Wakefields and HOMs Studies of a Superconducting Cavity Module with the CESR Beam*

S. Belomestnykh†, W. Hartung, G. Flynn‡, J. Kirchgessner, H. Padamsee, and M. Pisharody
Laboratory of Nuclear Studies, Cornell University, Ithaca, NY 14853 USA

Abstract

Several aspects of the beam-cavity interaction were investigated in a beam test of the superconducting accelerating cavity module for the CESR upgrade: the time structure of the cavity wake potential, sampled with two bunches, the effect of the module on the total machine loss factor, and the influence of the cavity tuner position on the frequencies and damping times of coupled bunch modes. The spectra of some of higher-order modes excited by the beam were also recorded. The results are discussed.

I. INTRODUCTION

The CESR luminosity upgrade plan calls for increasing the average current to 500 mA per beam and shortening the bunch length to 1 cm [1], in comparison with the present operating conditions of approximately 150 mA per beam and 1.8 cm bunch length. At the higher current, the parasitic interaction of the bunched beams with the surrounding structure will be much stronger. We therefore pay special attention to the design and testing of new components for operation at higher current. Four cells of superconducting (SC) cavities with specially designed higher-order mode (HOM) dampers [2-4] will be installed in the CESR to replace the existing 20 cells of copper cavities. This reduce the parasitic impedance of the RF system and its parasitic interaction with the beam. Calculations [5] and measurements of the copper model of the cavity [6] indicate that the design is adequate to the requirements of a high current storage ring.

The beam test of the superconducting cavity took place recently at the CESR storage ring [7, 8]. Experiments were undertaken in an effort to understand the time structure of the cavity's wake potential and to observe the interaction of the beam with the cavity HOMs. Beam stability studies were done for different bunch patterns. No instabilities due to the SRF cavity were encountered. The spectra of some HOMs were recorded and no resonant excitation of those modes was found.

II. TOTAL CESR LOSS FACTOR

Studies of the higher mode losses for CESR have been done by M. Billing [9]. Scaling laws for the loss factor of different components in the vacuum chamber are in good agreement with experimental data; we used them to predict the total loss factor of the machine under the conditions of our test. Both the predictions and the separate calorimetric measurements of the loss factor of the superconducting cavity module [8] show that the loss factor of the SC cavity is much less that the total CESR loss factor. Nevertheless we measured the total loss factor of the machine before and after installation of the SC cavity, to make sure that there were no gross errors in the calorimetric measurements. The predicted and measured total CESR loss factors are shown in the Fig. 1.

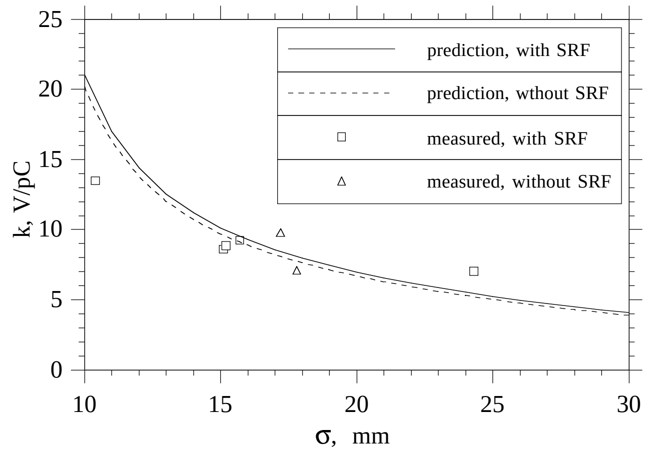

Figure 1. The total CESR loss factor (experimental data and prediction).

III. TIME STRUCTURE OF THE WAKE POTENTIAL

An elegant method of wake potential sampling, proposed by A. Temnykh [10], was used in the beam test: with two bunches of equal current, placed close to each other, one can measure the power loss due to the HOMs of some discontinuity of vacuum chamber. By using different bunch spacings we can obtain information about the time structure of the wake potential. Also, we can calculate the loss factor and wake potentials for the two-bunch case using computer codes like ABCI [11] and AMOS [12] and compare these calculations with the measured values. Let us define the loss factor for this case as

$$k = \frac{N\,P\,f_{rev}}{I_o^2},$$

where I_o is the average beam current; f_{rev} is the revolution frequency; N is the number of bunches, and P is the HOM power.

The loss factor will be equal to the loss factor of a single bunch if the wake potential decays completly before the arrival of the second bunche, or if the HOMs with high R/Qs are all detuned far enough from harmonics of one half the RF frequency (so that the wake fields are not close to being completly in phase or completly out of phase).

* Work supported by the National Science Foundation, with supplementary support from the US-Japan Collaboration

† On leave from Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia

‡ Present address: LURE, 91405 Orsay, France

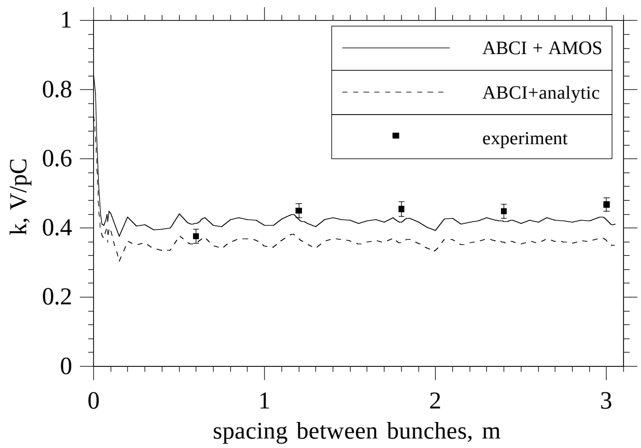

Figure 2. The loss factor of the SRF cavity assembly sampled by two bunches (experimental data and prediction).

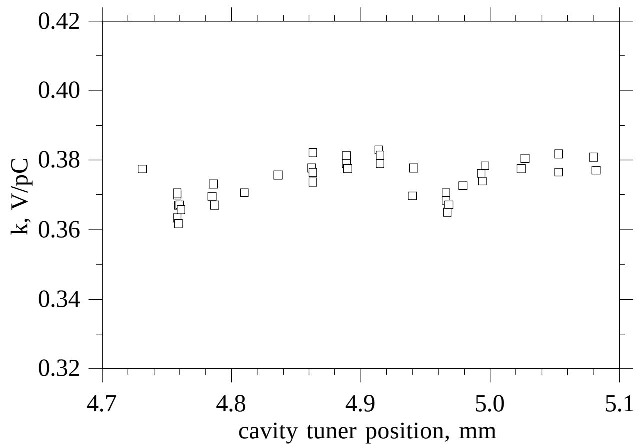

Figure 3. Dependence of the cavity loss factor on the cavity tuner position.

The minimum spacing between two bunches is equal to the wavelength of the RF system, i.e. 60 cm for CESR. We measured the power dissipation in the HOM loads of the cavity module calorimetrically [8] and varied the bunch spacing from 1 to 5 buckets. The measurements were done for a beam energy of 5.3 GeV and for three different total beam currents: 10, 20, and 30 mA. Figure 2 shows the measured loss factor in comparison ABCI and AMOS calculations. The agreement is very good.

IV. OTHER TESTS

A. Influence of the Cavity Tuner Position on the Beam Dynamics

Using the cavity's fundamental mode frequency tuner, we changed the HOM frequencies to investigate the influence of the HOMs on the beam dynamics and to look for any unexpectedly dangerous (high $R/Q*Q$) HOMs. In these tests, the RF power for the SC cavity was switched off and the fundamental mode frequency remained detuned. While scanning the tuner position, we were able to maintain a 100 mA beam, and there were no beam instabilities. We continuously monitored the HOM power deposited by the beam. The loss factor was calculated from the temperature of the HOM load. The dependence of the loss factor on tuner position is shown in Figure 3. The small variation of the loss factor shows that there was no resonant excitation of HOMs as their frequencies changed. In addition, we measured the tunes and damping times of coupled bunch modes with a nine bunch beam, using a spectrum analyzer, for two positions of the tuner. The technique of these measurements is the same as described in [13]. No significant changes in damping times or tunes were observed between the two tuner positions: all changes were within the repeatability of the measurements.

B. Dipole loss factor

We tried to investigate the dipole component of the cavity loss factor by displacing a 120 mA (in 9 bunches) beam (with a bunch length of about 15 mm) horizontally and vertically by ±10 mm in the SC cavity. According to calculations, the monopole component of the loss factor is 0.43 V/pC, and the dipole component is 0.006 V/pC for a 10 mm beam displacement. The cooling water ΔT was about 3.5^{o}C for each HOM load. That means that the contribution from the dipole component should be of order of 0.05^{o}C, according to the prediction. The resolution of our calorimetry is 0.03^{o}C, and the noise level is of the same order. No changes in the cooling water ΔT were seen in excess of the resolution and noise level of the measurement.

C. Spectra of HOMs

Experiments were done to search for dangerous HOMs by exciting the cavity via a single-bunch beam of 30 mA, with a varying transverse displacement of the beam. The HOM spectra were observed and recorded using a spectrum analyzer.

We used results of URMEL [14] and CLANS (for monopole HOMs) [15] calculations and measurements of the copper cavity model [6] to compare with the beam test measurements. Unfortunately we did not succeed very much in exact identifying of the HOMs though we can say that for monopole HOMs Q-factors are of order of one hundred, and for dipole and quadrupole HOMs Q-factors are typically less then one thousand. That is consistent with previous measurements. No resonant excitation of HOMs or beam instabilities were observed.

V. CONCLUSIONS

Several aspects of the beam-cavity interaction were investigated in the beam test of the superconducting accelerating cavity module for the CESR upgrade, in an attempt to find dangerous HOMs, to understand the time structure of the cavity wake potential, and to check the effect of the module on the total machine loss factor. The loss factor results are in a good agreement with the predictions. The results of wake potential sampling indicate that the wake fields of the SRF cavity will not limit the CESR performance in bunch train operation[1]. No beam instabilities or dangerous HOMs were encountered while sweeping the HOM frequencies using the cavity tuner or exciting multipole HOMs by displacing the beam off axis horizontally and vertically.

VI. REFERENCES

[1] D. Rubin, “CESR Status and Plans”, *these proceedings*

[2] H. Padamsee, et al., “Accelerating Cavity Development for the Cornell B-Factory, CESR-B”, *Conference Record of the 1991 Particle Accelerator Conference*, Vol. 2, pp. 786-788, San Francisco, CA, May 1991

[3] H. Padamsee, et al., “Design Challenges for High Current Storage Rings”, *Particle Accelerators*, 1992, Vol. 40, pp. 17-41

[4] H. Padamsee, et al., “Development and Test of a Superconducting Cavity for High Current Electron Storage Rings”, *Proceedings of the Fourth European Particle Accelerator Conference*, Vol.3, pp. 2048-2050, London, Great Britain, June 1994

[5] V. Veshcherevich, et al., “Higher Order Modes Damping in CESR B Cavity”, *Proceedings of B Factories: The State of the Art in Accelerators, Detectors and Physics*, SLAC-400/CONF-9204126, pp. 177-180, Stanford, CA, April 1992

[6] W. Hartung, et al., “The Interaction of a Beam with a Beam Line High-Order Mode Absorber”, *Proceedings of the 1993 Particle Accelerator Conference,* Vol. 2, pp. 3450-3452, Washington, D.C., May 1993

[7] H. Padamsee, et al., “Beam Test of a Superconducting Cavity for the CESR Luminosity Upgrade”, *these proceedings*

[8] S. Belomestnykh, et al., “Comparison of the Predicted and Measured Loss Factor of the Superconducting Cavity Assembly for the CESR Upgrade”, *these proceedings*

[9] M. Billing, “Higher Mode Power Loss Limitations for Beam Currents in CESR”, *CBN 84-15* (1984)

[10] A. Temnykh, “Wake function study using two spaced bunches”, *CON 95-06* (1995)

[11] Y. H. Chin, “Advances and Applications of ABCI”, *Proceedings of the 1993 Particle Accelerator Conference,* Vol. 2, pp. 3414-3416, Washington, D.C., May 1993

[12] J. DeFord, et al., “The AMOS (Azimuthal Mode Simulator) Code”, *Proceedings of the 1989 IEEE Particle Accelerator Conference,* Vol. 2, pp. 1181-1183, Chicago, IL, March 1989

[13] M. Billing, et al., “Measurements of Vacuum Chamber Impedance Effects on the Stored Beam at CESR”, *these proceedings*

[14] U. Laustroer, et al., “URMEL and URMEL-T User Guide (Modal Analysis of Cylindrically Symmetric Cavities; Evaluation of RF-Fields in Waveguides)”, *DESY M-87-03* (1987)

[15] D. G. Myakishev, V. P. Yakovlev, “The New Possibilities of SuperLANS Code for Evaluation of Axisymmetric Cavities”, *these proceedings*