BEAM CHOPPER FOR 750 KEV LEBT OF MMF LINAC

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Abstract

A travelling wave beam chopper for the 750 keV H^+, H^- ions of INR Linac is described. The chopper consists of a helix and a ground plate. The latter serves as a beam absorber which allows operation with a deflecting voltage below 4.5 kV. The chopper aperture can be varied from 2 to 6 cm, the plate length is 80 cm. The ion beam with unnormalized emittance ~8 π·cm·mrad is deflected and absorbed at the water-cooled ground plate. Available chopped beam pulse edges are less than 20 ns. A special shape of ground plate is used in order to depress the secondary electron emission arising from proton beam deflection. The deflecting plate structure and electronic circuits are presented, and theoretical and experimental results are discussed.

750 KEV H^+, H^- TRANSPORT LINE OF MMF LINAC

The neutron experiments at the Moscow Meson Factory (MMF) and the MMF proton storage ring operation need a device for a creation of beam time structure. Travelling-wave chopper for 750 keV H^+, H^- ions in the MMF transport line has been developed and installed on the LEBT. The MMF chopper consists of a helix and a ground plate. The use of the ground plate permits ion beam absorption directly inside the chopper [1,2]. Therefore no additional beamstop is needed. In addition the chopper has only one electronic modulator. The chopper deflects 750 keV ion beam with the emittance ≤8 π·cm·mrad with pulse rise and fall times less than 20 ns. The chopper consist of 80 cm plates and occupies 90 cm along the beam line.

The chopper is located downstream of the high voltage column in the first part of the beam transport line to protect a transport line equipment and especially diagnostic equipment that makes direct contact with the beam, from damage during accelerator commissioning. The charged particle current in the first part of the MMF is a train of pulses ~100 µs long repeated at 50 Hz containing 200 mA. This corresponds to 1.5 kW as several macroimpulses are deflected into the absorber. The injected beam unnormalized emittance is 8-10 π cm mrad, its transverse diameter is about 5 cm and this complicates considerably the situation with the beam deflection and particularly with fast chopping over the beam current macroimpulse. All of these have demanded a creation of a special device for a macroimpulse deflection, an absorption and a fast chopping.

To measure the beam microstructure a special wideband Wall Current Monitor (WCM) has been designed and installed downstream of the 45^0 bending magnet. Bending magnet operates like a particle separator so undesirable ions flowing from the injector are reduced.

DEFLECTING PLATES

Chopper deflecting plates are placed into a vacuum chamber. There is a possibility of changing a distance between upper spiral plate and lower ground one. The deflecting structure scheme is shown in Fig.1.

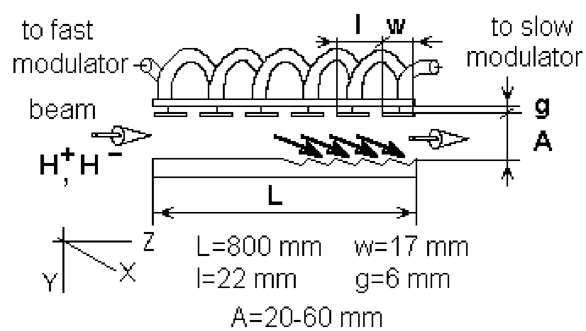

Figure 1 Scheme of deflecting plates structure

The aperture (A) can be changed from 20 to 60 mm without vacuum violation by a manual actuator during chopper commissioning to achieve optimum conditions of the beam deflection. The upper plate represents a train of spiral-like connected strip and coaxial lines with a 75 Ω wave resistance hence the wave propagation along beam line equals a beam velocity v= βc, where β= 0.04 (750 keV beam), c is the speed of light in vacuum. This field moving together with the particles deflects them to the lower ground plate. The deflected particles are absorbed at the ground plate.

The lower plate is made from metal and water-cooling is provided for heat irradiation. The special lugs are made to decrease deflected beam angle of incidence and to prevent secondary electron emission from the surface. For small angles of incidence (θ) an amount of a secondary electron production is proportional to $1/\cos^4(\theta)$ [3]. A deflecting field for positive particles also is an accelerating field for electrons. So all secondary emissioned electrons get to the upper plate. This can change the deflecting field and even damage a deflecting voltage power source. We found there is no influence of secondary electrons on this chopper operation with relatively high beam power: beam energy is 750 keV, beam current is 200 mA with 100 μs pulse length at 50 Hz. Using absorber plate allows to have small aperture of the chopper and only a 4.5 kV modulator. Also this minimises the electronic equipment considerably.

The electric field distribution inside deflecting plates in a quasi static approximation can be obtained by means of a Fourier analysis:

$$E_y(r,t)=\sum_m A_m(\omega_m)\sum_n K_n(r)\cdot\cos(\omega_m t+\varphi_m+\varphi_n), \quad (1)$$

where $A_m(\omega_m)$, φ_m are amplitude, phase of a frequency domain ω_m in Fourier-series expansion, $K_n(r)$ and φ_m are the influence coefficient and phase from the n-th strip to the point with a radius-vector r(x,y,z). For $K_n(r)$ with x= 0 (for simplicity) one can obtaine the following expression (see Fig.1):

$$K_n(r)=\frac{\sigma}{2\pi\varepsilon_0}\sum_{i,j=0,1}\left\{(-1)^i \operatorname{arctg}\frac{(z-nl+(-1)^i w/2)l}{2(2jA-(-1)^j y-g)R_{ij}}\right\}, \quad (2)$$

where $R_{ij}=\sqrt{(z-nl+(-1)^i \frac{w}{2})^2+(2jA-(-1)^j y-g)^2+(\frac{l}{2})^2}$,

where σ is the surface charge density of n-th plate, ε_0 is a permittivity of vacuum. (2) shows the influence superposition of the n-th strip and its reflections from metallic surfaces. σ can be expressed from a deflecting voltage U according with [4]:

$$\sigma=\frac{\varepsilon_0 w_{eff} U}{wg},\ w_{eff}=w\left[1+1{,}735\left(\frac{w}{g}\right)^{-0{,}836}\right], \quad (3)$$

Summing (2) for different strips n one can get a static deflecting electric field distribution. The corresponding distributions along with Z and X axes are shown in Fig.2, U/A represents an electric field of a flat condensor with the same aperture.

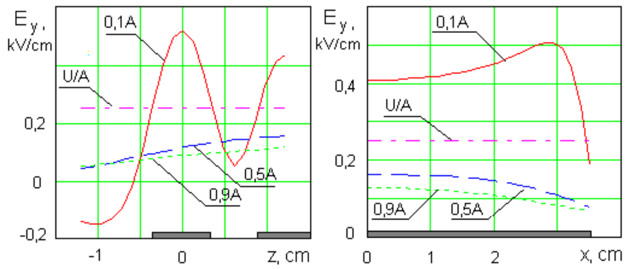

Figure 2 Electric field distribution along with Z and X axes for different value of Y over an aperture

Using a Fourier-series expansion of an input signal, one can calculate dynamic characteristics of the deflecting field at any point between the deflecting plates with help of above expressions. Corresponding calculations for MMF transport beam line show that for deflecting structure parameters in Fig.1 and aperture A=4 cm, the deflecting electric field intensity rise and fall times can not be more than 10 ns. However the beam rise and fall times can be much smaller that the rate of icrease of the deflecting voltage. This is one of principal advantages of the described deflecting structure.

ELECTRONIC CIRCUITS

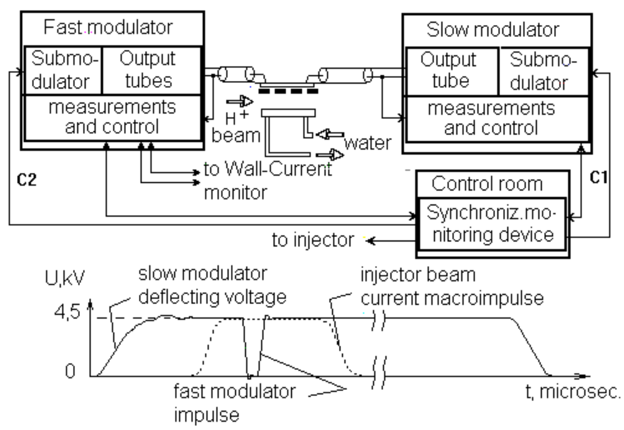

Figure 3 Electronic circuits block diagram

The electronic circuits block scheme is shown in Fig.3. Since only one plate has a special spiral structure and the other one always has a ground potential, only one modulator is needed for time microstructure creation. It is the fast modulator shown in Fig.3 used for this purpose. The slow modulator serves for a beam macroimpulse deflection to implement an emergency fast beam stop and control the average beam intensity by means of deflection of a part of beam macroimpulses. These functions could be realised with help of the fast modulator but it is difficult to overlap a duration time range from few nanoseconds to few hundred microseconds. The fast modulator overlaps a range from few nanoseconds to 5 microseconds with 10 ns rise and fall times. The slow one operates with 400 µs duration, 20 µs edges and up to 5 kV impulses, usually 4- 4,5 kV is used.

If a positive (for H^+) or negative (for H^-) voltage is applied to the upper plate charged particles are deflected and absorbed at the lower ground plate. A beam goes through the deflecting structure without an absorption if no voltage is applied. It is necessary to mention that a special two level fast protection system (deflecting voltage and syncronization shifting) was designed and realised on a base of the beam control device (see Fig.3) which monitors and synchronises the operation of the injector and two chopper modulators.

The slow modulator serves for the fast modulator like an anode voltage power supply, so the upper plate is on the anode circuit of the fast modulator output tubes. The GI-30 (impulse generator) tubes are used. They do not need a water cooling, are compact enough (about 10 cm) and each of them provides an impulse current more than 10 A with a 5-10 ns pulse edges. Four tubes in parallel connection are used at the output circuit of the fast modulator. To compensate a rest voltage of an open tube a 500 V negative bias power source is applied to a tube cathode.

A matching circuit on a slow modulator cable terminal has been included in order to prevent reflected wave propagation and slow modulator signal oscillations. The corresponding circuits are shown in Fig.4.

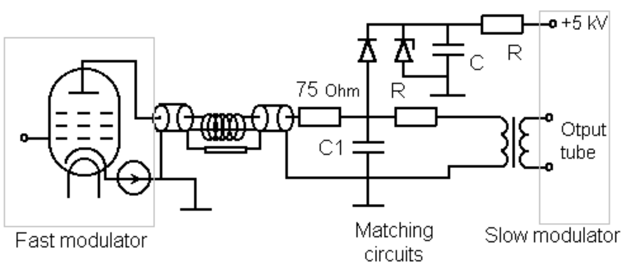

Figure 4 Matching circuits

The capacity C1 value matches the pulse duration from the fast modulator. This value has been chosen to overlap the fast modulator possibility (up to 5 µs). No matching circuits are need at the fast modulator cable terminal, so as it is not important for slow waves with 20 µs pulse edges and moreover it would double the power dissipation.

A specially designed detector with a wide frequency range from 20 kHz to 1 GHz to measure the continuous 750 keV proton beam impulses with a time duration up to 5.0 µs and pulse edges about 20 ns is used. The wall-current monitor (WCM) was created for these measurements. A shape of the chopped beam current impulse is shown in Fig.5.

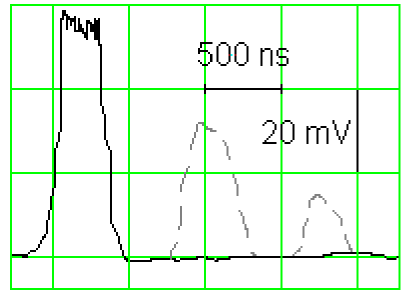

Figure 5 Wall-current Monitor signal from H^+ beam

The dash line represents the shape of tail beam current impulses which would occur together with a single impulse (solid line) due to a reflected waves if no matching circuit were used. However the WCM does not measure the absolute beam current amplitude of the chopped beam because of its frequency dependence. This estimation can be made with help of neutron beam loss monitors or by means of a Faraday cup signal integration. One can estimate a correlation between full and chopped beam current amplitudes from knowing the shape and an amplitude of a full beam current macroimpulse also a shape of a chopped one (from WCM) and analysing the values of loss monitors or a Faraday cup in both cases. The analysis shows that the chopped beam current amplitude is at least 95% of a full one.

CONCLUSION

The chopper operates at the proton beam transport line. A number of physics experiments with impulse neutron sources have been done successfully at the MMF. The design of such device for the H^- beam transport line is under progress.

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