RF-SYSTEM OF THE PRAGUE MEDICAL SYNCHROTRON

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Abstract

Calculation results of the capture, acceleration and special beam preparation before the slow extraction are discussed briefly. Conceptual design of the RF-system for a medical proton synchrotron is presented. This synchrotron named as a PRAgue MEdical Synchrotron (PRAMES), will be used as a kernel of an accelerator complex of the Oncological Hospital which is planned to be built in Prague (Czech Republic) [1]. The RF-system must supply 1.5 kV peak voltage in the frequency range from 0.8 to 5.0 MHz. The highest ramp velocity should be 30 MHz/s. The length of the cavity should be less than 1m. The basic circuits of the RF-system have been chosen and the design of the RF-cavity loaded by ferrite rings is determined in this work. The basic parameters of the compact RF-system are presented.

1 INTRODUCTION

An accelerator designed for the hospital must meet a number of requirements, which substantially differ from those of a machine to operate for research [2]. Main features of the dedicated proton synchrotron are discussed in the report [3]. The synchrotron is designed for the raster scanning treatment of cancer. It requires to provide a spill length of the extracted beam about 500 ms. Special manipulations should be performed before extraction to get a coasting beam with the necessary homogeneity. The dedicated medical machine should guarantee the step of the energy variability less than 0.4 MeV. The energy variability accuracy should be ± 40 keV in the range of the output energy from 60 till 220 MeV. Investigation of the longitudinal particle motion in the medical synchrotron is important to define behaviour of the main parameters during capture, acceleration and extraction of particles.

The single-turn injection with the kinetic energy of 7 MeV is chosen to use a commercial linear accelerator as an injector. The beam intensity in the synchrotron should be $6.25 \cdot 10^{10}$ particle per pulse at the repetition rate of 1Hz. The ring circumference is equal to 41 m. To provide stable transverse motion in the ring at the injection energy, the peak current of the circulating beam should be less than 12 mA. It means that the phase length of the trapped proton beam should be ± 2.5 rad (h=1). The momentum spread of the trapped beam should be ± 0.3%.

2 CALCULATION RESULTS

The capture, acceleration and special beam manipulation before the extraction should be performed during 250 ÷ 300 ms. It is necessary to get the maximum capture efficiency of the injected beam into the acceleration regime. It is possible to do it using 'quasi-adiabatic' capture. Particle losses during acceleration should be eliminated by a special choice of the magnetic field, the RF voltage and the RF phase, which are functions of time. Particle capture and acceleration processes should provide the beam without filamentation. From the technical point of view the maximum magnetic field ramp should be less than 10 T/s. The maximum RF frequency ramp – less than 40 MHz/s.

The longitudinal particle dynamics in the dedicated synchrotron can be calculated under the adiabatic condition of the motion. To model the longitudinal particle motion in the synchrotron the tracking program has been developed.

To reduce the particle losses during capture, the phase of the reference particle should be equal to zero. The initial RF-voltage should provide the bucket height enough for the injected beam. The phase length of the injected beam must be equal to ± 2.75 rad and the momentum spread – to ±0.1% to meet the requirements mentioned above. The longitudinal phase space of the trapped particles is presented in Fig.1. The initial RF-voltage is equal to 100 V, the final value at the end of the capture is 200 V. The capture time is about 50 ms.

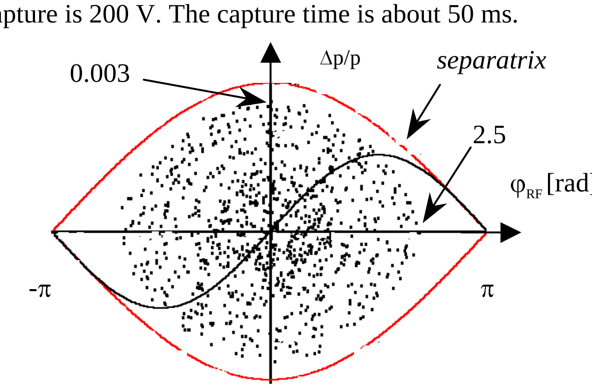

Figure 1: Longitudinal phase-space of the trapped particles (1000 particles).

To accelerate the trapped particles till the maximum output energy of 220 MeV, the RF-voltage should be less than 525 V. The maximum RF-phase is equal to 17.5 degrees. The acceleration time is 250 ms. The longitudinal phase space of the accelerated particles till the final energy of 220 MeV is presented in Fig.2 and the particle distribution in the bunch is shown in Fig.3. Particle losses during capture and acceleration is less than 15%.

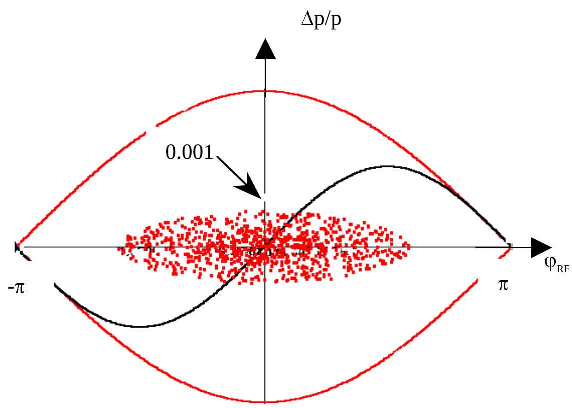

Figure 2: Final particle distribution in the longitudinal phase plane after acceleration till the energy of 220 MeV.

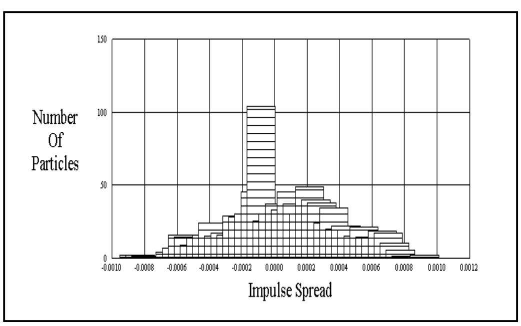

Figure 3: Impulse distribution of the accelerated particles (220MeV).

The RF-gymnastics after the acceleration should be utilised to get the coasting beam. The maximum RF-voltage in this case is about 1.5 kV to get the required momentum spread before the slow extraction.

3 RF SYSTEM

The RF system of PRAMES is the system with tuneable RF-cavity. The resonance frequency of the tuneable RF-cavity is changed by the bias magnetic field in the ferrite. The bias winding placed directly on the ferrite rings produces the bias magnetic field. The bias winding is connected to a controlled source, which is able to generate the current in the winding up to several hundred Amperes. A power amplifier drives the RF-cavity.

The analysis of some similar systems [4] developed earlier for proton synchrotrons has shown that the ferrite 8C12 (PHILIPS) can be used for the RF-cavity. The PHILIPS firm produces ferrite rings T/498/270/25 8C12 [5] especially for accelerators. Their main parameters are given in Table 1.

Table 1: Main parameters of the ferrite 8C12 ring.

Outer diameter	mm	498
Inner diameter	mm	270
Thickness	mm	25
Initial μ		900
Remanent μ		600
Dielectric constant ε		~ 10
Quality factor, 1 MHz:	B_{rf} = 10 mT	7.5
	B_{rf} =20 mT	5.0
Frequency range	MHz	1 ÷ 10
Curie point	° C	≥ 125
Mass	kg	17

3.1 RF cavity

The sizes of the ferrite rings, the bias winding and the vacuum chamber of the accelerator define the sizes of the cross - section of the RF-cavity loaded by the ferrite rings. The vacuum chamber is an ellipse with axes of 138 and 70 mm long.

The ferrite length of the cavity is proportional to the gap voltage. For the initial frequency of 0.8 MHz with the 100 Gauss induction, the length of the ferrite part of the cavity is 0.42 m. It means that we can place 12 ferrite rings. The total length of the cavity is 0.82 m including the bias field windings and the ceramic gap.

The cavity is composed from one-quarter-wave-length coaxial line loaded with the ferrite material (Fig.4).

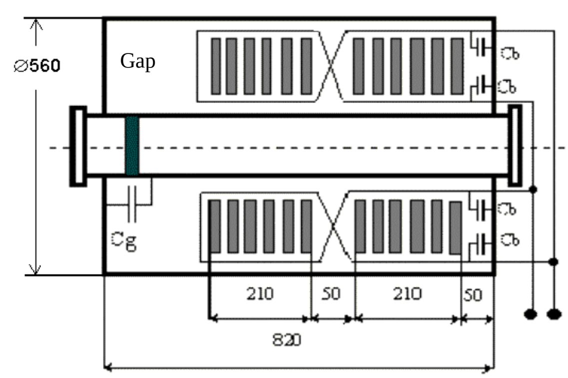

Figure 4: Schematic drawing of the RF cavity.

The space between the inner and outer conductors of the cavity is filled with the ferrite rings. The ferrite rings are stacked axially with spacing for the cooling air. Internal bias winding installed directly on the ferrite rings creates the magnetic bias field. Twelve rings are divided into two blocks and the winding is fixed as a figure of eight. The 800 A current is needed to reach the maximum frequency of 5.0 MHz. The RF-power loss in the ferrite is 2 kW. The RF-cavity parameters are summarised in Table2.

Table 2: Main parameters of the RF cavity.

Peak RF - voltage kV	2.0
Frequency range MHz	1.2÷5.0
Frequency ratio (Kf)	4.17
Electrical length degree	13
Tuning capacitor pF	680
RF - power W	2000
Bias current A	800
RF - induction T	0.01
Number of ferrite rings	12
Dimensions of ferrite ring mm	498/270/25
Outer diameter of cavity mm	560
Inner diameter of cavity mm	200
Ferrite length mm	420
Cavity length mm	820

3.2 Power amplifier

The amplifier chain is composed of the 6 kW final stage, a 1.0 kW driver and a linear amplifier with the control gain. The air-cooled tetrode (for example, Gu-90 B) is used for the power final amplifier. This RF - tube operates with the anode voltage of 6.5 kV and maximum power of 6 kW working in class AB. The driver and the linear amplifier compose a broadband solid-state amplifier.

The final stage is installed under the cavity. The driver is located outside the prohibited accelerator area. They are connected with the 50 Ω coaxial cable. The DC voltages operating on these stages are constant and the RF-envelope is controlled by modulating at a low-level stage (linear amplifier).

3.3 Cavity tuning

The ferrite-loaded RF cavity is tuned by the bias magnetic field in the ferrite. The variation of the bias magnetic field changes the permeability μ, and then the inductance of the cavity changes as well as the resonance frequency. The winding, connected to a regulated power source, produces the bias magnetic field. The bias current is varied in the range from 0 to 800 A. The control signal for the RF - cavity tuning comes from a function generator. It is added with the signal from a phase detector and then the summarised signal regulates the power supply.

The cavity is tuned automatically by the control loop. This control loop detects the phase difference between the grid and anode of the Gu-90 B tetrode and keeps it close to 180° during the acceleration cycle. The RF - amplitude information is obtained from the capacitive divider connected to the anode Gu-90 B tetrode. The RF - envelope is detected, compared to the reference and directed to the input of the gain controlled RF - amplifier. The block diagram of the tuning system is shown in

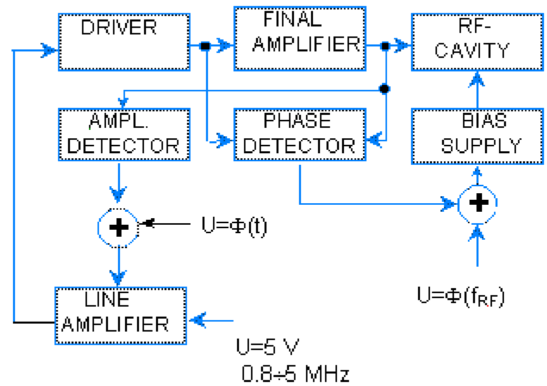

Figure 5.

Figure 5: Block-diagram of the tuning system.

4 CONCLUSION

The compact synchrotron with single-turn injection and slow extraction is proposed for medical aims. The synchrotron is designed for the raster scanning treatment of cancer. At the injection energy the transverse motion stability of the particles in the ring is provided by the beam current restriction. The RF-voltage is about 1.5 kV on the gap of the RF-cavity for the RF-gymnastics of the beam after acceleration. The RF-cavity is composed of •/4-resonator with the internal bias winding. The conceptual design of the RF-cavity is offered on the basis of the ferrite 8C12. For the real design of the RF-cavity it is necessary to carry out practical research of the 8C12 ferrite samples. Prototypes of the RF-cavity, amplifier and tuning system should be developed to confirm the concept of the RF system for the synchrotron.

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