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Development of a Wall Current Beam Position Monitor for a KAON Factory Ceramic Chamber

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Abstract

The rapid cycling synchrotron proposed for the TRIUMF KAON Factory uses ceramic beam pipe to suppress eddy currents. One design has metallic strips fixed onto the inner surface to carry the wall currents. A beam position monitor has been designed using these strips and tested successfully with the TRIUMF cyclotron beam.

I. Introduction

When beam goes through a beam pipe, an image current of the beam flows along the wall of the pipe. For an off axis beam the wall current distribution is asymmetric, the asymettry being a function of beam position. A conventional wall current monitor diverts the current through resistors bridging a ceramic spacer between metal beam pipes. Positional information is obtained by comparing the voltage across resistors grouped in quadrants. The beam pipe devised by SAIC carries the wall current in silver strips 4 mm wide, 1 mm apart painted along the inner surface of the pipe which is then fired at 850°. A gap of 5 mm is introduced in the middle third of the strips on each wall. Fig. 1. Each set of these strips is merged at the gap and the current brought through the wall on pin vacuum feedthrus. Resistors soldered to the pins bridge the gap.

The test WBPM was fabricated by M. Featherby[1] using a spare section of 1 cm wall pipe 15 cm long with inner dimensions 9.4 cm high and 5 cm wide, Fig.1. Metal transition pieces matched this rectangular pipe to the 10 cm diameter circular TRIUMF beam pipe. The circulating current in the KAON Factory will be ~1 A and resistors < 1 ohm offer ample signal strength and low impedance [1] [4], however ~150 μA cw extracted from TRIUMF has low peak intensity (1.5 mA) and 10 ohm resistors were used. The vertical surface has adapters on which tooling balls were mounted during bench calibration for alignment purpose.

II. WBPM Transfer Function Measurement

The transfer function was measured before installation using an antenna mounted on an X-Y table [2]. A 20 MHz sinewave from an HP8753 network analyzer was used for calibration (the TRIUMF rf is 23 MHz). After amplification of 40 dB the signals were collected by the analyzer, and stored in a computer for calculation and plotting. The mapping was done within the square area from -10 to 10 mm in both x and y direction with steps of 5 mm. The equations

$$U_I = (V_R - V_L)/(V_R + V_L) \tag{1}$$

$$V_I = (V_U - V_D)/(V_U + V_D) \tag{2}$$

are used to indicate the position. Because of the intrinsic non-linearity of the BPM, the polynomials

$$x_I = \sum_{i=0}^{N}\sum_{j=0}^{i} a_{i-j,j}(U_I - U_0)^{i-j}(V_I - V_0)^j \tag{3}$$

and similarly for y_I, are used to approximate the transfer function. U_0 and V_0 are the BPM readings when the antenna is at the center point. A least squares method is used to calulate the coefficients $a_{i-j,j}$, for the x and y directions separately. Using N=3, $a_{i-j,j}$ will have 10 numbers and the beam transfer function error will be less than 0.1 mm. The offsets between the electrical and mechanical center in the x and y directions can be also given.

A BPM transfer function was calculated for comparison with the measured one. J.H.Cupérus [3] expanded the beam charge in a Fourier series and obtained an approximate expression for the charge density induced on a surface at y=-b :

$$\sigma_{y=-b}(x,z) = -D_\lambda \cos\left[\frac{2\pi}{\lambda}(v_t + z_\lambda - z)\right] \times \sum_{m=1}^{\infty} \frac{\sinh[\alpha_m(b-y_0)]}{a\sinh(2b\alpha_m)} \sin\left[\frac{m\pi(x_0+a)}{2a}\right] \sin\left[\frac{m\pi(x+a)}{2a}\right] \tag{4}$$

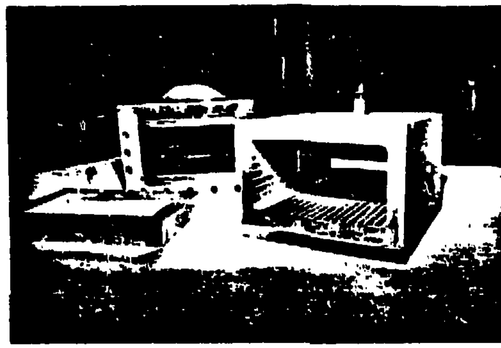

Figure 1: The ceramic chamber wall current monitor

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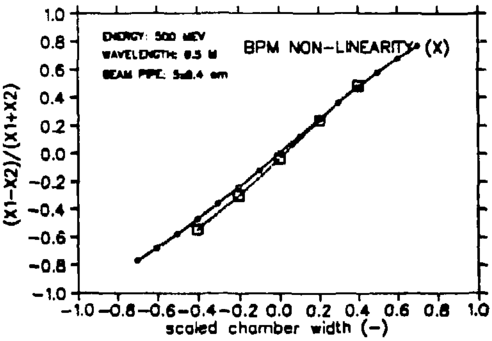

Figure 2: BPM Transfer Function (X)

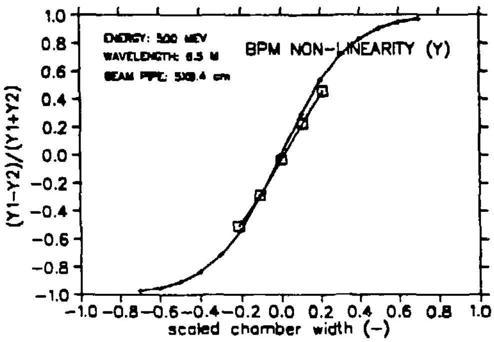

Figure 3: BPM Transfer Function (Y)

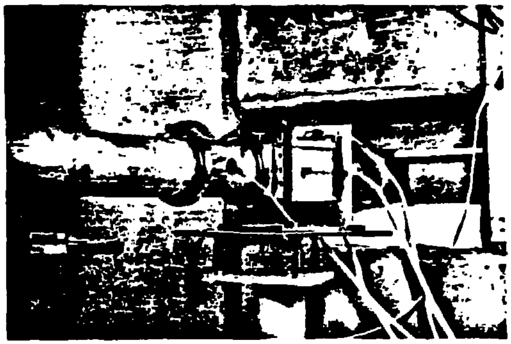

Figure 4: Experiment set up for the wall current BPM

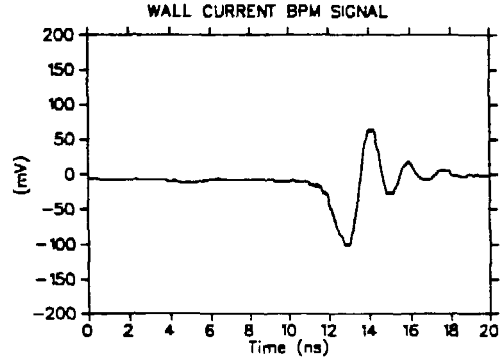

Figure 5: Beam signal picked up by the wall curren BPM

$$\alpha_m = \sqrt{\left(\frac{2\pi}{\gamma\lambda}\right)^2 + \left(\frac{m\pi}{2a}\right)^2}$$

In the formula, a is the half width of the chamber, b is the half height of the chamber, v_t is the speed of the particle, D_λ is the amplitude, λ is the wavelength of the Fourier component.

The transfer function calculated using eq. 4 is compared with that measured in Fig. 2 and 3. Fig.2 and 3 show the theoretical and measured non-linearity of the transfer function along the x and y axes. They are quite consistent.

III. Measurement With Cyclotron Beam

A. *Experimental procedure*

The WBPM was installed in a drift section in the TRIUMF high current beam line 1A between a multiwire and a scanning wire monitor. These gave both the profile and position.

The beam could be steered completely across the WBPM by horizontal and vertical steering magnets located upstream. The relation between steering magnet setting and beam position at the WBPM was inferred from measurement at the up and downsteam monitors. WBPM signals amplified by 40 dB were recorded as a function of the magnet settings. The experiment compares the WBPM reading and the position reading determined by the steering magnets.

Two methods were used to process the data. One method stored and transfered the raw signals, digitized by Tektronix 2440 oscilloscope, into a computer via a HPIB interface, then analysed them later with FFT. The other used the AM/PM electronic circuits originally obtained from Fermilab [5] which are used for other TRIUMF position monitors. These give a voltage which is a function of to V_R/V_L or V_U/V_D. The beam current was 3 μA with a 3% microduty cycle, equivalent to 100 μA cw, and for most of the measurement with a 10% microduty cycle at 23.055 MHz; equivalent to a peak intensity of 1 mA. The AM/PM circuits operate at 46 MHz. This frequency was also chosen for digital processing to reject any 23 MHz background.

B. *Processing data with the FFT method*

The WBPM signals were first enlarged by a 40 dB amplifier, then collected by electronics or oscilloscope (Fig.5). The FFT method was used to single out the amplitude of the 46 MHz component , then to calculate the position of beam from formulas (1) and (2).

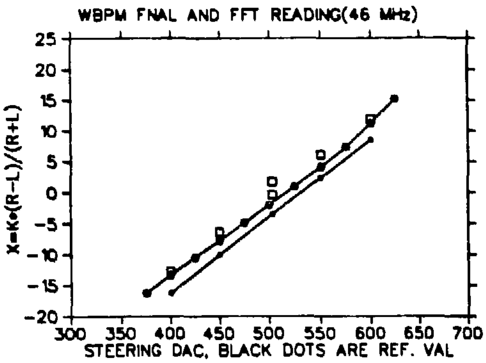

Figure 6: Beam reading via FFT and AM/PM circuit (X)

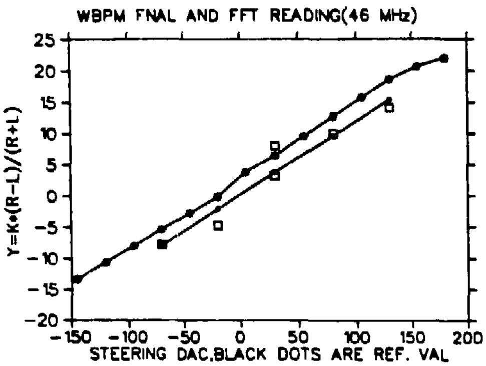

Figure 7: Beam reading via FFT and AM/PM circuit (Y)

Since only 2 cables were available for the experiment and horizontal and vertical data were taken separately the two dimenional equation (3) could not be used for analysis. The bench test data were re-analyzed in terms of separate planes, coefficients K_x and K_y determined for each plane and the measured data interpolated to determine the position. The position was also calculated from the Log ratio, 20Log(A/B), where A and B are the FFT 46 MHz component of opposite pairs of signals. The results agree with those from equation (1) and (2). The position sensitivity is $\approx$ 8 dB(voltage ratio) /cm.

C. *Processing Data With Fermi Lab Electronics*

The output of the Fermi Lab module [5] is a voltage

$$V = k[arctan(A/B) - \frac{\pi}{4}] \qquad (5)$$

where A and B are the signal strength of the 46 MHz component. Normally the input signals are sufficient to saturate internal amplifiers and k =3.5, however in this case insufficient preamplification was available and a value of 3.2 for x and 3.0 for y were determined experimentally.

IV. Results

Position

The position calculated from the off-line FFT analysis(□) and the AM/PM module output (*) compared with the position interpolated from adjacent beam line monitors in Fig 6 and 7. The slopes agree for small displacement. The AM/PM unit is less linear at large displacement. There appears to be an offset of 2 mm, which may be due to misalignment of the existing monitors; this is being re-checked during the current shutdown.

Amplitude

It was estimated [1] that the peak beam intensity will be about 1.5 mA and that about 10% of the wall current is shunted through each resistor to give peak voltages of 1.5 mV for a horizontally centred beam. The measured horizontal peak amplitude was 2/3 of this because the large resistance and capacitance bridging the gap reduce the high frequency response. Equipment is available to measure the longitudinal distribution but this was not used on this occasion.

Bandwidth

It was expected that reducing the resistor value from 10 ohms to 2 ohms would extend the high frequency response with reduced signal strength. Slits were used to reduce the beam bunch length below 2 ns however no change was seen with the amplitude. A reduced amplitude could be detected with a bunch length increased to 6 ns . The feedthru pins were actually 6.4 mm diameter rods, larger than specified, only less than one mm apart which increased their capacitance signifigantly.

V. Conclusion

The aim was to devise a BPM for the KAON Factory which could exploit the technology used to fabricate its vacuum chamber and thus reduce construction expense. The external dimensions are identical to the chamber and the device may be located at the end of, eg. a quadrupole, reducing demands on available lattice space. The KAON Factory beam will be ~1A, the resistors will be low, reducing impedance and extending the high frequency response to the 1.6 GHz measured in model tests [1].

VI. References

[1] Yan Yin:*A Wall Current BPM Built on a Ceramic Chamber*,TRI- DN-90-K144, July,1990.

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[5] S.P.Jackim, R.C.Webber, R.E.Shafer, *An RF Beam Position Measurement Module for the Fermilab Energy Doubler*, IEEE NS-28,1981,P2323