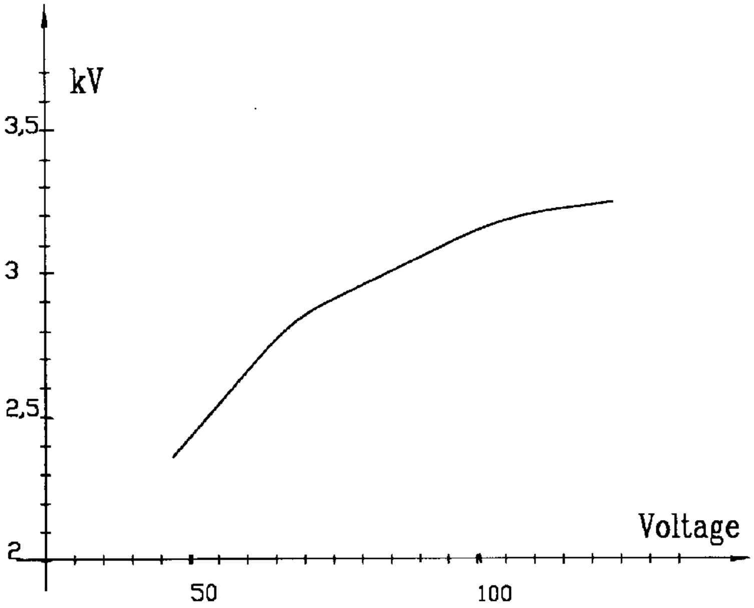

Figure 3: RF voltage of the csvity vs. the exciting voltage of the cascade.

At the base of these measurments the calculations of the cavity quality factor depending on the RF flux density level of ferrites were made. The curve of this dependence is given in Fig.4. From this characteristic it is clear that the ferrite quality factor falls nearly by half with increasing of RF flux density from 150 Gs to 200 Gs.

Using this characteristic, it is possible to choose such diametral cavity dimensions which would permit to obtain a considerably higher RF voltage with given excitation power or the same voltage, but with a less power. However, in our case, using such a high tuning speed it is expedient to conserve the earlier chosen dimensions of a cavity section,

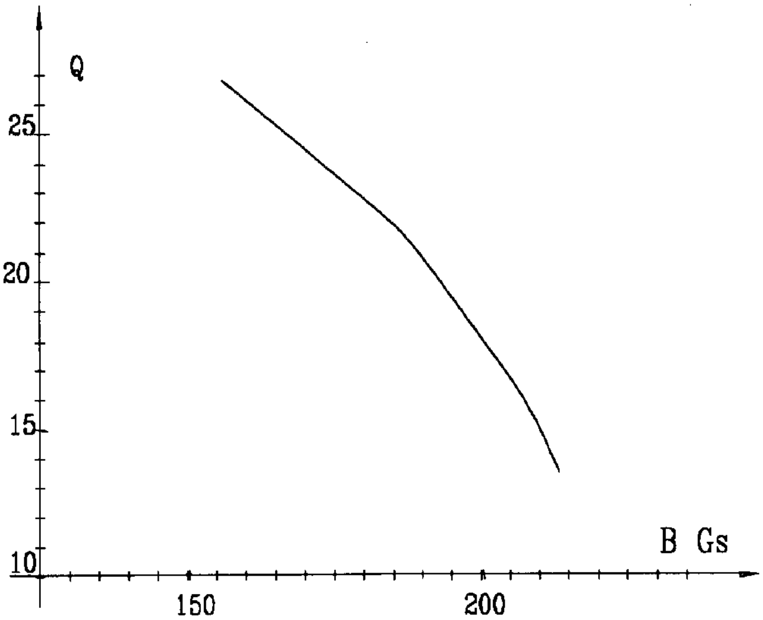

Figure 4: RF cavity quality factor vs. RF flux density in the ferrite.

in spite of the high flux density (200 Gs) of ferrites. Such a choice permites to limit a reactive biasing power and to obtain the voltage of 3100 V of a cavity section.

Figure 3 shows that for obtaining 3100 V of the RF cavity for exciting the final tube GU-92A, the voltage of 90 V is required. That approximately corresponds to half an anode current of a tube. That's why for a full tube usage it is expedient to load it on two cavity sections. In this case a full accelerating voltage can be obtained from four equal cavity sections with accelerating gaps and suppliing from two GU-92A tubes.

The constructive scheme of the STAC accelerating system with the biasing device are given in Fig.5.

Four equal cavity sections are geometrically installed in series and are united into two groupes forming two RF cavities. Every RF cavity is supplied by a particular RF power amplifier and is tuned by a particular biasing system. RF cavities are installed in a straight section to meet each other and they are fed with counter-phase voltage. The full lenght of the accelerating system is 470 mm.

Ferrites are surfaced for every section all over the surfaces and are glued in the section housing with a heat conductive glue "Elastoseal". The heat which is given off out ferrites in every section is carried off through a thin glue layer on the housing, from which it can be taken off by convection or by water with increasing of accelerating cycles.

The open end of every section is loaded on 440 pF capacitor which form an accelerating gap.

Length of ferrite set of a section, number of rings, flux density and specific losses are given in Table 2.

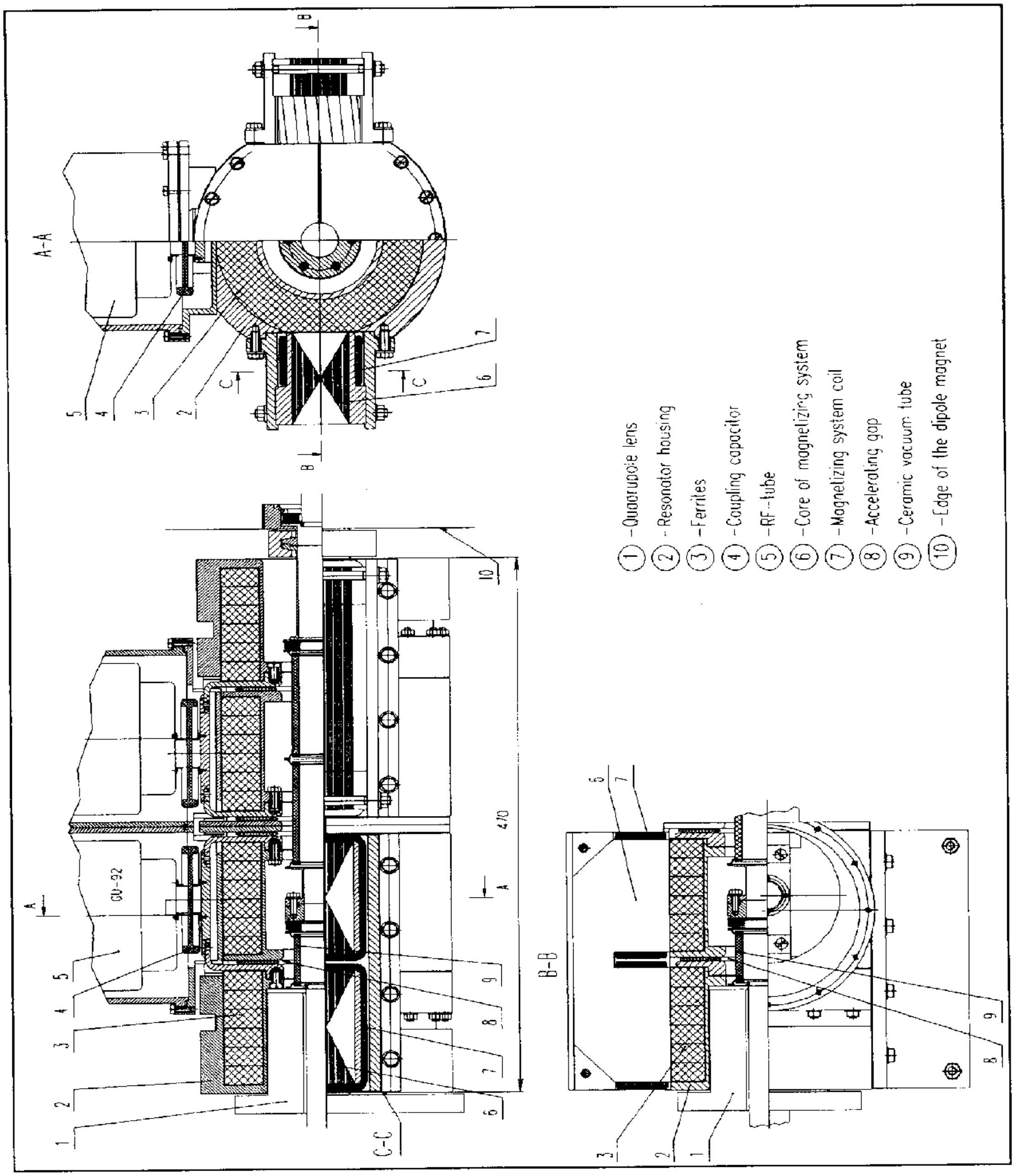

Figure 5: Constructive scheme of the STAC accelerating system with the biasing device.

Table 2.

Length of ferrite set, mm	Number of rings	Flux density, Gs	Specific losses, W/sm^3
100	5	200	0,15

Table 2 shows that the specific losses of ferrites are small. It allows to increase the number of operating cycles per seconde of RF system, if it is necessary.

The tuning of every cavity by frequency is executed in a particular electromagnetic biasing device. The electromagnet's magnetic circuit looks like two equal halfs in the form of letter O. The both electromagnets create equal biasing fields in cavities, directed oppositely, thus a necessary compensation of penetrating biasing fields is obtained in a synchrotron orbit.

The biasing electromagnets are supplied by semiconductor biasing amplifiers. The windings of the biasing electromagnets are made of eight sections, isolated galvanically, every one of them contains 20 turns. The sections are distributed uniformly between electromagnet's poles. 5500 Amp. turns are required for tuning of a RF cavity containing two cavity sections.

The RF power supply of the accelerating system is executed by 3-cascade resonance amplifier. The final cascades of the amplifier are made on standart tubes GU-92A. Every RF cavity is supplied by a tube. The final cascades are excitated by a preliminary resonance amplifier with a push-pull output.

The final cascades in RF power amplfiers operate automatically with the help of feed back system as it is usual in such devices. Preliminary cascades also operate automatically with the help of feed back systems.

The power amplifier is made physically as an united compact device, and it is installed directly in the accelerating system.

The total power consumption of the RF system is $7-8$ kW.

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References

[1] *L. Picardi, C. Ronsivalle, A. Vignati (Centro Ricerche Frascati, Roma), G. Silvestrov, T. Vsevolozshaya (BINP, Russian Academy of Sciences, Novosibirsk, Russia), R. Bartolini (Fondazione per Adroterapia Oncologica. Via Puccini, 11, 28100 Novara).* Preliminary design of a technologically advanced and compact synchrotron for proton therapy. ENEA, Centro Ricerche Frascati. RT/INN/94/20.

[2] *I.I. Averboukh.* Accelerating RF cavities for ion synchrotron. PTE, 1978, N4, p.19.

[3] *I.I. Averboukh et al.* RF system for synchrotron B-4. Proceedings of 11 All-Union conference by accelerators of charged particles, Doubna 1989. v.1, p.323.

[4] *I.I. Averboukh.* RF cavity for compact proton synchrotron. BINP 95-67, Novosibirsk 1995.

[5] *I.I. Averboukh, M.M. Karliner.* Methods of increasing of the voltage of RF cavities with tuning frequency. PTE, 1985, N2, p.29.

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