

Studies on high order mode of bell-shaped prototype cavities*

MA Guang-Ming(马广明)^{1,2} ZHAO Zhen-Tang(赵振堂)^{1;1)}

1 (Shanghai Synchrotron Radiation Facility, Shanghai Institute of Applied Physics, CAS, Shanghai 201800, China)

2 (Graduate University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract Aluminium and copper prototype cavities were designed to study higher order modes (HOM). An automatic field mapping system was developed with LabVIEW to measure the radiofrequency (RF) characteristics, such as resonant frequency, Q -value, shunt impedance and electromagnetic field distribution of the higher-order modes in a model RF cavity. Two kinds of the bell-shaped cavities were measured using the field mapping system, their frequencies are 1.5 GHz and 800 MHz respectively. The fields' distributions of the monopole modes and dipole modes, as well the R/Q values, were measured.

Key words perturbation method, higher order modes, LabVIEW, superconducting RF

PACS 29.20.db, 29.27.Bd

1 Introduction

The superconducting RF cavity, which is widely used in particle accelerators of the world, has the advantages of low RF power consumption on the cavity wall and high cavity shunt impedance. However, to ensure stability of the storage ring, Higher Order Modes (HOM) of the cavity have to be heavily damped.

Here we set up a new system of HOM field mapping, R/Q measurement, etc. This system is used to study the bell-shaped cavity, the common shape of the superconducting cavities.

The prototype shown in Fig. 1(a) is the newly developed 1.5 GHz higher harmonic cavity for the SRF storage ring^[1]. Some copper prototypes were also made to study the RF modes' characteristics. The other one, Fig. 1(b) is an 800 MHz cavity. Previous measurements have been done at Tsinghua University, including HOM measurement, LHC type HOM coupler^[2] and CWCT type HOM coupler^[3], etc.

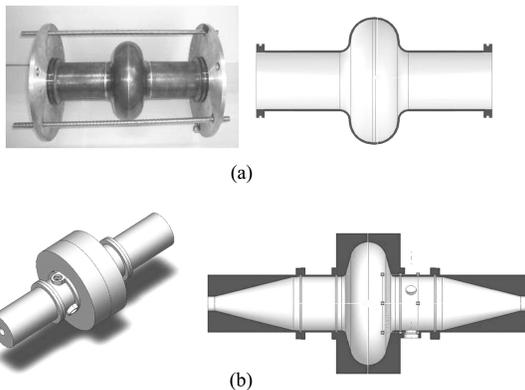


Fig. 1. Two kinds of prototype cavities.

(a) The 1.5 GHz single cell copper harmonic cavity shape; (b) 800 MHz aluminum cavity shape.

2 Field mapping system

The measurement system is a computer aided automatic system based on a perturbation technique, which is employed to evaluate higher order mode and shunt impedance characteristics of RF cavities. A small object is suspended on a nylon thread down the central beam pipe of the cavity and is drawn along its entire length, perturbing the electromagnetic fields. The longitudinal and transverse mode impedances are then calculated from the resultant shift in resonant frequency.

Received 10 March 2008

* Supported by Science and Technology Commission of Shanghai Municipality (026505027, 036505011)

1) E-mail: zhaozt@ssrc.ac.cn

2.1 Perturbation method

Perturbation measurements involve drawing a perturbing object (usually a bead, with radius r , permittivity ε) through the central beam pipe of the cavity, while at the same time monitoring the cavity's resonant frequency as the object travels its entire length. The bead perturbs the stored energy of the resonant system by a very small amount, which is a small shift in the resonant frequency (Δf). This frequency shift is related to the relative E-field and H-field strengths in the area of the beam^[4].

Perturbation measurements are performed on RF cavities to evaluate R/Q , which is a figure for the impedance of an RF cavity at resonance. The equation used to solve R/Q for an RF cavity is derived from Slater's Perturbation theory^[4] and normal tuned circuit theory as following^{1,2)}

$$\frac{R}{Q} = \frac{B}{f_0} (I_1^2 + I_2^2), \quad (1)$$

where,

$$I_1 = \sum_{i=1}^N S(i) \cdot \sqrt{\Delta f_i} \cdot \cos \frac{2\pi f_0 z}{c} \cdot dz;$$

$$I_2 = \sum_{i=1}^N S(i) \cdot \sqrt{\Delta f_i} \cdot \sin \frac{2\pi f_0 z}{c} \cdot dz;$$

f_0 is resonant frequency without perturbation; f_i is resonant frequency with perturbation; Δf_i is $|f_i - f_0|$ in the i -th interval; $S(i)$ is sign of E_z axial electric field in the i -th interval; B is shape factor of the bead; dz is step of the bead moved along axial direction; λ is wavelength corresponding to f_0 ; N is the total number of the steps to be measured.

2.2 Programming

The measurement system consists of a network analyzer which is controlled by a computer via a GPIB-USB interface using the data acquisition software LabVIEW. The perturbing object (or bead) is suspended on a nylon thread and is drawn through the center of the cavity. A step-motor controlled by computer via 6030 PCI card³⁾, drives a roller assembly on each side of the cavity. The network analyzer feeds the cavity with a narrow bandwidth signal and a calibration measurement is made whereby all losses are eliminated due to lengths of cable, etc. The structure of the system is shown in Fig. 2.

The system uses LabVIEW® to integrate the motion control and data acquisition. LabVIEW® is a commercial high level graphical programming lan-

guage. Every module of the software is called a Virtual Instrument (VI). The VIs are the building blocks for every program.

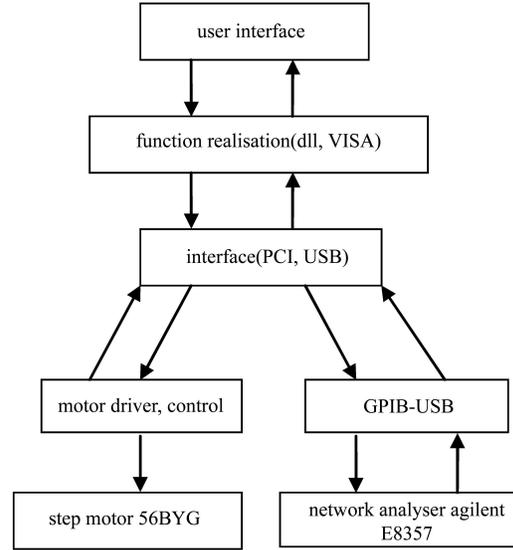


Fig. 2. The signal diagram of the field mapping system.

The coordination between the motion and data acquisition is tricky. There are two methods of dealing with it: one is to probe the position of the perturbing object and the frequency of the network analyzer in a certain time gap, while the motor is running with a constant speed; the other way is to stop the motor while the computer is acquiring data. The former method is faster, while the latter one is more accurate. When the whole path is not immensely large, the latter way is preferred.

2.3 Perturbing objects

Two perturbing objects are made. "PO1#" is a cylinder ($\phi 3.8$ mm, $L=9.9$ mm, thickness is 1 mm) made of copper sheet. It mainly perturbs the axial field; "PO2#" is a copper disk with a diameter of 20 mm, it is used to probe the electric field component E_r . Perturbing object "PO3#", developed at Tsinghua University, is like a cage^[5], which effectively perturbs the axial electric field E_z while the radial field E_r is nearly undisturbed.

Higher order modes are identified by the field distribution on axis. For the monopole modes, we use perturbing object "PO1#" to perturb their electric field component on axis, E_z . For dipole modes, we use "PO2#" to perturb the electric field component along the radius direction, E_r .

1) Tong D. Higher Order Mode Measurements on the HERA Superconducting Cavity Modules, DESY-M-87-05. 1987.

2) Marchand P, Proch D. Higher Order Mode Measurements in a 5-cell Copper Cavity at 1 GHz and Application to a Superconducting Cavity for PETRA, CERN-EF-RF 82-7. 1982.

3) Beijing Hollysys Electric Technology Co. Ltd. User's Manual for 6030 Motor Control Card, 2002.

3 Calculation and experiment

3.1 1.5 GHz single cell higher harmonic cavity

We have investigated the high order modes up to 3 GHz in the cavity and measured their frequencies,

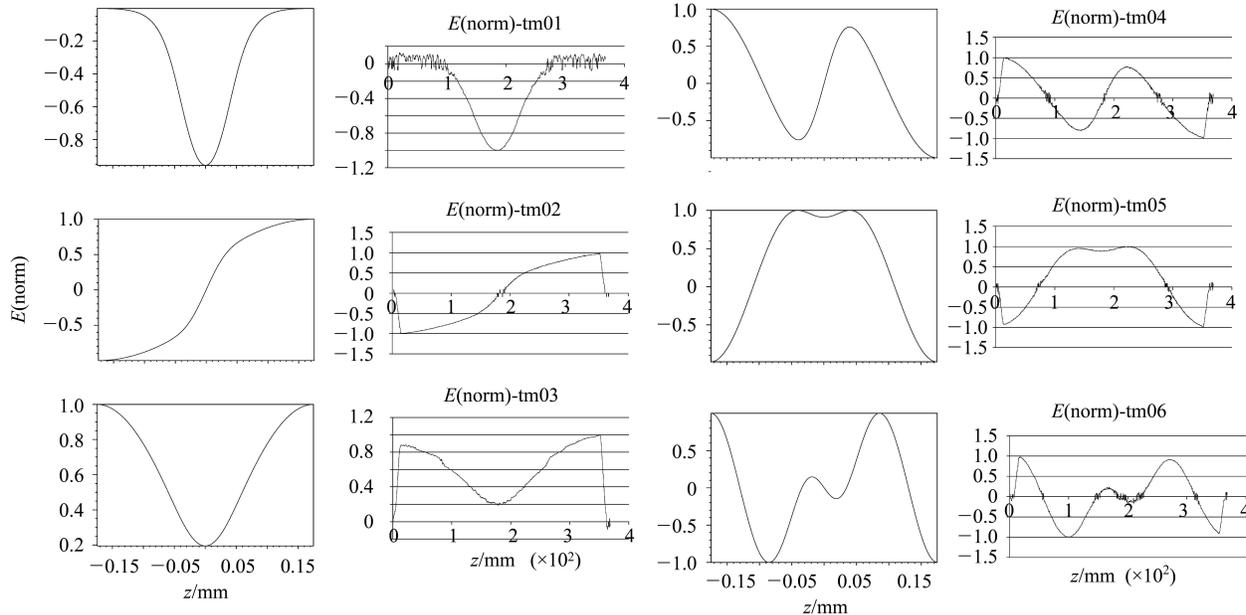


Fig. 3. Electric fields distribution of the monopole modes in the single cell 1.5 GHz higher harmonic cavity.

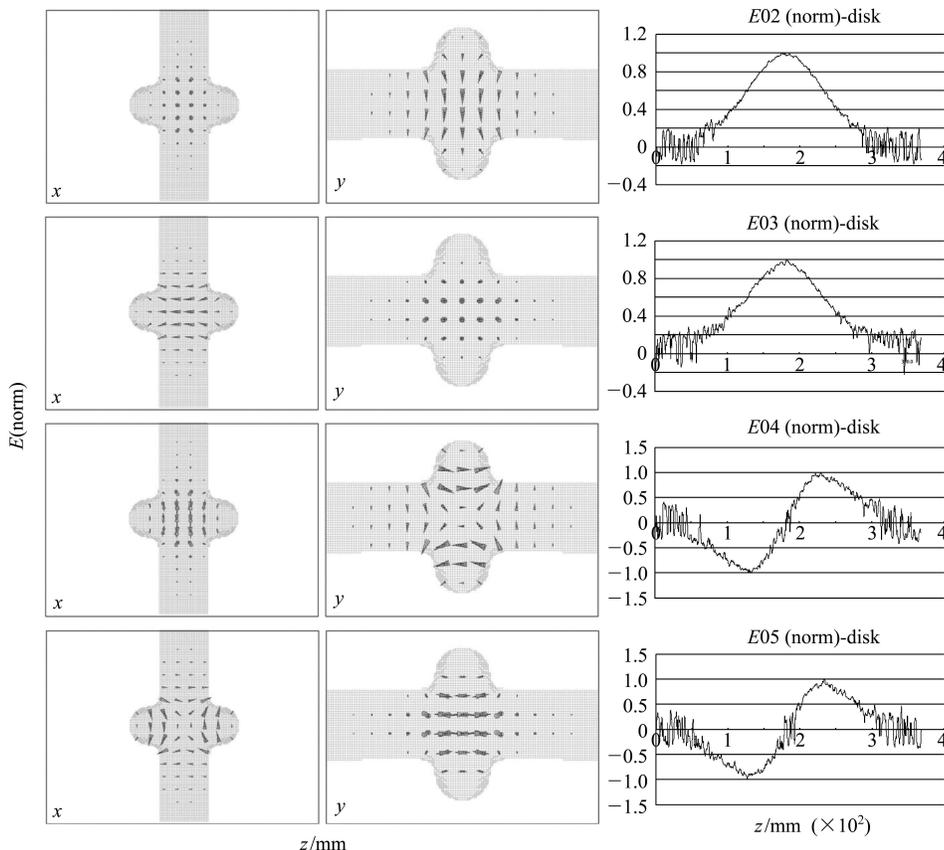


Fig. 4. The lowest two dipole modes of the sing cell 1.5 GHz higher harmonic cavity.

quality factors (Q), and R/Q values, etc. Calculations including its on-axis field distribution, R/Q , etc, were performed using MAFIA before measurements.

In Fig. 3, the longitudinal monopole modes are calculated by MAFIA, CLANS, etc. The comparison of calculation and experiment shows that most modes can be identified, as shown in Fig. 3.

The problem of the lowest dipole modes is a dilemma of the “single-mode” cavity. Because they don’t propagate out the cell even the beam pipe’s radius is increased. Since the dipole modes may deflect electrons off the synchronous orbit, it’s an important issue.

In the experiment, we found the two modes, each one has two degenerate modes. Their electric fields and E_r component along the axis are shown in Fig. 4. These two modes can’t propagate along the beam pipe so that they can’t be damped by the ferrite HOM (higher order modes) damper. In order to damp these two modes, special treatment of the beam pipe need to be applied, e.g. to enlarge the beam pipe like KEK-B cavity, or to flute the beam pipe like CESR cavity^[6].

3.2 800 MHz bell-shaped aluminum cavity

We also performed a test of the 800 MHz bell-shaped aluminum cavity. The following steps were taken to measure the HOM characteristics:

- 1) Clean the cavity parts using ethanol and acetone;
- 2) Make bead, i.e. perturbation object, and scale the perturbation object’s shape factor. The shape factor scaling is performed like this: we use SuperFish or MAFIA to calculate the fundamental mode’s R/Q first, and then adjust the factor until the fundamental’s measurement results are consistent with the calculation results.
- 3) Perform the “bead-pull” experiment, identify each mode, see Fig. 3;
- 4) Measure the mode’s R/Q value.

The results of 1# bell-shaped cavity R/Q mea-

surement are in Fig. 5. They are as expected, but do not exactly correspond to the calculation results. The reasons are due to the bead’s vibration during the measurement and the errors of positioning the bead. The R/Q calculation method needs to be studied further.

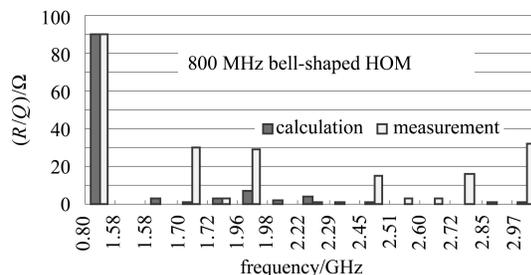


Fig. 5. Monopole mode results.

4 Conclusion and discussion

The field mapping system has been developed. The results of the cavities tests demonstrate that its main functions have been realized. Two different kinds of cavities are measured by using this system. The system can be well used to identify the different modes in the cavities. It roughly provides the monopole modes’ R/Q values. More work will be done to improve the system.

The authors would like to thank Prof. TONG Dechun, as well as TAO Xiaokui, from Tsinghua University for their enthusiastic help. The RF group colleagues of SSRF are also acknowledged for their support.

References

- 1 MA G, ZHAO Z, LIU J. Chinese Physics C, 2008, **32**(4): 275
- 2 TAO X K, CHEN H B, TONG D C. Study of HOM Couplers on an 800 MHz Prototype Cavity. In: Proceedings of the Asian Particle Accelerator Conference. Beijing, China, 2001, 746—748
- 3 LIANG Y Z. Research on HOM Coupler for Higher Harmonic Cavity. Master thesis, at Engineering Physics Department, Beijing: Tsinghua University, 2003
- 4 Maier L C, Jr., Slater J C. Journal of Applied Physics, 1952, **23**: 68
- 5 XIAO L, LIANG Y Z, TONG D et al. NIM A, 2001, **463**: 86—93
- 6 Padamsee, Barnes P et al. Particle Accelerators, 1992, **40**: 17