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BEAM DIAGNOSTICS WITH WALL CURRENT MONITOR

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Abstruct

In order to observe the fast longitudinal bunch structure at the KEK proton accelerator, a wide band wall current pick-up was installed in the 20 MeV transport line and main synchrotron ring (0.5∿12 GeV).
The characteristics of the pick-up and some results are described.

Introduction

When the proton beam is passing through the vacuum chamber, a wall current is induced on the inner surface of the vacuum chamber. The current is measured by shunt resistors which are mounted across the gap of the beam duct. The gap capacitance and the shunt resistance provide a high frequency cut off. The impedance of the external shunt path limits the low frequency cut off.

The duration of the beam at the 20 MeV transport line is 5 microseconds, and the Linac acceleration frequency is 200 MHz. The required frequency range is 3 KHz to 1∿2 GHz.

The acceleration frequency of the main synchrotron is 6∿8 MHz, and the shortest bunch length is about 10 nanoseconds. The pick-up frequency required is from 200 KHz to 1 GHz.

Characteristics of the pick-up at 20 MeV line

The gap resistance of $R_s=1\ \Omega$ is produced by the parallel connection of 48 resistors. The capacitance across the gap is C=30∿40 pF. High frequency cut off is calculated to be $1/2\pi RC=5$ GHz.

The low frequency cut off of conventional type is higher than the required one to observe the Linac beam which continues for 5 microseconds. The required low frequency cut off is about 3 KHz to observe the beam signal with droop less than 10 %. Measurements have been made of the decay time without the external shield or ferrites. The result is 0.4 microsecond.

The low frequency cut off is determined by the inductance of the beam pipe. This can be made relatively high by loading the pipe with high permeability alloy. Permalloy rings which are made of 0.05 mm thick tape are installed to increase the inductance of the beam pipe. The dimensions are shown in Fig. 1. The effective permeability of the permalloy is 10000 at 10 KHz and 45000 at 3 KHz. The low frequency cut off becomes about 3 KHz with these eight permalloy rings. The external shield of the gap is not used because no noise pick-up was observed. The disturbance arising from the cavity resonance is avoided. The wall current pick-up for the 20 MeV transport line can be used in the frequency range from 3 KHz to about 1 GHz. The high frequency cut off of the transmission line is 500 MHz.

A signal from the wall current pick-up which is mounted on the most down stream point of the transport line is shown in Fig. 3. Figure 2 is a photograph of the pick-up. Figure 4 shows the signal from the current transformer. Because the energy of the beam from the Linac has some spread, the shape of the bunch is elongated and joins with its adjacent bunch. The white part in Fig. 3 is the remainder of the bunch component of Linac acceleration frequency (200 MHz).

Because the wall current pick-up is a balanced type, a coaxial cable is not suitable to transfer the signal from the pick-up. The unbalance current would generate noise. A choke coil is connected between the pick-up and the coaxial cable to remove the unbalance current.

Velocity effect

The velocity ratio of the 20 MeV proton is $\beta=v/c\simeq 0.2$. Because the electric field is not affected by Lorentz contraction, the signal from the pick-up will be wider than the real charge distribution. If a point charge travels through the beam duct with a velocity of v, the charge distribution seems to be a Gaussian distribution of $\mathrm{FWHM}\simeq 1.4a/\gamma v$, where a is the radius of the pipe. Minimum resolution with the pick-up in the 20 MeV transport line is estimated to be 1.5 nanoseconds with a=6 cm. The signal from the wall current pick-up which is located just down stream of the Linac accelerating tank is shown in Fig. 6. The measurement agrees with the calculation. According to the measurement done by the Linac Group, the beam length at this position is less than 0.75 nanoseconds[1].

Application of the wall current pick-up in the 20 MeV transport line

Three wall current monitors are installed in the 20 MeV transport line. The location of each pick-up is indicated in Fig. 5.

The band width of the WCM1 is 300 KHz to 1 GHz. Here the high frequency pick-up is enough to observe the beam shape because the beam is completely bunched. The longitudinal length of the pick-up is about 3 cm.

The low proton velocity enables us to measure the beam energy and its distribution within each bunch by a time of flight method.

The bunch shape at WCM3 changes every microsecond. This means that the energy spread of each bunch changes every microsecond. The signal from WCM2 was compared with the signal from WCM1 to measure the energy spread and the drift of the average energy of each bunch. The energy spread can be calculated from the width of the beam at each location. The signals from both WCM1 and WCM2 are shown in Fig. 6 a)∿c). The average energy of the beam from the Linac shifts about 1 % in the time interval of 5 microseconds and the energy spread of each bunch is also 1 %.

The data obtained from the momentum analyzer shows that the total energy spread is about ±1 %, and the average energy is 21.8 MeV.

The relation between the phase or the field amplitude of the debuncher and the bunch component at the WCM3 was observed. When the power in the debuncher is decreased the energy spread of the bunch is increased and the RF component of the signal from the wall current monitor is decreased.

When the phase of the RF signal to the debuncher is changed, the time structcure of the bunch component changes as shown in Fig. 3. It seems that mismatching of the phase between the beam bunch and the debuncher RF arise from the drift of the beam energy.

Wall current pick-up at the main synchrotron

The wall current pick-up in the main synchrotron has an external shield and ferrite toroids over the beam pipe. The low frequency cut off is about 160 KHz with four ferrite toroids. This is low enough to measure the beam bunch in the main synchrotron.

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The high frequency cut off of the transmission line is 500 MHz which is lower than the cut off frequency of the pick-up.

The out put signal from the wall current pick-up is compared with one from the current transformer. Figure 7 shows both signals at injection.

The rise time and the time constant of the azimuthal current were measured with a test bench assembly. The rise time of the wall current monitor is less than 1 nanosecond. The time constant of the azimuthal current is about 4 nanoseconds which agrees with the calculation[2].

Some resonances above 1.6 GHz are observed by use of a spectrum analyzer.

The signals, which were observed with an oscilloscope TEKRRONIX 7800, from a wall current pick-up in the main synchrotron are shown in Fig. 8 a) and b). Figure 8 a) and b) are photographs of the detailed structure of the beam at phase transition. Full width at half maximum of the signal is 5 nanoseconds. Sometimes we can observe a fine oscillation with about 1 nanosecond structure as shown in Fig. 8 b). This characteristics is useful for accelerator study as for example in the measurement of the longitudinal emittance of the beam at phase transition.

The wall current pick-up is used as a fast intensity monitor only because of the short time constant of the azimuthal current.

Conclusion

The monitor is very useful as a fast intensity monitor or an energy analyzer. The pick-ups can be used as a nondestructive energy analyzer for low energy bunched beams. Work on the improvement of these monitors for routine operation are in progress.

References

1. KEK ANNUAL REPORT 1977

2. R.K. Cooper and V.K. Neil
   Resistor Beam Bugs - Scientific Explanation
   UCID-16057 june 12, 1972

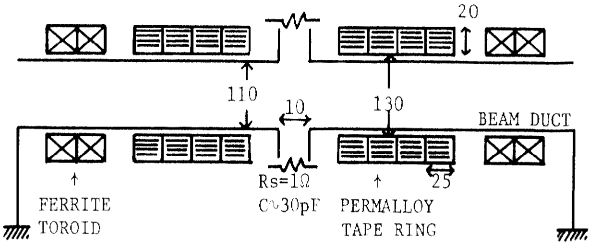


Fig. 1 Dimensions of the wall current pick-up at the 20 MeV transport line (WCM2, WCM3).

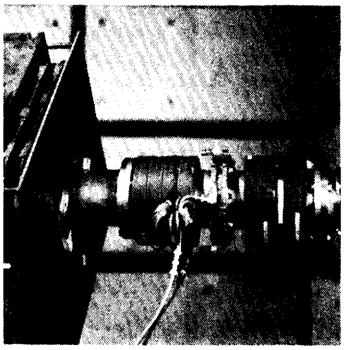
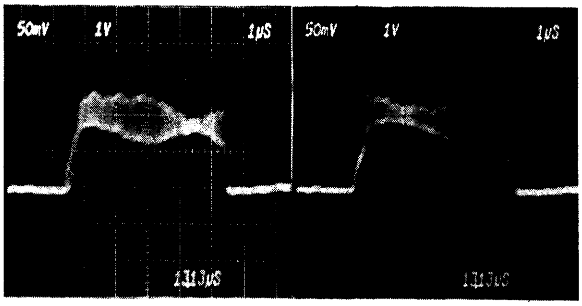


Fig. 2

Photo of the wall current pick-up at the 20 MeV transport line.



(a) (b)

Fig. 3 The signals from WCM3. Phase of the debuncher is a) +38°, b) -44° from the normal operation point.
Vertical 50 mA/div.: Horizontal 1 μs/div.

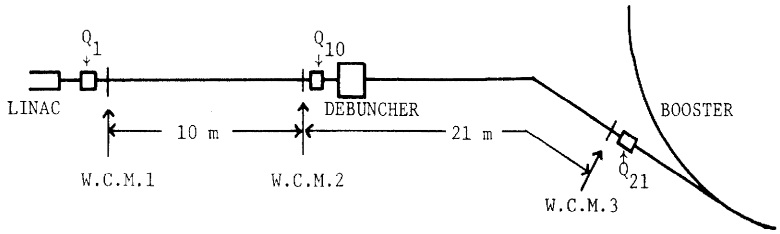


Fig. 5 The location of the wall current pick-up at the 20 MeV transport line.

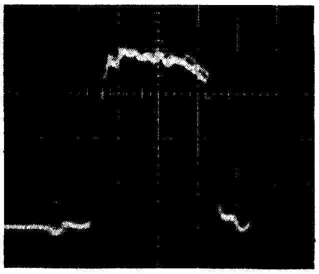
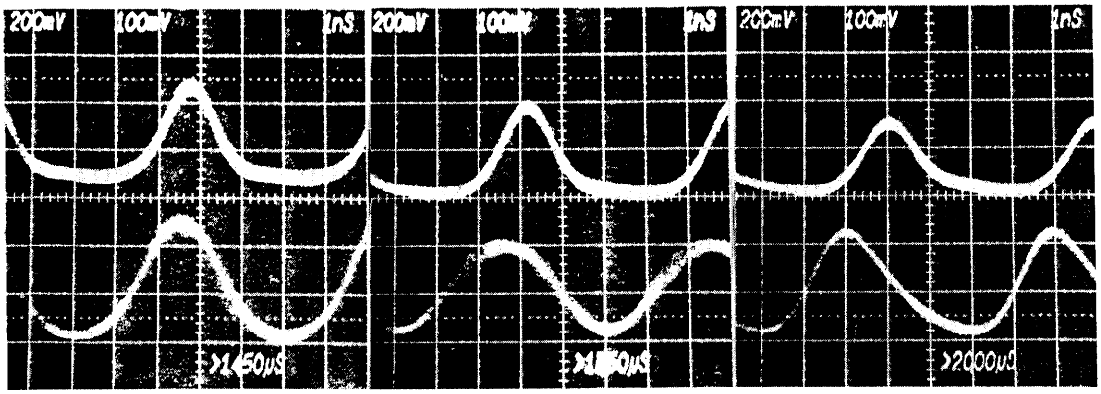


Fig. 4

The signal from the current transformer at the 20 MeV transport line.
Vertical 25 mA/div.
Horizontal 1 μs/div.



(a) (b) (c)

Fig.6 Signals from WCM1(upper) and WCM2(lower), 200 mA/div. and 100 mV/div.
a) the top of the beam b) 4 μs later c) the end of the beam.
Time scale 1 ns/div.

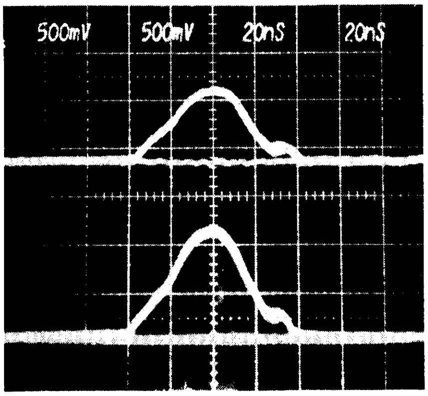
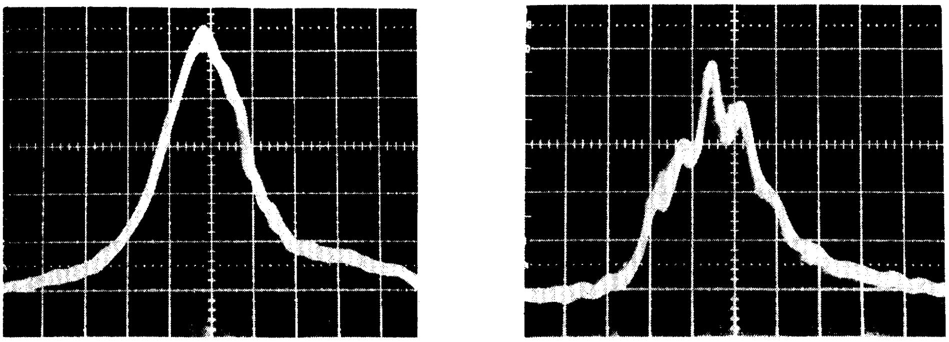


Fig.7
The signals from both the wall current pick-up (lower) and the current transformer(upper) at injection time in the main synchrotron.
Time scale 20 ns/div.



(a) (b)

Fig.8 Signals from the wall current pick-up at phase transition in the main synchrotron.
1A/div. , 2 ns/div.