NANOSECOND DIAGNOSTICS OF PROTON BEAM CURRENT IMPULSE WITH WALL CURRENT MONITOR ON MMF LINAC

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Nanosecond pulse creation of proton beam current on the Moscow meson factory linear accelerator is necessary for neutron physics experiments and the storage ring operation. The diagnostics of such pulse with a few nanoseconds rise and fall times and with a pulse length from few nanoseconds to few microseconds is needed. The Wall Current Monitor (WCM) applied for this purpose in the 400 keV linac beam transport line is described. The WCM bandwidth is from 20 kHz to 1 GHz. The Wall-Current monitor being used now at the MMF Linac's beam transport channel is described. The test structure, experimental results and the construction of the operational device are presented, the method of the precise injector energy measurements are discussed.

INTRODUCTION

Measuring beam parameters after an injector is very important task for accelerator commissioning, particularly while using the beam of micropulse regime for neutron experiments. It is necessary to control beam parameters directly behind the chopper [1, 2] that is a basic device for creating the micropulse regime at the MMF Linac. To measure the continuous proton beam pulse with the length from 0.2 to 1.0 μs and rise and fall times less than 10 ns one need to create the detector with a wide frequency range from ~20 kHz to 1 GHz. Also good matching and shielding are needed for the device operating in a very high noise level conditions. The Wall-Current Monitor was created for these measurements.

1. THE TEST WALL-CURRENT MONITOR

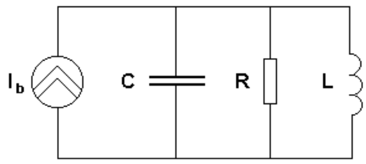

Fig.1 Simplified equivalent circuit of the Wall Current Monitor

400 keV H^+ beam micropulses created by the chopper during the accelerator operation for physics experiments were used. The micropulses from 200 ns to 1.0 μs are usually used and are needed as small rise and fall times as possible. Now ~20 ns is available with the chopper. The pulse beam current on the beam transport channel is about 60 mA.

Specially designed test equipment was created to check the required parameters for the WCM. The simplified WCM equivalent circuit [3] is shown in Fig. 1.

The corresponding frequency response of the WCM will be:

$$Z(\omega)=\frac{V(\omega)}{I(\omega)}=\frac{1}{j\omega C+1/R+1/j\omega L} \qquad (1)$$

Analyzing this expression one can conclude that the time constant $\tau_c = RC$ is corresponding to the high frequency response and $\tau_L = L/R$ to the low one.

Usually the gap resistance R is about 1 Ohm. As far as the capacitance across the gap is about C = 30÷40 pF, the high frequency cut off is calculated to be 1/2πRC = 5 GHz. The low frequency cut off of a conventional type is higher than the required one to observe the Linac beam pulse that continues for few microseconds. Increasing the inductance of the WCM is necessary for decreasing the low frequency cut off.

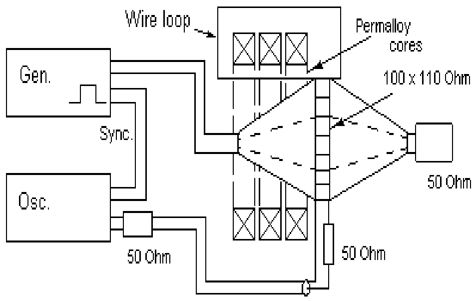

Fig.2 Wall Current Monitor test bench.

The WCM test bench scheme is presented in Fig.2. Two commercial 50 Ohm matching structures are divided by the ceramic ring and connected with 100 x 110 Ohm resistor over the perimeter of the ceramic ring. The square wave-form oscillator represents the beam current pulse. Up to six permalloy tape rings and up to four wire shielding rings were used to investigate the dependence of the WCM low frequency cut off. The corresponding experimental results are presented in Fig.3. Figures over the curves show the number of permalloy rings during the experiment and the number of the wire shielding rings are in brackets.

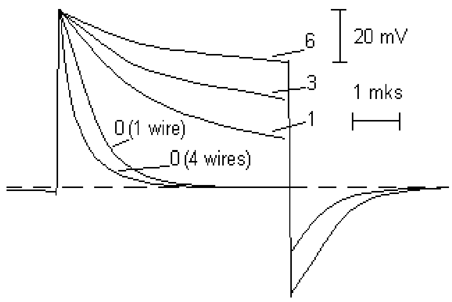

Fig.3 Test WCM responce

From (1), taking into account that $\tau_L \rangle\rangle \tau_c$, one can estimate the flat voltage droop ΔU during the time Δt as:

$$\Delta U = U_{\max}\left[1-\exp\left(-\frac{\Delta t}{\tau_L}\right)\right]. \qquad (2)$$

The corresponding time constants recalculated by (2) will be the following ones.

For four wire shielding rings without permalloy rings $\tau = 0{,}23\ \mu s$, for one wire shielding ring without permalloy rings $\tau = 0{,}64\ \mu s$, for one permalloy ring $\tau = 5{,}93\ \mu s$, for three permalloy rings $\tau = 10{,}95\ \mu s$, for six permalloy rings $\tau = 19{,}67\ \mu s$.

2. MMF H^+, H^- TRANSPORT LINE

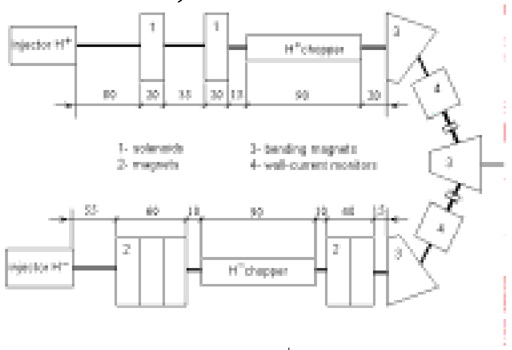

Fig.4. Schematic diagram of H^+, H^- beam transport line.

The schematic diagram of the MMF H^+, H^- beam transport line is illustrated in Fig.4.

The chopper is placed directly behind the injector in the first part of the beam transport line to protect transport line equipment and especially diagnostic equipment having a direct contact with the beam from a damage during an accelerator commissioning. The charged particle beam current at the MMF first part beam transport line represents the ~150 μs 200 mA pulse train with 50 Hz (it will be increased up to 100 Hz soon) pulse repetition rate. The injected beam unnormalized emittance is 8-10 π cm mrad, its cross diameter is about 5 cm. For MMF Chopper commissioning and a beam microstructure control a special wideband Wall Current monitor was designed and placed at the second part of the beam transport line. Using this device on the second part is conditioned on a cleaning effect of the bending magnet. Bending magnets operate like a particle separator so undesirable ions flowing from the injector are reduced.

To measure the continuous proton beam pulses with a pulse duration up to 5.0 μs and pulse edges about 20 ns we used WCM with a frequency range from 20 kHz to 3 GHz. An experimental shape of the chopped beam current pulse is shown in Fig.5. The dash line points to a shape of tail beam current pulses that appear together with a single pulse (solid line) due to reflected waves existence if no matching circuit is used.

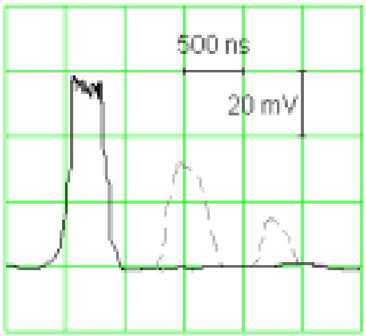

Fig.5 WCM signal from H^+ beam.

However, the wall-current monitor does not let to measure an absolute beam current amplitude because of its frequency dependence. This estimation can be made with the help of neutron beam loss monitors or by means of a Faraday cup signal integration. Knowing the shape and the amplitude of a full beam current macropulse as well as the shape of a chopped one (from wall-current monitor) and analyzing the values of loss monitors or a Faraday cup in both cases, one can estimate a correlation between full and chopped beam current amplitudes. The corresponding calculations show that a chopped beam current amplitude is at least 95% of a full one.

3. ENERGY MEASUREMENTS

With the help of two WCM it is possible to measure the absolute energy of the injector beam by measuring the time shift between signals. The block diagram of these measurements is shown in Fig.6. Here l is the known distance between two WCMs, t_1 (t_2) is the time that is taken by signal to go from WCM1 (WCM2) to the time shift measuring device and Δt_3 is a device systematic error. If we can measure the time signal shift, it is possible to determine the beam velocity as $\beta c = l/\Delta t$, where c is the velocity of light. By means of the following approach it is possible to determine the absolute time shift Δt between two WCMs.

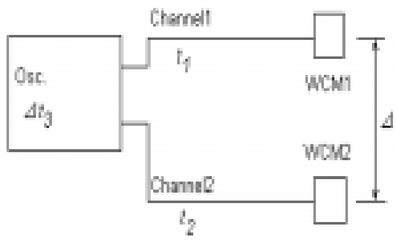

Fig.6 Energy measurement block diagram

Let $\Delta t'_1$ is the time shift measured by the device. Replacing the cables between WCMs as shown in Fig.6 we can get $\Delta t'_2$. These time shifts may be expressed as:

$$\Delta t'_1 = \Delta t + t_2 + \Delta t_3 - t_1, \quad (3)$$

$$\Delta t'_2 = \Delta t + t_1 - \Delta t_3 - t_2 .$$

So, from here one can get the absolute time shift:

$$\Delta t = (\Delta t'_1 + \Delta t'_2)/2. \quad (4)$$

Usually, it is not necessary to do this procedure every time you want to measure the beam energy. It is enough to determine the correction $\Delta = (\Delta t'_1 - \Delta t'_2)/2$ once. Finally, one can measure the absolute time shift as:

$$\Delta t = \Delta t'_1 - \Delta. \quad (5)$$

The accuracy of the measurements mainly will be defined by the noise conditions.

CONCLUSION

The described device now operates at the MMF H^+ beam transport line. A number of physics experiments with pulse neutron sources have been done successfully. The design of such a device for the MMF H^- beam transport line is needed.

REFERENCES

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