Proposal on BINP-BNL-KEK Experiment for Testing Beam Position Monitor for Linear Colliders.

Protvino, Russia, 1995.

1. Abstract

In the present document, the proposals on realization of the joint experimental studies of the new version of the beam position monitor (BMP) with the participation of
Branch of Institute of Nuclear Physics (BINP, Russia),
Brookhaven National Laboratory (BNL, USA),
National Laboratory for High Energy Physics (KEK, Japan)
are discussed. The main parameters of the BPM are grounded. The layout and circuit of the experiment are described.

2. Introduction

For the first time the idea of linear colliders was proposed in 1978 [1]. At present, some well-known projects of linear colliders for c.m.s. energies ranging from 300 GeV to 1 TeV are being discussed [2] [5]. Table 1 represents the main parameters of the colliders designed for 0.5 TeV [2].

Table 1. Selected Linear Collider Parameters for E_{CM} = 0.5TeV (G. Loew, LC93)

Parameter	TESLA	SBLC	JLC-I(X)	NLC	VLEPP	CLIC
L ($10^{33}cm^{-2}s^{-1}$)	7	4	6	8	15	2-9
RF Freq. (GHz)	1.3	3.0	11.4	11.4	14	30
Rep Rate (Hz)	10	50	150	180	300	1700
Bunches per RF pulse	800	125	90	90	1	1-4
N (10^{10})	5.15	2.9	0.63	0.65	20	0.6
BPM Precision (μm)	10	10	1.0	1.0	0.1	0.1
σ_{x0}/σ_{y0} (nm)	1000/64	670/28	260/3	300/3	2000/4	90/8
σ_L (μm)	1000	500	67	100	750	170
Active Linac Length (km)	20	29.4	17.7	14	6.4	6.6
Klystron Pulse Length (μs)	1300	2.8	0.84	1.5	0.7	0.011
AC Power (MW)	137	114	86	141	91	175

Construction of such an accelerator is going to be very difficult and expensive. It is very important to have high level of the main parameters. One of the main parameters of such colliders defining their efficiency and allowing to hope for physical results in the nearest future, is high luminosity.
Luminosity is known to be calculated by the formula:

$$L=N^2 f_b/(4\pi\sigma_x\sigma_y)\ ,$$

N being the number of particles in a bunch,

f_b - frequency of recurrence of collisions,

$\sigma_x\sigma_y$ - horizontal and vertical sizes of a bunch, respectively.

To increase either the number of particles, or the repetition rate is rather difficult. Therefore, in practice the only way to increase luminosity is to reduce the sizes of colliding bunches at the interaction point (IP).

As follows from Table 1, the required sizes of a bunch at the IP are very small. Here it is important that the vertical size of a bunch is hundreds times less than the horizontal one and makes 3 - 30 nanometers. This is due to the interaction conditions of the fields of colliding bunches at the IP. For example, at the international FFTB experiment in SLAC the minimum vertical size of the bunch reached lately was about 70 nanometers [3].

For an extremely small beam size at the IP, it is vital that the bunch emittance value should not increase throughout a linac. Really, bunches are accelerated under seismic ground motions, thermal displacement of parts of installations and unstable feeding power[1]. Due to these disturbances, the optical elements of an accelerator are shifted, the axes of the beam and acceleration section do not coincide. As a result, the last bunches in the train will be affected by the fields of all preceding bunches, which would lead to an increase of the beam emittance value - the so-called stochastic heating. Therefore, the beams cannot be focused at the IP. The preliminary alignment of the accelerator elements turns out not to be enough, and a permanent correction is required.

Ref. [6] presents an algorithm allowing to keep normal operation of an accelerator and achieve the required luminosity under constant revolting effects, are described in spite of the fact that a base line with the same high accuracy throughout the collider is unattainable. A practical way to preserve emittance is to perform an initially "rough" alignment and correct subsequently all magnetic elements of the accelerator according to beam position [4].

To use this algorithm, one has to know exactly (0.1 - 10 micron) the cross coordinates of a bunch at the positions of quadrupoles and accelerating sections and be able to tune them with equally good accuracy.

At present, several types of BPMs for linacs are known, and in many laboratories of the world the prototype of a BPM is being investigated [7], [8], [9], [14], [15]. Necessary theoretical and experimental studies with radiotechnical scale models have been done, among these the studies using antenna as a beam simulator.

However, since it is difficult to take into account how all beam-excited modes in the sensitive cavity affect the accuracy of measurements and complexity of the electronics applied, one can hardly state that the BPM problem is solved by now. Therefore, an experiment with the BPM using a real beam is needed that would allow to test the BPM sensitivity and accuracy.

For this purpose, a beam at the ATF BNL is well suitable having an E=45Mev, acceptable charge q =250 pC, a reasonably small longitudinal size 10 - 15 ps, a low significance emittance of 1 pi mm mrad. ATF can also operate in the multi-bunch mode[11]. Therefore, a complete scale experiment to study the BPM for future linacs can be conducted at this installation.

3. Description of Experiment.

We think that the most promising is the method of the bunch position measurements based on measuring the energies of transverse modes left by bunches in the sensitive cavity. The energy of a transverse mode is proportional to the deviation of the bunch trajectory from the electrical axis of the measuring cavity [10]. Important here is the simplicity of the design of the BPM of this type and a relative inexpensiveness of the electronics used. This is important, since the general number of BPMs in the projects of interest is very large. Besides, an advantage of this method is that the output signal contains information about both the absolute value of the deviation of the bunch from the BPM axis, and its direction. The necessary analytical estimates of this method and the results of the some testing of BPM are given in the Appendix.

Figure 1 represents the setup of the experiment to be conducted at ATF. Two independent BPMs are proposed. One of these (2) is rigidly clamped to the support table (5), whereas the second one (3) can be moved by the controllable precise electromagnetic mover (4) [12]. To be able to move freely, the movable BPM is connected to the vacuum channel through siphons (7). Simultaneously, the rigidly clamped BPM allows to normalize signals from the movable BMP.

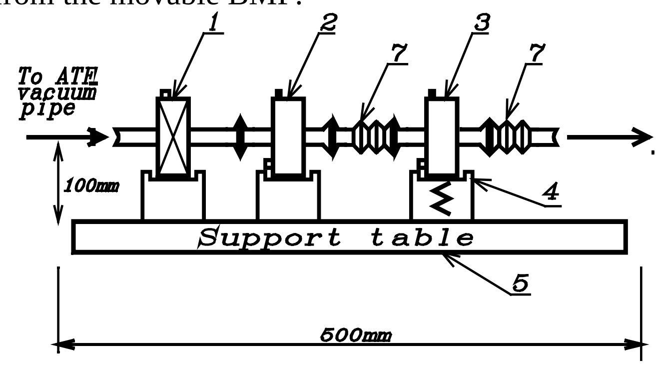

Fig. 1. Setup of Experiment

The normalized signals will, therefore, be independent of the seismic situation in the place of measurements, as well as of the instability of the beam position in the accelerator channel. The output signals from the both BPMs come to the measuring circuit (Fig. 2) including a bandpass filter, a mixer, a phase detector, an intermediate frequency amplifier and a video amplifier for each monitor.

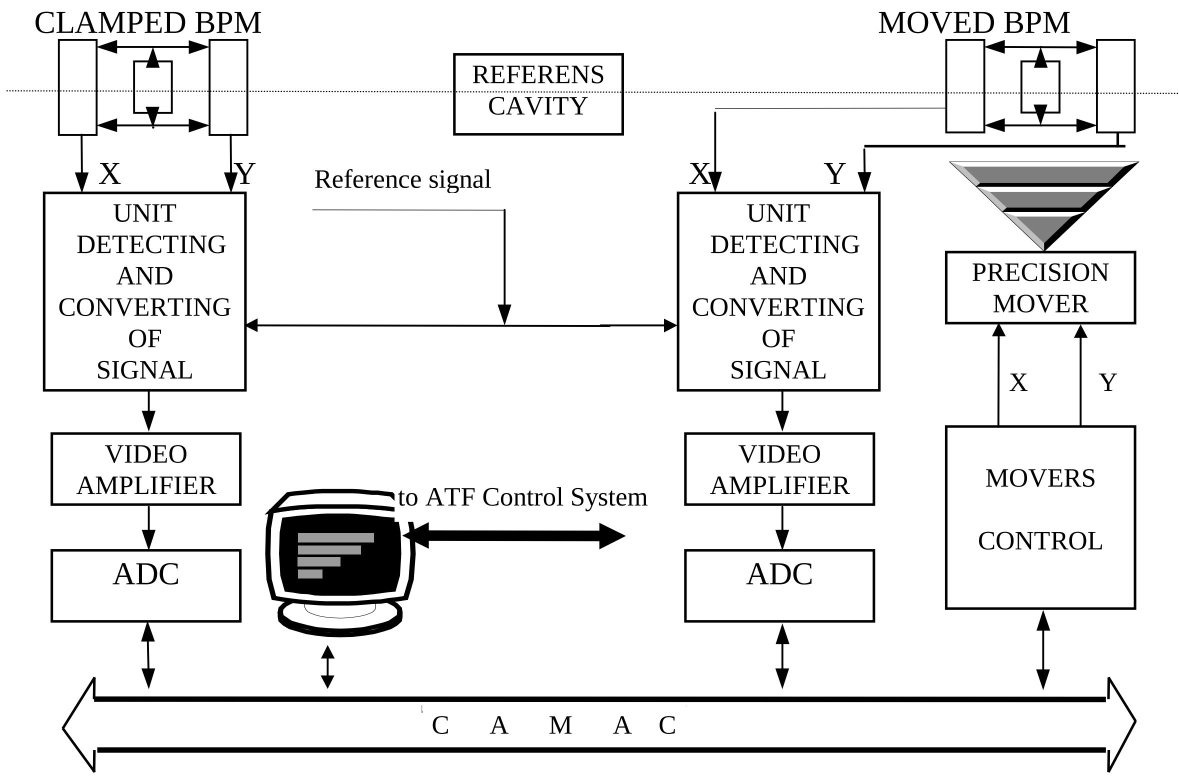

Fig. 2. **Block diagram of BPM's electronics.**

Afterwards the signal is transmitted from RF electronics to the analog-digital converter (ADC) located in CAMAC. Precision mover is connected with CAMAC, too. The above circuit allows to find the coordinates of both entire trains, and a single bunch in a train. The signals from ADC are statistically processed using the information about operational mode and the main ATF parameters. The suggested layout of the experiment allows to evaluate the sensitivity of the BPM of this type and its possible applications for future linacs.

4. Maintenance of the Experiment.

It is expected that the necessary equipment will be supplied (as far as possible) by all the parts of the experiment (BNL, BINP, KEK). BINP provides the experiment with BPM's, the precision mover, the mover controller, RF electronics and software for the experimental setup. The details of the duties of the parts will be specified later on. Since BNL is the place where the experiment is to be run, it seems suitable to exploit to the maximum the ATF equipment, such as: computers (IBM PC are preferable), CAMAC crate with modules (partly standard, partly developed by the participants of the experiment), power sources and necessary measuring devices. During the experiment run, the ATF control systems are required to provide the signals of synchronization with the beam, and the reference frequency. Also, it is necessary to measure and control (within ATF parameters) the following data : single bunch duration, the general number of bunches, bunch charge value, bunch coordinates at the nearest BMP used in ATF, and the beta function value at the point where the new type of BMP is mounted.

5. Time-Table

The 1-st working stage presupposes: Assembly of the electromagnetic mover and attached beam position monitor; assembly of the immobile BPM on the support table; connecting the equipment to the ATF vacuum system; also, disposition, assembly and adjustment of necessary measuring sensors.

Period -- 1 week.

2nd stage: Adjustment of equipment, necessary control measurements, testing software and ATF control programs interface. At the given stage, a beam should (sometimes) be present to ensure successful tuning measurements.

Period -- 1 week.

3rd stage: Experiment proper. The purpose is to estimate the accuracy of the beam position measurements at new type of BPM versus the bunch charge, bunch length and sizes in the single- and multi-bunch regime.

Period -- 2 weeks.

There should follow a break to go on for 2-4 months to process the data and get ready some modifications in the layout of the experiment. After the break and the re-assembly of the equipment, the experiment starts again.

Period -- 1 week.

Appendix 1

The simplest and most effective microwave BPM is a circular cavity excited in the TM_{110}-mode by the off-axis beam. The measured amplitude of the transverse mode is proportional to the beam offset and charge, and is stronger than in other monitors.

A serious problem here is a large amplitude value of the fundamental and other symmetric modes excited in the cavity by the beam irrespective of the beam offset[10].

The power of several modes excited in the cavity is defined as

$$P_i = \frac{1}{2Q_i}\omega_i^{\,2}\left(\frac{R_ø}{Q}\right)_i q^2 M^2 T^2,$$

where q means the beam charge,

M=sin(kh/2)/(kh/2) - beam transit time factor;

$T = \exp\left(-\frac{\omega_i^2\sigma_z^2}{2c^2}\right)$-space factor;

$(R_ø/Q)_i$- shunt impedance depending in the case of the transverse mode on the beam off-axis.

The ratio of the fundamental mode power to that of the TM_{110} mode for the displacement of 0.1 μm is $P_{010}/P_{110}=10^{10}$, because the attenuation of the common mode of about 100 dB is required. Let us estimate the attenuation of the fundamental mode due to the narrow - band receiver.

The amplitudes for the two modes, TM_{010} and TM_{110}, are of the form

$$P_i(t) = P_{0i}e^{-2\beta_i t}\cos(\omega_i t) \quad \text{for } t>0,$$

where $\beta_i = \frac{\omega_i}{2Q_i}$.

The Fourier transform yields the beam-driven spectral density

$$p_i^{\,b}(\omega) = P_i\frac{\beta_i^{\,2}+\omega^2}{\left[\beta_i^{\,2}+(\omega+\omega_i)^2\right]\left[\beta_i^{\,2}+(\omega-\omega_i)^2\right]} .$$

at frequency ω.

For Q_i>>1 at $\omega=\omega_{110}$ spectral density of TM_{010} and TM_{110} modes are:

$$p_{110}^b(\omega_{110}) = P_{110}\frac{Q_{110}^2}{\omega_{110}^2};$$

$$p_{010}^b(\omega_{110}) = P_{010}\frac{\omega_{110}^2}{\left(\omega_{110}^2-\omega_{010}^2\right)^2}.$$

The quantity

$$r^b = Q_{110}^2\left(1-\frac{\omega_{010}^2}{\omega_{110}^2}\right)^2$$

is the fundamental mode rejection by the frequency discriminator[10]. For Q_{110}=2000 and

electronics for BPM	$\AA_{010}$	$\AA_{110}$	$\AA_{020}$	$\AA_{120}$	
Frequency, GHz	9.2	14.0	22.2	25.9	calculated
Q-factor	750	7700	1300	6200	calculated
Input signal	0.59	6.6 $(à/\lambda)^2$	0.56	4.4 $(à/\lambda)^4$	calculated
Space filter	-65	-3	-37	-11	measured in model
Frequency filter	-41	-1	-46	-36	measured
Fm filter	-25	-6	-40	-20	estimated
Total, dB	-131	-10	-123	-67	

$\omega_{010}/\omega_{110}$=9200/14000=0.66, one has r^b=1.27*10^6, i.e. rejection is equal to 60 dB. This value does not suffice; therefore, other types of filters were proposed. In Table 1, the attenuation of each mode after passing through the filters is presented. The required

Table 1.

are presented. The obtained sensitivity of the order of 10^{-11} W corresponds to the 0.2 μm beam offset (if the beam charge is 250 pC).

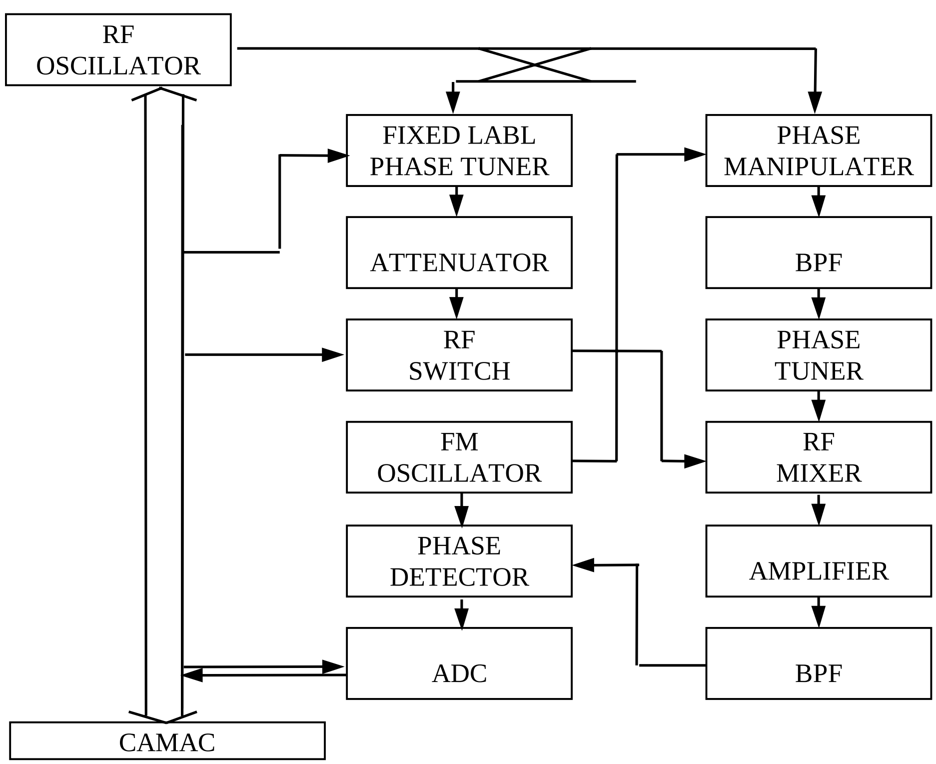

Fig. 1. Block diagram of electronics of BPM.

Fig. 3 shows the result of test measurements of BPM performed with an antenna. The antenna offset is measured by a sensor with 0.05 micron resolution. The level of input power is about 10mW, whereas the pulse duration - 50 ns [15]. The BPM prototype is shown in Fig. 4 [13]. The received resolution of this prototype is not worse than 0.3 microns.

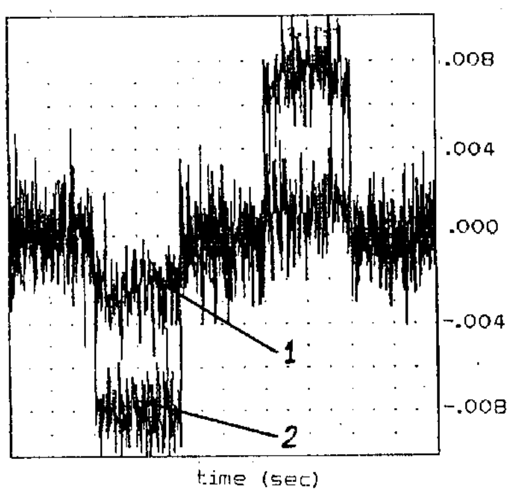

Fig. 2. The results of measurements of electronics sensitivity. 1-input power=10^{-11}; 2-input power=$2*10^{-10}$ W.

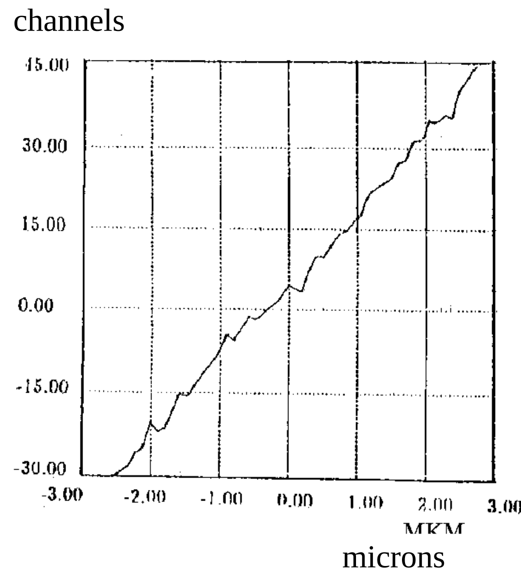

Fig. 3. Transmission voltage from BPM versus antenna position (1 channel=$2.5*10^{-13}$C)

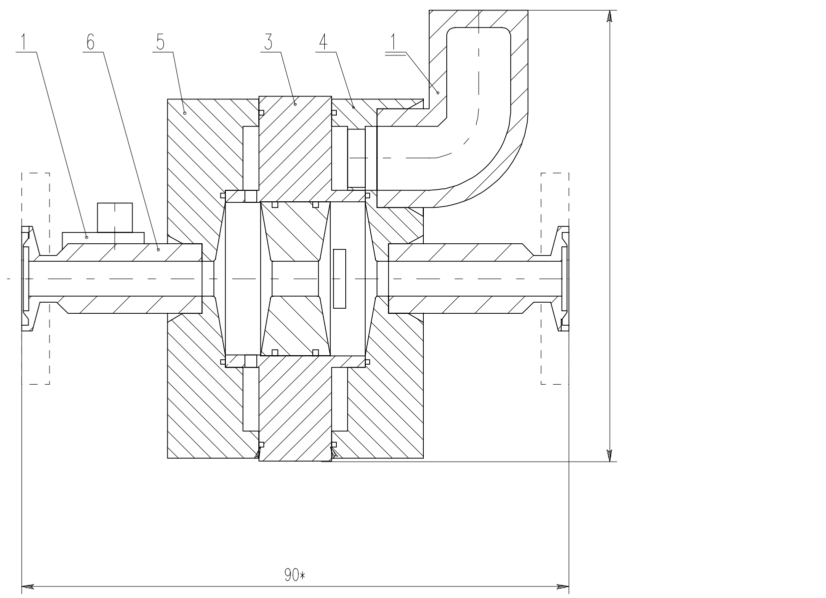

Fig. 4. BPM Prototype for VLEPP.

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