MEASUREMENT OF BEAM POSITION MONITOR USING HOM COUPLERS OF SUPERCONDUCTING CAVITIES*

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Abstract

The offset beam from the axis induces the HOMs in the cavities. These HOMs in superconducting cavities are usually damped by HOM couplers to suppress the beam instability. The induced HOM field of dipole mode is proportional to the beam offset and can be used to measure the beam position inside the cavity. Measuring the HOM power by scanning the beam permits to estimate the beam position using a known function of the HOM power. The steering magnet was installed to the JAEA superconducting ERL-FEL to vary the beam position. The beam position in the cavity was estimated with the measured HOM power from the HOM coupler.

INTRODUCTION

In a recirculating accelerator such as an energy-recovery linac (ERL) recirculating electron bunches pass through the same cavities and the off-axis beam induces higher order modes (HOMs). These HOMs can cause multi-pass, multi-bunch beam breakup (BBU) and limit the beam current especially for high Q-value superconducting accelerators (SCAs). It is therefore important to know the beam position in the cavity. Beam position monitors are installed at the beam transport line or between the cavities. Although the beam position in the cavity can be estimated by monitoring at these points, this estimation may include the error due to misalignment of the cavity.

The HOM power increases with the beam current and also with the beam position from the axis. The HOM power can be therefore used to characterize the beam position in the cavity. This indicates the possibility to detect the beam position along the long cryostat with many cavities between which the normal beam position monitors (BPMs) cannot be installed [1].

The beam position can be estimated from the HOM power if required parameters are all known. When the function between the beam position and the HOM power is known, the data obtained by scanning a certain parameter permit to estimate the beam position without knowing all the parameters.

Here we describe the method of the BPM of a combination of the HOM coupler and a steering magnet and the results of primary measurement of this method.

BASIC IDEA OF BEAM POSITION MONITOR

In a superconducting cavity HOM couplers are equipped to decrease the Q-values of the HOMs so that the HOM power rapidly damps in the cavity. The HOM power can be dissipated in the cryostat for low current beam accelerators since the total dissipated power is not large. The HOM power for high current accelerators such as ERLs should be brought out of the cryostat to reduce the load on refrigerator systems.

The HOM power extracted from the cavity includes the information of the beam position. Calculating the beam position from the HOM power requires such parameters as R/Q, the loaded Q-value, the external Q-value of the HOM coupler, cable attenuation and the beam current to be measured precisely. These parameters are however not easy to estimate precisely.

If the HOM power is a function of them and the beam position is also a function of a measurable independent parameter such as a steering magnet current, the HOM power can be written as a function of the measurable independent parameter. When the HOM power is measured by changing this independent parameter, the beam position can be estimated by fitting the HOM power data to the function.

ANALYSIS OF HOM POWER

It is assumed that the cavity has no length and that the excited HOM is related only to the beam position from the axis. The dipole HOM power excited in the cavity by the charge moving a distance r off axis can be expressed as

$$P_{cavity} = R_{HOM} I_b^{\,2} r^2 , \quad (1)$$

where R_{HOM} is a shunt impedance of the HOM and I_b is the beam current. If the beam position is stable, the on-axis beam excites no HOM. Hence the HOM power of on-axis beam shows zero watt. The minimum power obtained by sweeping the steering magnet current shows small but some power in practice. This is considered due to the fluctuation of the beam position. When the beam has the fluctuation of δ_n of the n-th bunch, the HOM power can be expressed as

$$P_{cavity} = R_{HOM} I_b^{\,2} (r + \delta_n)^2 . \quad (2)$$

The average power of the N bunches is written as

$$\begin{aligned}\overline{P}_{cavity} &= R_{HOM} I_b^2 \frac{1}{N} \sum (r + \delta_n)^2 \\ &= R_{HOM} I_b^2 (r^2 + \frac{1}{N} \sum \delta_n^{\,2}) \quad (3) \\ &= R_{HOM} I_b^2 (r^2 + \delta_{RMS}^{\,2}) \quad .\end{aligned}$$

Since the fluctuation of the beam is considered to be random, the average of δ_n becomes zero. The parameter

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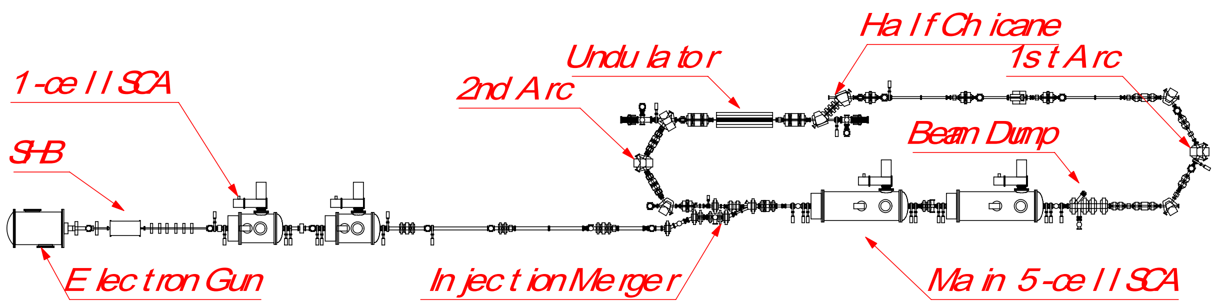

Fig.1 Layout of the JAEA ERL-FEL

δ_{RMS} is the RMS of the beam position fluctuation. The distance r at the cavity moved by the steering magnet can be expressed as

$$r = r_0 + \Delta r I\,, \qquad (4)$$

where r_0 is an initial beam offset from the axis at the position of the cavity. The parameters of Δr and I are the beam shift per unit current and the steering magnet current respectively. The HOM power can be written as

$$\overline{P}_{cavity} = R_{HOM} I_b^2 \left[(r_0 + \Delta r I)^2 + \delta_{RMS}{}^2 \right]. \quad (5)$$

Parameters such as coupling of a HOM coupler and attenuation of cables are required to estimate the HOM power at the measuring point out of the cavity. Representing some parameters as one parameter α simplifies the equation of the measured HOM power as the following.

$$\overline{P}_{measure} = \alpha \left[(r_0 + \Delta r I)^2 + \delta_{RMS}{}^2 \right] \qquad (6)$$

This equation permits to estimate the unknown parameters such as the beam position at the cavity by fitting the measured data as a function of the steering magnet current.

MEASUREMENT

Configuration

The layout of the JAEA ERL-FEL is shown in Fig.1 [2]. Fig.2 shows the 5-cell cavity, which has five RF couplers such as a main power coupler, a pick-up coupler and three HOM couplers. Two HOM couplers are designed to damp transverse modes (TE modes) and the other to damp longitudinal modes (TM modes). All HOM couplers are terminated to dummy loads outside of the cryostat

Setup

The first 5-cell cavity was used to measure the HOM power. In this cavity many HOM fields can be excited. The TE111 $\pi/5$ mode from the TE mode coupler #1 was decided to be used to measure the HOM power. A steering magnet was set about 2 m upstream of the first 5-cell cavity. In the ERL accelerating and decelerating beams pass through the same cavity that is to say two beam positions must be considered in one cavity. Since it is a little complicated to deal with these two beam positions at the same time, the recirculating beam was transferred not to re-enter the first 5-cell cavity and the only accelerating beam passed through the cavity.

The HOM power was measured with a real-time spectrum analyzer. Since the linac was operated in a pulse mode of 10 Hz repetition of macro pulse, the spectrum analyzer was used in trigger mode synchronized with the macro pulse. Since the fluctuation of the HOM power within the macro pulse is difficult to measure, the HOM power was averaged every macro pulse of the electron bunches.

Results

Fig.3 shows the measured HOM power as a function of the beam steering magnet current. The HOM power is

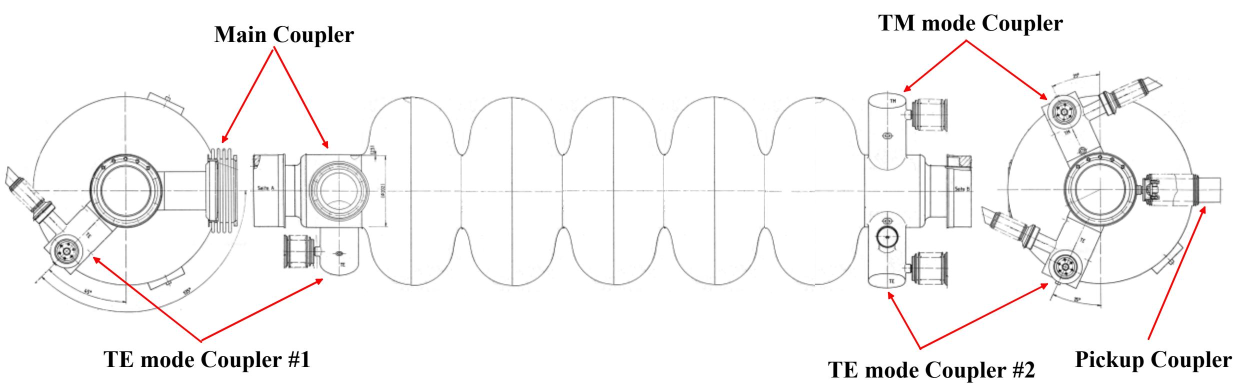

Fig.2 RF Couplers of the 5-cell cavity.

obtained by averaging the power spectrum of 300 macro pulses. The fitting line with Eq.6 is also shown in the figure. The beam position in the cavity is estimated to be 0.23 mm in horizontal and -0.31 mm in vertical. The fluctuation of the beam is 0.21 mm in horizontal and 0.60 mm in vertical.

CONCLUSION

The beam position monitor with a combination of the HOM coupler and the steering magnet is useful to estimate the beam position in the cavity without knowing the parameters of the cavity, the beam and the measurement system. This may be applied to estimate the beam positions of both accelerating and decelerating beam passing in the same cavity at a time for ERLs. Further analysis and measurement is required.

ACKNOWLEDGEMENTS

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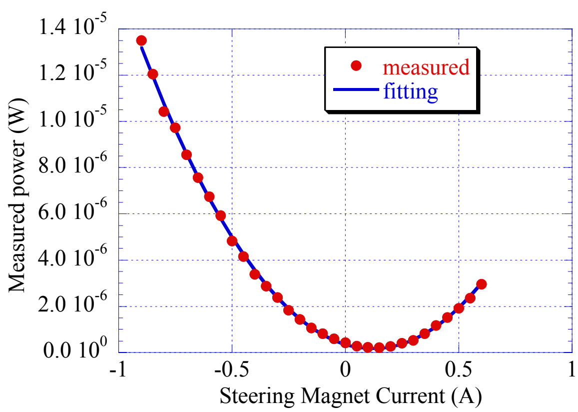

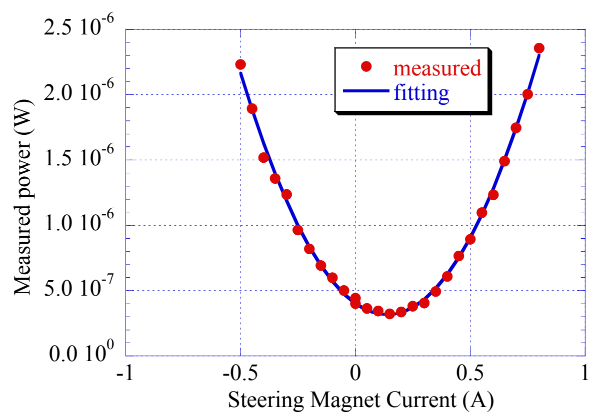

Fig.3 Measured HOM power as a function of the steering magnet current which bends the beam horizontally (left) and vertically (right).