*NANOMETER RESOLUTION BPM USING DAMPED SLOT RESONATOR**

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A new type of high resolution beam position monitor called the damped slot resonator rf BPM has been installed at the focal point of the FFTB[1]. It is comprised of a cylindrical resonant cavity with a tuned choke joint at the TM_{110} resonance[2]. The BPM has a large dynamic range from the nm to mm range with a minimum resolution of 1 nm. We report on the rf cavity cold tests performance, processing electronics design, and some experimental results obtained in the high energy electron beam line.

I. INTRODUCTION

Precise beam position measurement and control are two of the many important issues in developing technologies for a future linear collider in the TeV region. Typical final focus spot sizes at the interaction point of a few 100 nm horizontally and a few nm vertically pose a considerable challenge for those hoping to sustain collisions on this small scale. Nanometer resolution of the beam position will be required, a most promising candidate for this application is the rf BPM.

In particular the damped slot resonator design has been chosen to measure the transverse beam position with nanometer resolution in the final focus system of the FFTB.

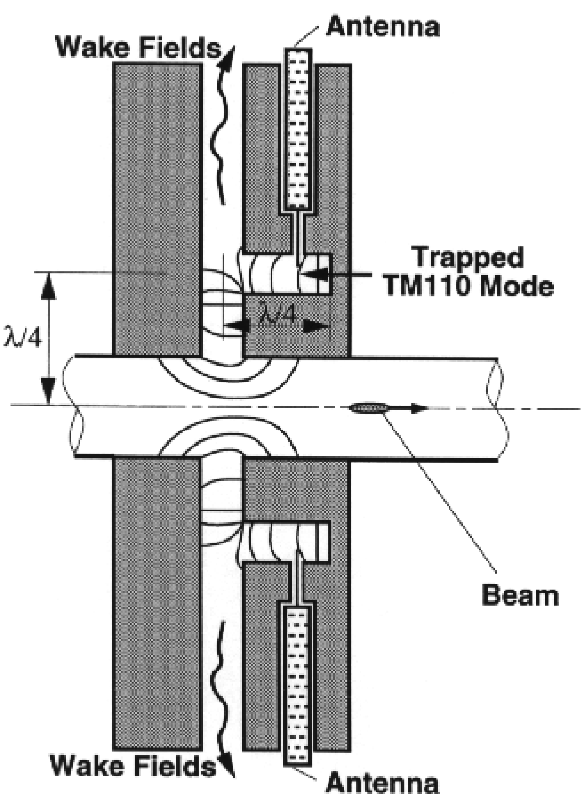

Figure 1. Damped Slot Resonator BPM.

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II. BPM RF CAVITY

The choice of the cavity frequency was dictated by the available space at the FFTB focal point where the real estate is in high demand. X-band is too high and the beam pipe becomes too small, whereas S-band has the opposite problem. The cavity diameter would not fit into the existing vacuum chamber so as a compromise C-band was chosen for the operating frequency.

Technically the most difficult problem is to reject the unwanted noise signal from the beam especially the TM_{010} common mode signal. The common mode is the lowest order TM mode which has a large position independent signal and can be as much as six orders of magnitude larger than the TM_{110} position signal. A rejection gain of 88 dB is necessary in order to be able to sense the position sensitive signal. A damped slot resonator is employed which accomplishes this common mode rejection. The cavity effectively has only a TM_{110} mode.

As can be seen from figure 1. the damped slot resonator is not like a conventional rf cavity. It appears more like a gap in the beam pipe which forms a transmission line on which the beam wakes may propagate radially away from the axis. A choke joint is placed $\lambda_{TM110}/4$ off axis such that the TM_{110} mode is trapped. The structures large slot at the node point of the wall current of the TM_{110} mode, causes most of all the lower and higher order modes to be heavily damped.

Therefore, the pick up antenna are located inside the choke joint where they are only sensitive to the TM_{110} signal whose

Frequency	5712 MHz
Wavelength	52.5 mm
Cavity Radius	32.0 mm
Slot Radius	15.8 mm
Beam Pipe Radius	5 mm
Slot Height	5 mm
Transit Time Factor	0.99
(R/Q)	12.2 Ω
Shunt Impedance	1.2k Ω/m
Voltage into 50 ohms/nm	14.5 μV @ 1.6 nC

Table 1 BPM Cavity Parameters.

amplitude is proportional to the beam offset from the axis. Table 1. gives the calculated rf cavity parameters and expected performance.

III. RF COLD TEST

The first step in the cold test tuning procedure entailed detuning the common mode by -88 dB. This was accomplished through careful adjustment of the two coupling antenna which are mounted on micro positioners. It was also necessary to add a phase shifter and a variable attenuator to one of the antenna lines to fully cancel the common mode signal which is insensitive to the electron beam offset. Because there is a small amount of leakage of the common mode into the choke joint where the pickup antenna are located it is necessary to pass the two signals through a magic tee looking at the difference signal.

The electron beam was simulated by placing an antenna near the axis of the rf BPM cavity. A network analyzer was used in a transmission through experiment, S_{12}, were the power was radiated from the on axis drive antenna and the difference signal was measured after the magic tee. Due to the low power output of the network analyzer a resonant antenna was used to boost the signal strength by 15 dB. The antenna was mounted on a computer controlled piezo-electric crystal moving stage which was stepped in 20 nm increments for a total of 1 mm. The resulting cavity signal versus antenna offset data was fit to a line which was then subtracted from the data to yield a 20 nm resolution on the cold test bench. The resolution was limited by the low signal power and also the micro seismic mechanical vibrations in the antenna supports. The raw data for the rf cavity signal versus the piezo mover position is plotted in Figure 2. below.

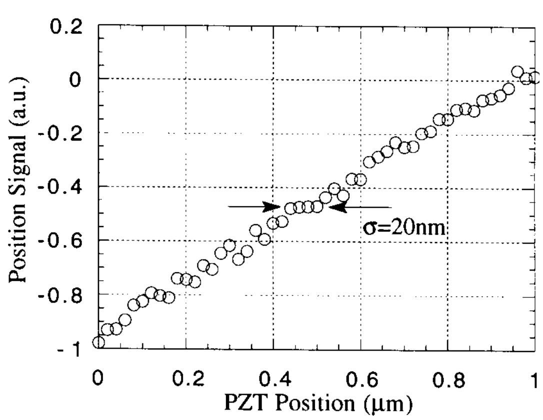

Figure 2. BPM Cavity Response Vs. Piezo Mover Position.

IV. SIGNAL PROCESSING CIRCUIT

The rf detection circuit is shown in figure 3. The rf cavity signal is amplified using a low noise, NF=0.8dB, and high gain, 28 dB, amplifier at 5712 MHz. A remotely controlled variable attenuator, 0-64 dB, is placed at the output of the magic tee to increase the dynamic range of the system and a limiter is placed before the high frequency amplifier for off axis pulse surge protection to the rf circuit. The beam can be misteered if a sub booster trips off and the beam looses a large amount of energy. The limiter that was used did an excellent job since the beam was misteered by 1mm and the limiter protected the sensitive preamp. After the pre-amp he signal is then mixed down to 500 MHz for transmission out of the FFTB experimental tunnel. This done to avoid large losses and rf pickup noise while transporting a high frequency signal along some 300' plus of cable.

The front end rf processor, the 5712 MHz end, is placed as close to the rf cavity as possible inside the shielding tunnel. Once the cavity signal and the phase reference signal are down converted to 500 MHz they are transported to an external electronics building were the BPM signal is rectified in synchronous detection mixers using the phase reference signal. The signal is then fed into a standard FFTB like NT&H[3] track and hold circuit were it is digitized by a 16 bit digitizer and sent to the SLC control system.

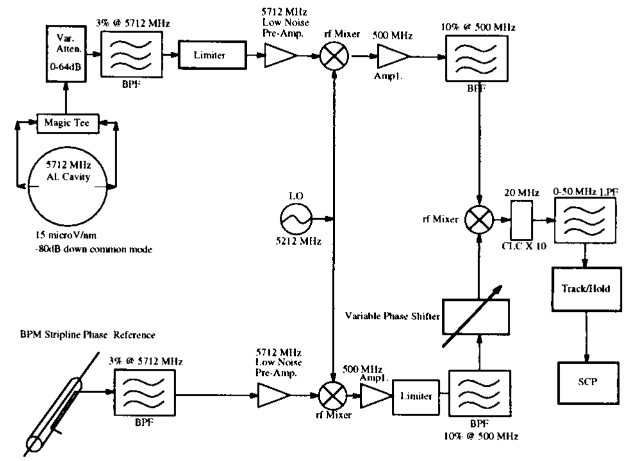

Figure 3 Rf Processing Electronics Block Diagram

The design shows a stripline which is to be used as the phase reference. The stripline is the preferable method of obtaining a phase reference because a 3% bandpass filter at 5712 MHz can be applied to its' broad band spectrum to select the desired phase reference frequency. This gives excellent FM or phase stability referred to the beam. Since the current in the SLC can be measured to less than 1% the induced AM fluctuation can be removed.

The BPM's read back is also sent into a feedback loop which controls a dither coil upstream of the focal point to correct for low frequency < 2 Hz position jitter. How ever due to the briefness of the FFTB run the loop was not fully commissioned and there is no data available for its performance at this time. It is interesting to note that all of the rf hardware used in the detection circuit is commercially available off the shelf.

Due to experimental difficulties during run time it was necessary to use a different phase reference source other than the stripline. The SLC main linac rf phase reference line operates at 476 MHz so it was necessary to frequency upshift by a factor of 12 to obtain the required phase reference signal. This amplifies any FM or phase jitter noise in the 476MHz signal which adds noise to the BPM signal.

V. EXPERIMENTAL RESULTS

The electron beam intensity throughout the run was kept at $0.7\text{X}10^{10}$ or 1.2 nC in order to have a very low emittance beam, $\gamma\varepsilon_y$=2X10^{-6}m-rad, measured at the entrance to the FFTB. The beta function at the focal point is set to, β^*_y=100μm. In order to place the waist longitudinally at the BPM an upstream quadrupole's vertical position is scanned versus the BPM signal. The quadrupole is located at a betatron phase such that when the waist is at the BPM position no correlation is seen. This is repeated for different waist positions until the waist is moved to the BPM longitudinal center. This turns out to be an excellent way to calibrate the waist shift knobs since we know the exact distance from the fringe pattern to the BPM to be 6.5 cm.

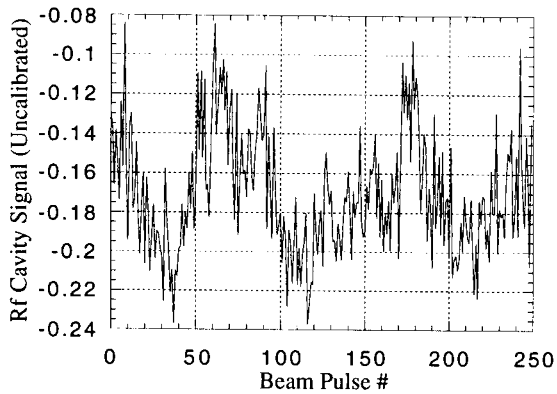

Figure 4. Typical BPM Signal versus Pulse to Pulse

Figure 4 shows a typical position signal read back from the rf BPM when the SLC is running at 30 Hz. One can see the few Hz low frequency jitter of the beam along with a very noisy high frequency component of noise. This noise comes from the FM and AM noise on the phase reference signal and will be corrected for the future FFTB runs by using a stripline BPM as a phase reference source.

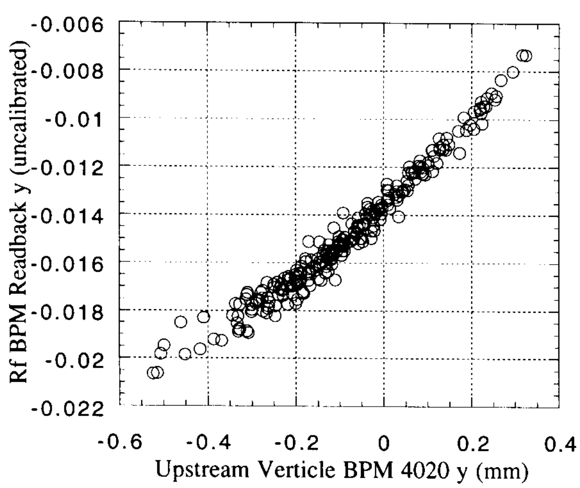

Figure 5. Correlation of rf BPM Vs an upstream Stripline

This will eliminate any FM noise and the AM noise can be normalized out of the signal by using a charge measurement good to less than 1%. Figure 5. shows a typical correlation with an upstream BPM in the FFTB line. Correlations are seen with BPMs as far away as sector 2 in the SLC. Figure 6. shows a calibration scan which is carried out by moving the centroid of the electron beam vertically a known amount at the focal point fitting the result to a line and extracting the scale factor. In the plot below the vertical axis has already been scaled. The plot shows that the BPM "signal" was mis-aligned by 0.6 mm. Note that this does not represent the actual electron beam position only the electrical signals zero point.

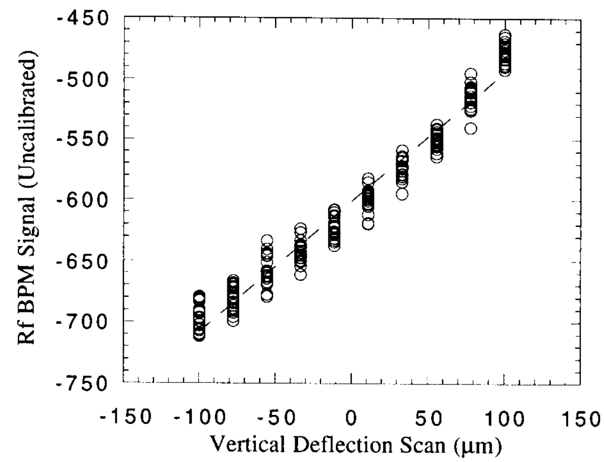

Figure 6. Calibration of Rf BPM Signal

The rf BPM cavity, processing electronics, and data acquisition system have been commissioned. The AM/ FM noise in the phase reference signal produces a large apparent jitter which can be corrected by using a stripline phase reference signal in the next experimental run. The large 0.6 mm offset in the BPM signal will be corrected for the next run via alignment and also by placing the BPM cavity on a vertical mover.

VII. ACKNOWLEDGMENTS

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