A WIDE-BAND PICK-UP FOR MEASURING BEAM SPECTRUM IN KEKB

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Abstract

A wide-band pick-up, which is mounted on the wall of waveguide between the klystron and the rf cavity, has been developed for measuring beam spectrum in KEKB storage-ring. The MAFIA simulation code and Network-Analyzer test-bench have been applied to design the pick-up structure. After investigation of various kinds of structures, a strip-line type pick-up, which has a bandwidth of 5~30GHz, is chosen. Some important considerations are also included, such as to avoid the couple of large fundamental forward power for safety. Measurement results of beam spectrum and synchrotron oscillation are presented in this paper.

1 Introduction

The bunch length and beam spectrum are important parameters in the observation of beam quality. Many efforts for beam diagnostics had been made with sophisticate electronics. By assuming the electrons with a Gaussian distribution in the beam bunch of a storage ring, beam spectrum can be derived by Fourier transformation. It is expected to be up to 30GHz with the bunch length of 6mm in KEKB [1]. In order to obtain this signal, cooperating with the KEKB beam-diagnostic group, we have designed a wideband pick-up, which is installed on the wall of the waveguide between the klystron and the rf cavity on KEKB.

2 Design of the pickup

When beam passes through the rf cavity, it induces an electromagnetic field in the cavity corresponding to the beam spectrum. Figure 2 shows the sketch of the pick-up system, which will be used for beam spectrum measurement. The signal from the pick-up is sent to a spectrum analyzer (HP8564E). As the beam frequency components we are interested in are pretty high (5GHz to 30GHz), these signals can propagate in the waveguide (WR1500) since they are much higher than the cut-off frequency of the transmission line for (the fundamental component) TE10 mode of 508.88MHz.

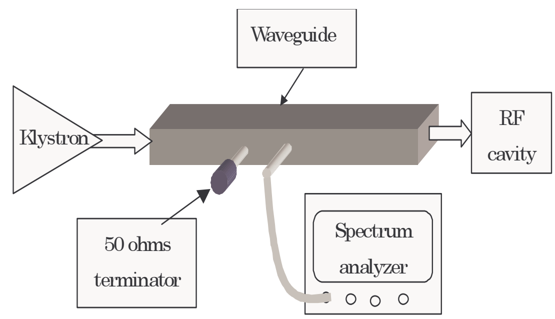

Figure 2: Sketch of the pick-up system

For the transmission of high frequency signal, a proper coaxial line should be chosen to transmit electromagnetic waves in only a single mode; otherwise the impedance is indeterminate that results to erratic in operation. TE11 mode, which is the lowest of all the higher-order modes, is most likely presented in the coaxial line. On this account, we can select the dimensions of the cable and the connectors according to the following empirical argument [2]:

$$\lambda_c \approx \pi(a+b) \qquad f_c = \frac{v}{\lambda_c} \approx \frac{c}{\pi(a+b)\sqrt{\mu_r \varepsilon_r}}$$

Where b is the inner radius of outer conductor, a is the radius of the inner conductor. This approximate expression for the cutoff of the TE11 mode in a coaxial line is accurate enough within 5 percent for b/a<7. For the frequency up to 30GHz, a semi-rigid cable of type EZ141 associated with SMA connector is selected being used in our pick-up system. It's dimensions are: a=0.45975mm, b=1.4925mm. The cutoff frequency of TE11 mode is 30.35GHz with the dielectric constant of 2.6.

2.1 Simulation of Pick-up by MAFIA

Several typical antennas such as probe, coupling-loop and strip-line with different dimensions were simulated by the use of MAFIA code.

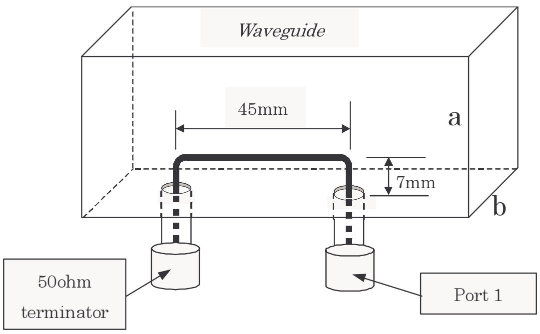

Figure 3: Sketch of the pick-up structure.

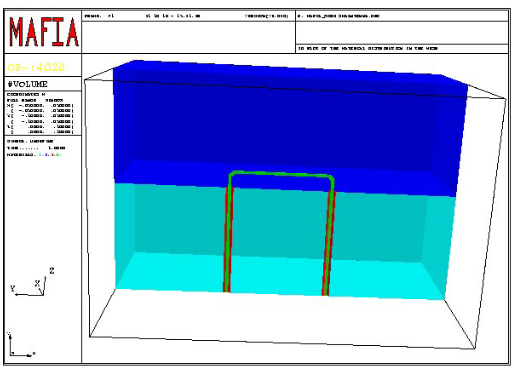

Figure 4: The Structure of the pick-up antenna. (The upper part of the box is inside of the waveguide.)

Finally a strip-line type structure shown as Fig. 3 and Fig. 4 was determined. Cutting the outer conductor and the dielectric material, the semi-rigid cable is fixed on the wall with the cut cross section identical to the inner surface of the wall. To compromise with the total response in the whole bandwidth, final dimensions were chosen as in Fig. 3. The reflection coefficient S11 at input port (Port 1) in the frequency from 5GHz-35GHz is shown in Fig. 5.

Considering the safety of spectrum analyzer, the pick-up is mounted on the narrow plane of the waveguide instead of the wide plane. Before this new wideband pick-up was used, a very short probe was mounted on the wide plane for picking up the beam spectrum. The confliction between coupling high electric field of TE10 mode and the safety of the equipment resulted a low sensitivity of the old one.

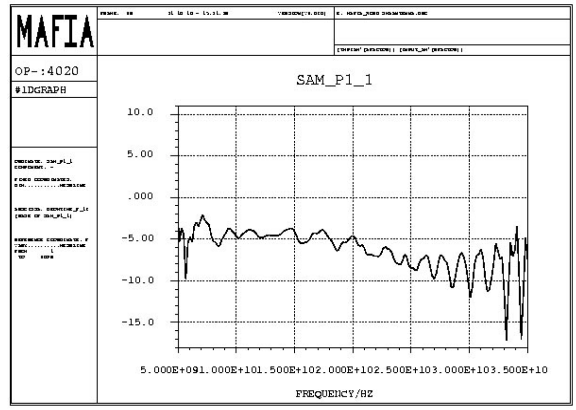

Figure 5: S11 at the input port of the pick-up in the frequency range from 5GHz to 35GHz.

2.2 Test of Pick-up by Network Analyzer

The structure was tested on a network analyzer bench. Normally for measuring the coupling of electromagnetic field picked up from a waveguide, S21 should be measured with some suitable matching and adaptor for coaxial to waveguide transfer in a certain frequency range. However, in our case, the spectrum is so rich with lots of its higher order modes in a wide scope of frequency, it is impossible to establish such a complicated system to measure S21. But we can simplify the system by measuring S11 from the port 1 in Fig.3, because the size of the waveguide for TE10 mode of 508.88MHz is much larger than our frequencies so that the waveguie can be looked as a free-space while the pick-up is just like an antenna, which is reciprocal between emitting and receiving. The experimental results give a good agreement with the simulation. Fig. 6 shows the experimental result of S11 from 5GHz to 40GHz. It is almost less than –5dB at the range from 5-30GHz. It can be seen that at the frequency higher than 30GHz, an obvious oscillation appears with a complete reflection. This proves the TE11 mode presenting in the coaxial line at the high frequency end. The TE11 mode is reflected between the cross section of the cable and the analyzer leading to the resonance inside the coaxial line.

To check the coupling of the fundamental component of 508.88MHz, an experiment was performed with an rf power emitter as the source of the tested waveguide system. The improved pick-up antenna is installed on the narrow plane. And the strip-line is parallel to the microwave propagating direction. In this case neither the electric field nor the magnetic field of TE10 mode is coupled. This is confirmed by the coupling of TE10 mode less than –70dB.

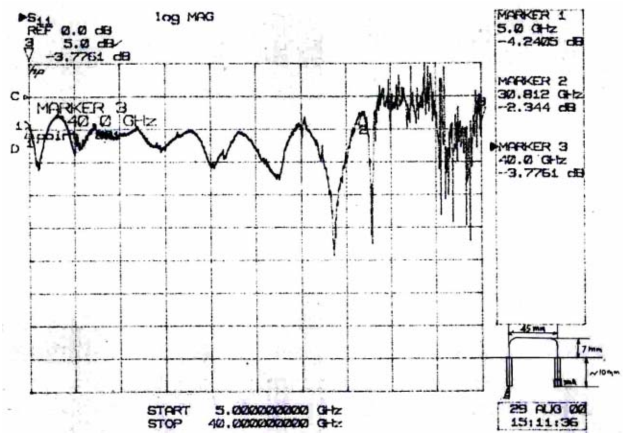

Figure 6: The testing result of S11 in the frequency range from 5GHz to 40GHz.

3 Measurement results of beam spectrum

The new pick-up was installed on the waveguide before the start of KEKB operation in Oct. 2000. The signal to noise ratio was checked before and after the klystron rf power was on when the beam was off. The spectrum analyzer is connected to the HP VEE programmable controller so that the beam spectrum can be monitored day and night automatically.

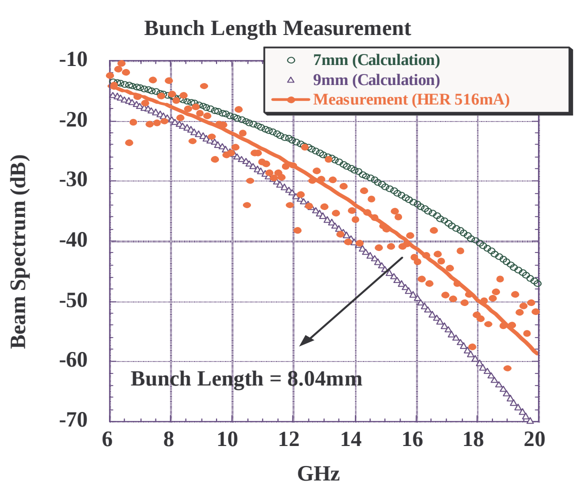

Figure 7: Frequency component picked up every 127MHz. And expected spectrum of several bunches length of the beam.

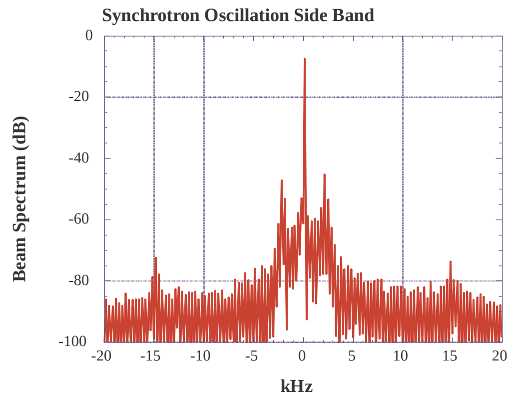

Figure 8: Synchrotron oscillation Side-band at KEKB LER

Clear beam spectrum and some other beam instability phenomena such as synchrotron oscillation side-band are attained as shown in Fig. 7 and Fig. 8 [3].

4 Conclusion

The advantage of this new pick-up is the reasonable response in a very wide bandwidth of several 10GHz. With this simple apparatus, beam information can be monitored at an extremely high frequency point. The attenuation is around –2db/meter for the used cable. Further improvement is in plan for higher sensitivity. More detailed beam measurement and analysis are being done that shows the good performance of the pick-up system.

Reference

1. “KEKB B-Factory Design Report” KEK Report 95-7, August 1995. A
2. Peter A. Rizzi, “Microwave Engineering, Passive Circuits”
3. T. Mimashi, B.Hong, et al, “Bunch Length Measurements and the Beam Signal Observation Through High Power RF Waveguide system” Proceeding of HEACC2001, March 2001, Japan