Beam Position Monitor with nanometer resolution for Linear Collider

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Abstract

The design and recent results of low power tests of Beam Position Monitor (BPM) and electronics with submicron resolution are presented. For achieving high resolution at single bunch regime the three types of filters are proposed: space filter, time filter and frequency filter.

1 INTRODUCTION

For preserving the beam emittance on Next-generation of Linear Colliders the high accuracy of aligning of quadrupoles and accelerating structures is require. For VLEPP project the needed tolerance is about 0.1 micrometer, so the sensitivity of designed BPM can't be worse this value. The simplest and effective microwave BPM is circular cavity, exited in TM_{110}-mode by an off-axis beam [1]. The cavity can be machined with micron tolerance. The measured amplitude of transverse mode is proportional the beam offset and charge and is stronger then in other monitors. For VLEPP beam parameters ($N = 10^{11}$) the BPM accuracy of about 10-50 nanometer can be achieved [3-5]. The similar types of BPM are designed for other Linear Colliders [6-8].

One the main problem, is the large amplitudes of the fundamental and others symmetrical modes exited in cavity by beam, independently of it's offset. For deep dumping of this huge signal a different types of filters (space, time and frequency) were proposed [2-5]. Other limits of resolution are determined by thermal noise that is order $10^{-13}W$, and noise of electronics.

2 SIGNAL DETECTION AND BPM ELECTRONICS

In Fig.1 the signal processing scheme for BPM output is shown. Two signals from sensitive and reference cavities are used for phase detecting that allow to determine the amplitude and sign of the beam's displacement. TM_{010}-mode in reference cavity and TM_{110}-mode in sensitive cavity have the same frequency 14 GHz. Other modes from sensitive cavity are dumped three types of filters: space, time and frequency. As a space filter a ring-combiner is used, connected with cavity by two coupling holes (see Fig.3).

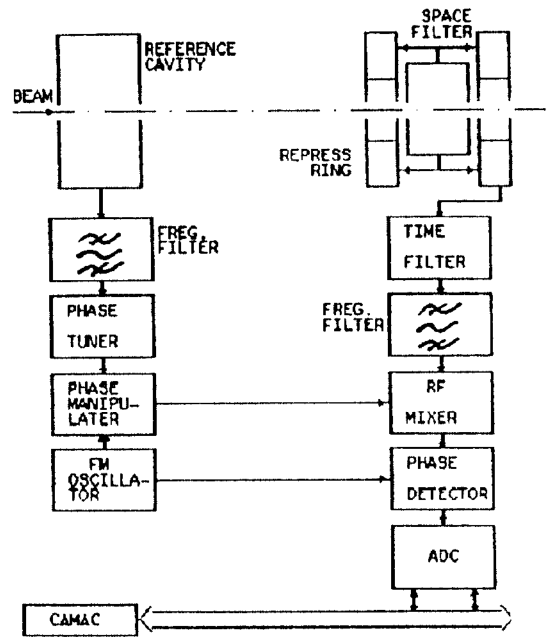

Figure 1. *The block diagram of the electronics of BPM*

For 14 GHz ring-combiner work as hybrid with good rejection of symmetrical modes.

For time filtration of signal the RF switch is used, that switch on with time delay, providing the additional attenuation of parasitic modes because of their low Q-factors. In Table 1 the attenuation of each of modes after filters are presented.

Table 1. *Signal Attenuation of different modes*

	E_{010}	E_{110}	E_{020}	E_{011}	E_{120}	E_{030}	
input signal	$2.4\cdot10^{5}$ W	$2.7\cdot10^{4}(a/\lambda)^{2}$	$2.3\cdot10^{5}$	$0.6\cdot10^{2}$	$1.8\cdot10^{4}(a/\lambda)^{4}$	$8.2\cdot10^{7}$	calculated
space filter	-65	-3	-37	-41	-11	-33	measured on model
time filter	-20	-7	-30	-43	-36	-53	calculated
freq. filter	-41	-1	-46	-44	-36	-15	measured
Fm filter	-25	-6	-40	-30	-20	-35	estimation
TOTAL	-151	-17	-153	-158	-103	-136	

After filtration the measuring signal is mixed down with manipulating reference signal. The final frequency in phase detector is 700 MHz, this signal contents all information about beam's displacement. The low frequency allow to use low noise amplifiers and phase detector with wide dynamic range.

The needed electronics of BPM was completed and tested. The result of testing of electronics sensitivity is shown on Fig.2. For measuring and reference signals the signal from generator was used. In tests we changed the amplitude and the phase of signal by step from -180° to 0 and +180° to simulate the real signal. The phase dependence of signal for two power levels are presented. The obtained sensitivity in order $10^{-11}W$ corresponds a few nanometers VLEPP beam's offset.

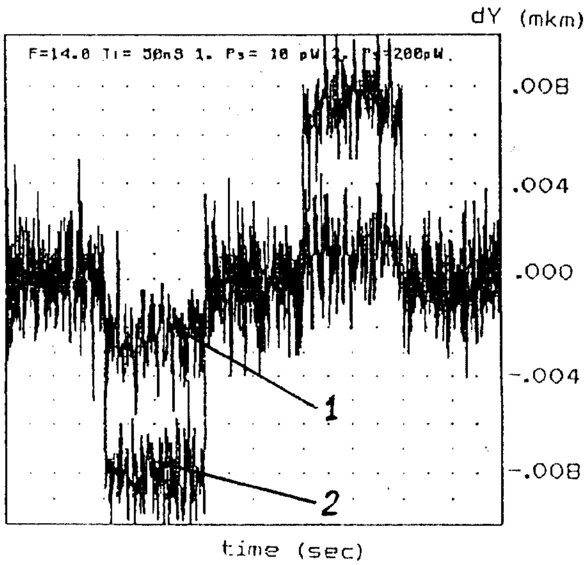

Figure 2. *The results of measurement of electronics sensitivity. 1 - input power=*$2.10^{-10}W$*, 2 - input power=*$10^{-11}W$

3 BPM SENSITIVE CAVITY

The prototype of BPM (see Fig.3) consists of two equal cavities, one for X-direction (1) and another one for Y (2). Each cavity is connected with ring-combiner by two symmetrical coupling holes. Output power is extract from ring-combiner (3) through coaxial plug (4), the angle between X and Y outputs is equal 90°. Additional coaxial cavity (5) with very low Q-quality (loaded by ferrite) is connected with sensitive cavities and used for dumping of parasitic modes.

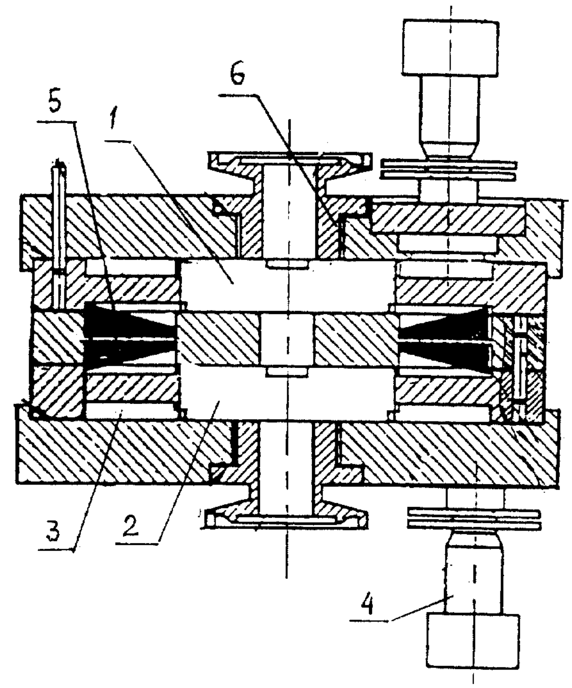

Figure 3. *Prototype BPM for VLEPP.*

The narrow slot (6) in cavity provides additional attenuation of parasitic modes, without influence on TM_{110}-mode.

4 RESULTS OF BPM ANTENNA MEASUREMENTS

On Fig.4 the test setup for BPM antenna measurements is shown. The antenna can move in transverse direction by micromover with step resolution 0.11 micron, and about 1 mm by hand along the axis of BPM.

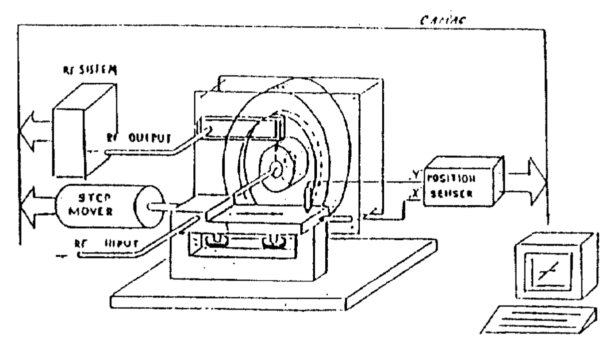

Figure 4. *Test setup of BPM.*

The antenna offset is measured by sensor with 0.05 micron resolution. Input power level was about 10 mW, pulse duration - 50 nsec. The signal from BPM after filtration and phase detecting was measured. The results of measurements are shown on Fig.5 (without phase detecting) and on Fig.6 (with phase detecting).

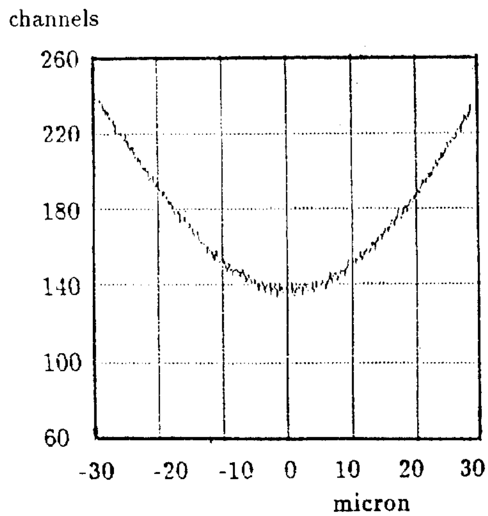

Figure 5. *Amplitude BPM output for different antenna position (1 channel=* $2.5 * 10^{-13}$ *C*

The comparison of this two Figures shows, then phase detector increase the sensitivity of this scheme in a few times, and gives the sign of antenna offset. The received resolution of this prototype of BPM is not worse then 0.3 microns.

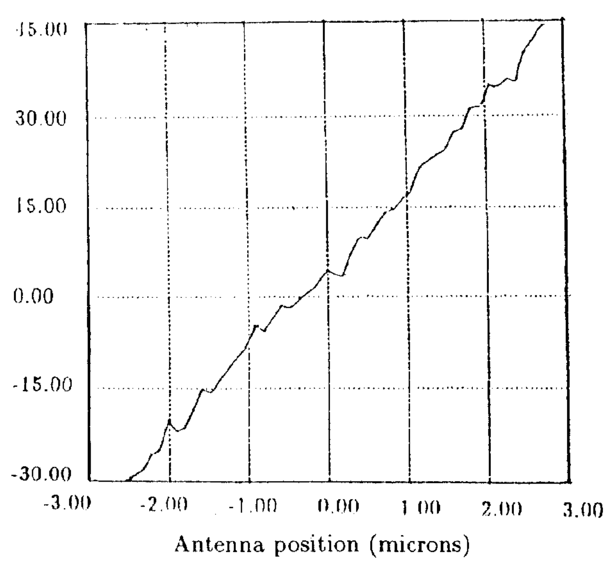

Figure 6. *Transmission voltage through BPM versus antenna position (1 chanel=*$2.5 * 10^{-13}$ *Coulomb).*

CONCLUSION: The "cold" BPM antenna measurements show that the accuracy of a few nanometers for with $N=10^{11}$ particles in the bunch can be achieved. However, in virtue of the difficulties encountered in isolating the transverse mode in presence of beam-exited symmetrical mode with a large amplitude, an experimental test of the BPM with the real beam in the single bunch regime is needed.

5 REFERENCES

[1] W.Schnell, "Common-mode rejection in resonant microwave position monitors", CLIC Note 70, CERN-LEP-RF/88-41.

[2] V.Balakin, "Concept BPM for VLEPP", in Proc. of Third Int. workshop on Linear Collider (LC 91), Protvino, 17-27 September,1991, v.3, p.155.

[3] V.Balakin, N.Solyak, V.Vogel, "The model of BPM for VLEPP", in Proc. of Third Int. workshop on Linear Collider (LC 91), Protvino, 17-27 September,1991, v.3, p.188.

[4] V.Vogel et al., "BPM for VLEPP", presented at ECFA-workshop on e^+e^- Linear Colliders (LC92), Garmish-Partenkirchen, 25 Jul-2 Aug 1992.

[5] V.Vogel et al., "BPM with the nanometer resolution for VLEPP", in Proc. of the Int.Workshop on emittance preservation in Linear Colliders (Emittance-93), KEK, Tsukuba, 19-23 April,1993, pp.664-671.

[6] I.Wilson, "CLIC BPM Tests", in Proc. of The 5th Int. Workshop on Next-Generation Linear Colliders (LC 93), SLAC, Stanford, 13-21 Oct, 1993.

[7] R.Lorenz, K Yezza, "Beam Position Monitors for TESLA Test Facility", presented on The 5th Int. Workshop on Next-Generation Linear Colliders (LC 93), SLAC, Stanford, 13-21 Oct, 1993.

[8] H.Hayano et al., Submicron Beam Position Monitor for JLC, presented at Linac 92, Ottawa, 1992.