FIRST OPERATING EXPERIENCES OF BEAM POSITION MONITORS IN THE TESLA TEST FACILITY LINAC

R. Lorenz, TU Berlin, Einsteinufer 17, 10587 Berlin, Germany
M. Sachwitz, H.J. Schreiber, F. Tonisch, DESY-IfH, Platanenallee 6, 15738 Zeuthen, Germany
M. Castellano, P. Patteri, F. Tazzioli, INFN-LNF, Via E. Fermi 40, I-00044 Frascati, Italy
L. Catani, INFN-ROMA2, Via Ricerca Scientifica 1, I-00133 Roma, Italy

Abstract

Different types of monitors were installed in the TESLA Test Facility Linac to measure the beam position. At each superconducting quadrupole, the transverse beam position will be measured with a resolution of better than 10 μm, using a cylindrical cavity excited in the TM_{110}-mode by an off-center beam. In addition, two 'warm' cavities working at room temperature were built for the Injector I and the Bunch Compressor. The amplitude of the TM_{110}-mode and its phase are measured in a homodyne receiver. For the experimental area, stripline monitors having a resolution of better than 100 μm were built, tested and installed. The averaged position of the whole bunch train of Injector I is measured in a narrowband receiver using the amplitude-to-phase conversion. This paper summarizes the designs, cold tests and first operating experiences of both monitor types.

1 INTRODUCTION

In order to establish a technical basis for a superconducting Linear Collider, the TESLA Test Facility is an essential part of the development of injectors, accelerating structures, cryostats and diagnostic techniques [1].

Because of special requirements at different locations three types of beam position monitors were installed in the TTF Linac [2]. The purpose of this note is to discuss the cavities attached to cold quadrupoles and at two warm locations close to the Injector, and the striplines, installed in the temporary beamline and in the experimental area. Results of first beam tests are presented.

2 CAVITY-MONITORS

For the alignment of the quadrupoles a single circular cavity was designed because of the limited longitudinal space and the desired resolution of 10 μm in a cold environment. The amplitude of the TM_{110}-mode excited by the beam in the cavity yields a signal proportional to the beam displacement and the bunch charge, its phase relative to an external reference gives the sign (up/down, left/right). Both TM_{110}-polarizations have to be measured to get the x- and y-offset.

2.1 Monitor Design and Signal Processing

After cooling down, the seventh harmonic of 216.7 MHz has to be within the TM_{110}-bandwidth for the cold monitors to avoid an active tuning system inside the cryostat. A pre-tuning before cooling down can be realized by adjusting the coupling of each antennae. The temperature of the 'warm' cavities is stabilized in a thermostat and can be changed to tune the monitor slightly (about 20 kHz/K).

In both cases CrNi was chosen as the cavity material to measure individual bunches spaced at 1 μs (Injector II). Most of the parameters given in Table I were calculated, whereas the resonant frequencies and the coupling factors were measured at room temperature.

Parameter	**'Cold' cavity**	**'Warm' cavity**
Cavity radius R_0	115.2 mm	117.6 mm
Cavity length l	52.0 mm	52.5 mm
Beam pipe radius	39.0 mm	29.75 mm
Loss factor k_{110}	0.24 V/pC	0.23 V/pC
Unloaded Q_{110}	2965	3025
Frequency f_{110}	1.513 GHz	1.517 GHz
Coupling β_{110}	1.31	0.95

Table 1: Design and measured parameters (at 25 ^{0}C)

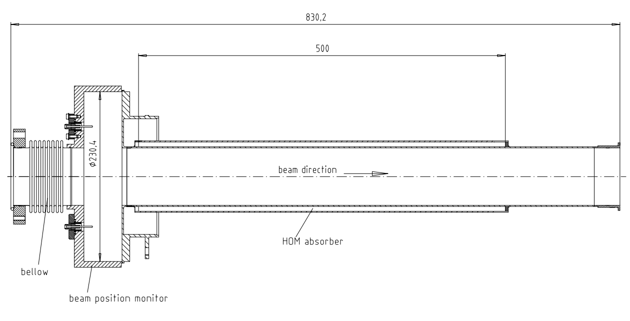


Figure 1: Cold cavity BPM with HOM absorber

Since the field maximum of the common modes is on the cavity axis, they will be excited much stronger than the TM_{110} by a beam near the axis. The estimated resolution near the electrical center is only 60 μm for a single cavity output, due to residual signals even at f_{110}. This can be reduced by combining two opposite outputs in a field selective filter [2]. Because of the limited space inside the cryostat, a stripline hybrid was used outside. The rejection of common field components is limited by its finite isolation between the Σ- and the Δ-port; an isolation of 20 dB brings the theoretical resolution down to less than 6 μm. In addition, a frequency sensitive TM_{010}-rejection of about 69 dB is required to detect a beam displacement of 10 μm. The resolution near the electrical center of the cavity is also limited by the thermal noise of the electronics [2].

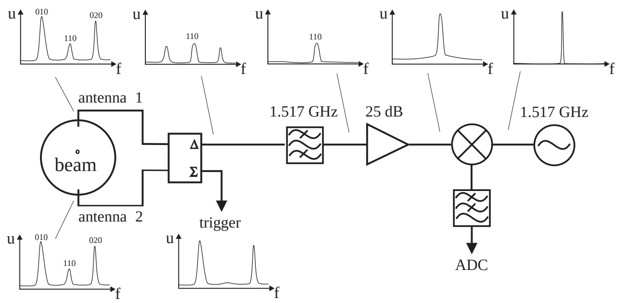


Figure 2: Signal processing scheme for a cavity BPM

The TM_{110}-amplitude is detected in a homodyne receiver by mixing the cavity output and a reference signal down to DC (Fig.2). A frequency sensitive TM_{010}-rejection of more than 100 dB is realized by the coupling factors of the antennae, the hybrid and the stopband attenuation of the bandpass filter. No additional phase stabilization for the reference is needed by using a I/Q-mixer scheme (*In-phase/quadrature*), providing two equal amplitude IF outputs that are in phase quadrature. Two narrowband devices were realized with different types of mixers, one using the MD-164 of M/A-COM, Inc., and the other one the M2G of W.-Johnson Company. Both mixers shown in Fig.3 contain the same components (from right to left): a hybrid, two mixers, a power divider and two IF-amplifiers. In addition, an error-correction scheme was developed for calibration. After passing a low-pass filter and a bipolar video amplifier, the signal may be either viewed directly on an oscilloscope or digitized by 12-bit ADCs [3].

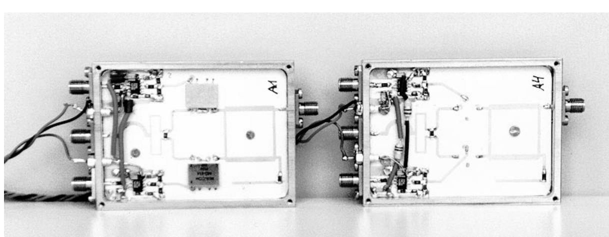


Figure 3: Realized I/Q-mixers: MD-164 (left) and M2G

2.2 Test Results

Bench tests were carried out on a stainless steel prototype to determine the resolution near the center and to test the electronics. Therefore, the cavity was excited by an antenna, fed by a network analyzer. A resolution of about 5 μm was measured in the frequency domain [2].

Another prototype was tested at the CLIC Test Facility (CERN) to demonstrate the principle single bunch response and to measure the TM_{110}-amplitude as a function of the relative beam displacement. The BPM was installed in the spectrometer arm and the beam was moved vertically by changing the current of the steering coil. Due to the measurement position, the mechanical setup and some machine parameters it was not possible to measure the minimum detectable signal. For a single scan, the output of the electronics vs. the relative beam position is shown in Fig. 4. More details are given in [2].

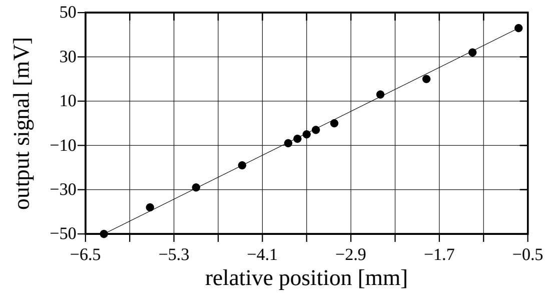


Figure 4: Test at CTF - output versus rel. position

3 STRIPLINE-MONITORS

3.1 Monitor Design

Stripline monitors were built for the experimental area and a temporary beamline because of the relaxed requirements - 100 μm resolution around the center - and the warm location. All monitors consist of four 50 Ω coaxial striplines, positioned 90 degrees apart in azimuth [2].

The BPM body is machined from a single block of stainless steel, four holes and the beam aperture are drilled. Each electrode is 175 mm long and shorted at the end; the geometrical coupling is about 3 %. The main distortion in the transition from the electrode into the cable is caused by the feedthrough, selected for mechanical reasons. All 9 monitors were built and tested at DESY-IfH Zeuthen.

3.2 Signal Processing

The electronics to detect the $\frac{\Delta}{\Sigma}$-signal of two opposite electrodes were built and tested by INFN-LNF [4]. Signal processing is done in the frequency domain by using the amplitude-to-phase conversion scheme together with heterodyning (intermediate frequency of 50 MHz). A normalized output over a wide dynamic range is the main advantage of this system. Furthermore, it is relatively insensitive to electromagnetic noise.

During electronics tests, a peak-to-peak noise of less than 4 mV was measured, corresponding to a position resolution of about 40 μm. This agrees very well with bench test results, where the position of a thin wire was changed until the first 'significant' readout of the electronics was detected. The whole system (monitor and electronics) gives a linear response for off-center positions of up to 5 mm.

4 BEAM TESTS

After the installation of all stripline monitors and the 'warm' cavities in the TTFL beamline, a first test was performed with a 10 MeV beam from Injector I. The beam pulse duration was about 30 μs. For both types of monitors the beam current was varied and the current of a steering coil close to a BPM position was changed. Due to the limited time and some problems with beam parameters it was not possible to get a full scan.

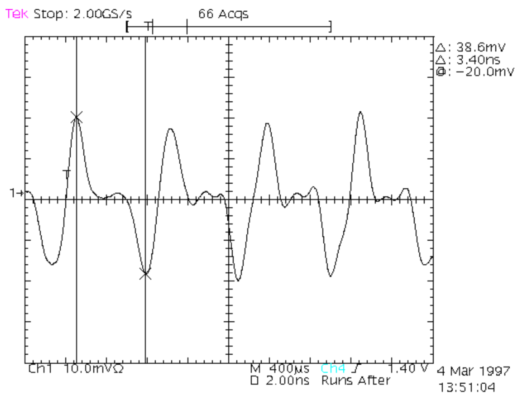


Figure 5: Measured signal for a stripline BPM

Figure 5 shows the output signal of a single stripline monitor channel after 25 m long cables, measured on a fast Tektronix-scope. One clearly sees the expected waveform for 4 bunches. The analog waveform from the detection circuit (prop. to the beam displacement, Fig. 6) shows an initial transient fluctuation of about 10 μs. It seems to be attributable to the beam because the electronics time constant is less than 1 μs. The dynamic range of the circuits has been checked by verifying that the steady state value of this waveform did not change for beam currents of $.5$ mA $\cdots 5$ mA.

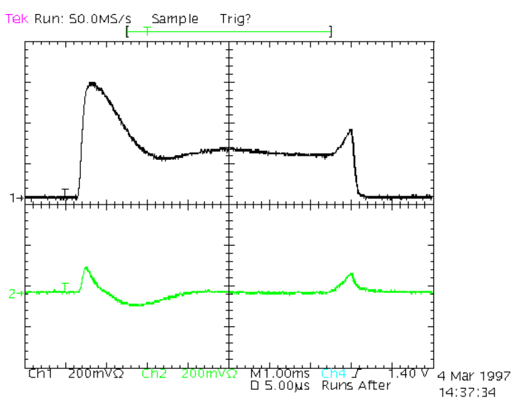


Figure 6: Measured signal of the detection circuit

As a simple check of macroscopic mistakes in scale and offset settings, a cross comparison of the readings of a stripline monitor and a close-by viewscreen has been performed. Some results for the horizontal signals are shown in Fig.7. The discrepancies betweeen the two curves are due to partial misalignment of the target and to a slight change of shape of the image when the beam is steered. This measurement has to be repeated after the installation of the first 100 MeV accelerating module, with a finer beam steering to determine the resolution.

In addition, the readout of a stripline BPM and a 'warm' cavity were compared. Both curves shown in Fig.8-a have the same time structure. The ordinate is given in arbitrary units since all calibration constants are not included yet. Figure 8-b shows the measured signal for three different levels of beam currents.

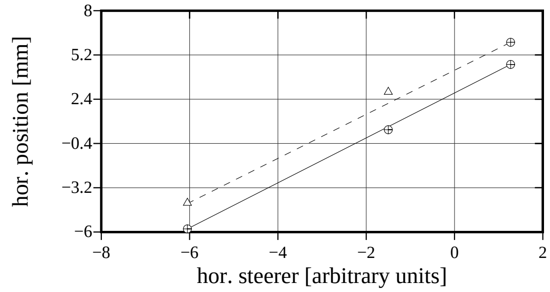
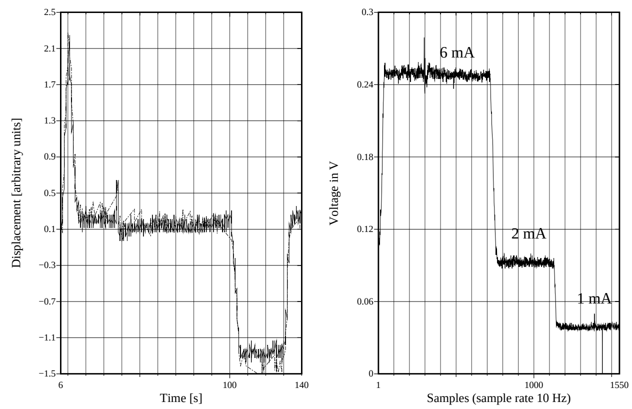


Figure 7: Beam deflection vs. steering - Full line (circles) = stripline readout; dashed line (triangles) = image center.



a) b)

Figure 8: a) Cavity signal (full line) and stripline signal b) Cavity signal for different beam currents

5 ACKNOWLEDGEMENTS

The authors would like to thank all people from the TTFL-group for their help in realizing the measurements. Special thanks are extended to Kay Rehlich and his group at DESY Hamburg for integrating the ADCs into the control system and for the software interfaces and drivers.

6 REFERENCES

[1] *TESLA TEST FACILITY LINAC - Design Report*, edited by D.A. Edwards, DESY Hamburg, TESLA-Note 95-01, March 1995

[2] R. Lorenz et.al., "Measurement of the Beam Position in the TESLA Test Facility", in Conference Proceedings of the LINAC96, Geneva, August 1996, pp. 527-529

[3] *COMET - VMEbus I/O Board, Reference Manual*, Omnibyte Corporation, 245 West Roosevelt Road, West Chicago, Illinois, Feb. 1994

[4] M. Castellano et.al., "TESLA Test Facility Stripline Readout System", in Conference Proceedings of the EPAC 96, Barcelona, June 1996, pp. 1633-1635