AUTOMATION OF THE CAVITY PARAMETER MEASUREMENTS

A.M. Porcellato, A. Battistella, S.Marigo

INFN Laboratori Nazionali di Legnaro (Padova), Italy

Abstract

The frequency perturbation produced by a small bead in a resonant cavity can be used to determine T.T.F., U/E_a^2, E_p/E_a, H_p/E_a. The bead motion, the acquisition procedure and the data analysis have been automatized using a P.C. IBM AT. The resulting measurement time is very much reduced and consequentely resonant frequency shifts due to thermal drift are negligible. Furthermore, repeating the measurement in the same conditions reduces the statistical errors too. As final result the accuracy of the measurement is impruved and it let us reduce the bead size to such an extent that the field details can be picked up very closed to the imperturbed situation. The data can be easily analyzed in order to extract the desidered cavity parameters which are actually of crucial importance for the cavity shape optimization.

Introduction

In a cavity the ratio between the mean energy ($<U_{em}>$), stored in the electromagnetic field, and the resonant frequency is a constant for an adiabatic transformation of the (perfectly conducting) walls.[1]

$$\frac{<U_{em}>}{f} = \text{cost}$$

If a small perturbation changes the stored energy by a quantity $\delta <U_{em}>$ the resonant frequency will change by a quantity δf according to the following relation:

$$\frac{\delta f}{f} = \frac{\delta <U_{em}>}{<U_{em}>}$$

If the cavity perturbation is caused by a sphere of a diameter small enough for that the magnetic and the electrical field can be considered uniform and constant around it, the fractional shift in the resonant frequency becomes:

$$\frac{\delta f}{f} = -\frac{3}{4}\frac{\delta V}{<U_{em}>}\left[\varepsilon_0 \frac{\varepsilon_1-\varepsilon_0}{\varepsilon_1-2\varepsilon_0} E_0{}^2 - \mu_0 \frac{\mu_1-\mu_0}{\mu_1+2\mu_0} H_0{}^2\right]$$

where:

- ε_0, μ_0 are the dielectric constant and the permeability of the medium in the umperturbed cavity, respectively
- ε_1, μ_1 are the dielectric constant and the permeability of the bead
- E_0, H_0 are the unperturbed electrical and magnetic fields
- δV is the bead volume.

In this way the magnetic and the electrical field modules at the point where the bead is located can be computed measuring the eigenfrequency shifts induced by the beads (a couple of metallic and dielectric beads can be used alternatively in zones where magnetic and electrical field are both present). Knowing the field distributions in the cavity it is easy to compute the characteristic resonator parameters: optimum β (β_{op}), transit time factor (T.T.F.(β)), stored energy (U/E_a^2), peak electrical field (E_p/E_a), peak magnetic field (H_p/E_a).

The measuring system

The set-up used for the frequency shift measurement is presented in fig. 1. A voltage-controlled signal generator feeds the cavity. Part of the signal is fed into the L input of the mixer via an attenuator and a couple of phase shifters, permitting power level and phase adjustment. A signal picked up from the cavity and properly amplified is fed into the R input of the mixer.

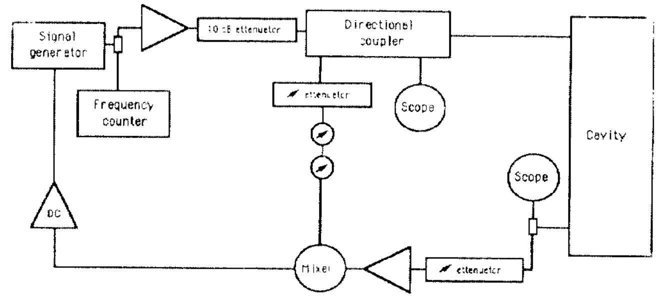

Fig. 1 Block diagram of the frequency shift measurement setup

As matter of fact if the resonant frequency of the cavity (f_r) changes with respect to the frequency (f_g) delivered by the generator to the cavity, the two signals will present a phase shift θ such that:

$$\mathrm{tg}\theta = Q\left(\frac{f_r{}^2}{f_g{}^2} - 1\right)$$

where Q is the loaded Q of the cavity. If the phase shift between the two signals is adjusted to be equal to $\Pi/2$ at the mixer inputs, when $f_r = f_g$ (null output for $\theta = 0$), a DC voltage U_m will be present at the I port of the mixer (used as phase detector). U_m is given by:

$$U_m = k_m \cos(\theta + \frac{\pi}{2})$$

where k_m is a constant which depends on the mixer characteristics and on the amplitude of the signals at the inputs L and R (It is convenient to have the same power, the nearest to 7 dBm for a 7 dBm mixer). Remembering that, for small θ :

$$\cos(\theta + \frac{\pi}{2}) = \frac{\mathrm{tg}\theta}{\sqrt{1+\mathrm{tg}^2\theta}} \cong \mathrm{tg}\theta$$

Then:

$$U_m = k_m Q\left(\frac{f_r{}^2}{f_g{}^2} - 1\right) \cong \frac{k_m Q}{f_g{}^2}(f_r - f_g)(f_r + f_g) \cong \frac{2 k_m Q}{f_g}(f_r - f_g)$$

Such a signal can be used to tune the signal generator to follow the signal of the resonant frequency of the cavity.

$$f_g = f_0 + \frac{\Delta f_m}{\Delta V_m} A(U_m+Z)$$

where :

- f_0 is the unmodulated generator frequency
- A is the gain of the DC amplifier
- $\Delta f_m / \Delta V_m$ is the change in the generator frequency $(f_g - f_0)$ per a DC voltage ΔV_m
- Z represents the disturbances superimpose upon the mixer output and thus taking part in the frequency modulation. If:

$$B = \frac{\Delta f_m}{\Delta V_m} A \qquad K = \frac{2 k_m Q}{f_g}$$

Then:

$$f_g - f_0 = BK(f_r - f_g) + BZ$$

and with some algebra:

$$(f_g - f_0) = \frac{BK}{1+BK}(f_r - f_0) + \frac{BZ}{1+BK}$$

The measured frequency shift $(f_g - f_0)$ is related to the real value $(f_r - f_0)$ by the classical feedback formula. It means that the more the loop gain BK increases the closer the measured value gets to its real value. Moreover, for a given loop gain and a given change in the resonant frequency, an increase in the K value reduces the weight of the noise Z, as results from the formula:

$$\frac{(f_g - f_0)}{(f_r - f_g)} = \frac{BK}{1+BK}\left(1 + \frac{Z}{K}\frac{1}{(f_r - f_0)}\right)$$

Measurement of the values of the B and K constants permits to correct the measured frequency shifts; this correction is necessary for low Q resonators (the measured value for a 7 dBm mixer SRA1 from Mini Circuits was $K_m = 1.6 \times 10^{-4}$ V/Hz). Moreover the B value is limited by oscillations which appear in the feedback loop at high gain.

Data acquisition and analysis

The hypothesis of small perturbations and uniform and constant fields restricts us to the use of a small bead. Consequently it is necessary to measure small frequency shifts.

The method of measurement has to be therefore:

- sensitive; (the frequency shifts are of the order of hundreds Hz)
- fast; in order to minimize shifts in resonant frequency due to thermal drifts of the resonator
- reproducible; the repetition of the same measurement at the same conditions reduces the statistical errors
- easy; in order to be really useful in the definition of the cavity geometry details. They are important in order to reduce the magnetic and especially the electrical field, which often limits the cavity performance.

The automatic acquisition system developed satisfies these requirements. The data acquisition and manipulation system (see Fig. 2) is based on a MS-DOS computer with a minimum 640 Kbytes ram, 20 Mbytes hard disk and EGA graphic card.

This computer is interfaced with:

- a frequency counter by IEEE-488 bus
- a subsystem for bead motion, based on a stepping motor and on a G64 intelligent controller, by a serial line.

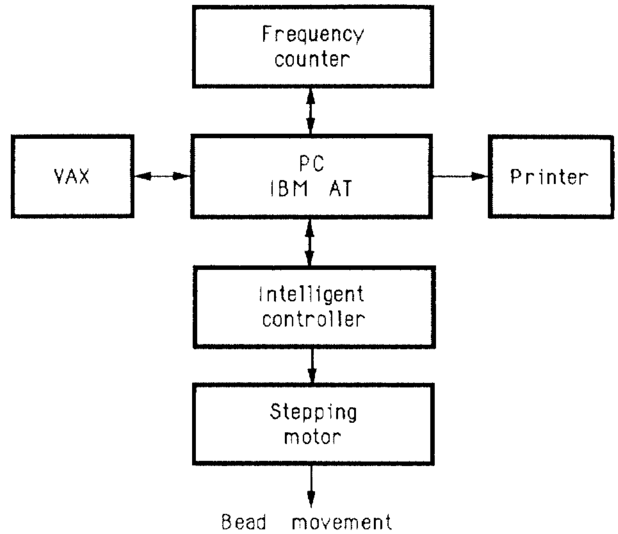

Fig. 2 Block diagram of the data aquisition and bead manipulation system

The software, which is self-explanatory, is divided into two main blocks:

- acquisition from the frequency counter
- graphics - data manipulation.

It is possible to choose the wanted operations between the permitted options presented on the screen by clicking with the mouse on sensitive areas created on the screen.

The acquisition process repeats, for chosen step numbers, the following procedure:

- advancement of the stepping motor and respective bead motion
- reading and storing of the resonant frequency for each bead position.

Each measurement cycle can be repeated up to eight times changing every time the direction of the motion.

The software for data manipulation and graphic display is divided in several blocks:

- visualization of the file data directory
- loading of the files of the chosen set of measurements
- displaying of each set of data for background subtractions (an adjustable straight line, which defines the unperturbed frequency, is fixed by marking two points on the screen with the mouse)
- simultaneous display of more graphs in order to correct the X axis offset, if necessary
- computing and display of the average of the frequency shift as a function of the positions of the chosen set of files
- search for the symmetry axis in order to define the resonator centre
- computations of the parameters T.T.F. and U/E_a^2 as a function of β and search for the optimum values T.T.F (β_{op}) and $U/E_a^2(\beta_{op})$.

The standard parameters used in the computations are loaded through a file and changed during the program execution by means of a menu. A file with the parameter configuration used is then associated with each set of data.

Applications

The method presented here has been used to measure the characteristic parameters of the ALPI accelerator cavity[2]. The stored energy value was computed starting from the resonant frequency shifts, produced by a teflon bead travelling along the beam line, measured both in under coupling (U.C.) and in critical coupling (C.C.) conditions. The frequency shifts (fig. 3), corrected, according to the prrsented method with the measured K and B coefficients, result in a U/E_a^2 value of 63 $mJ/(MV/m)^2$ for both cases, with excellent agreement with the value resulting from Superfish code analysis of the resonator (64 $mJ/(MV/m)^2$. The correspondent T.T.F. curve is presented in fig. 4.

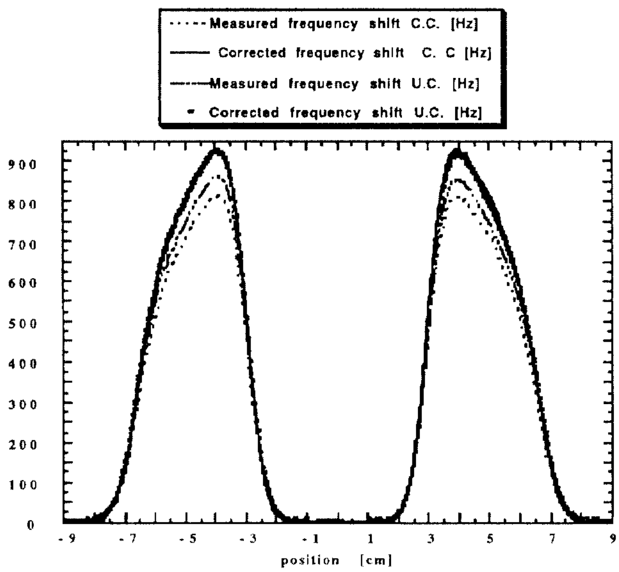

Fig. 3 Frequency shift caused by teflon bead perturbation measured along the beam line in under coupling (U.C.) and critical coupling (C.C.) condition

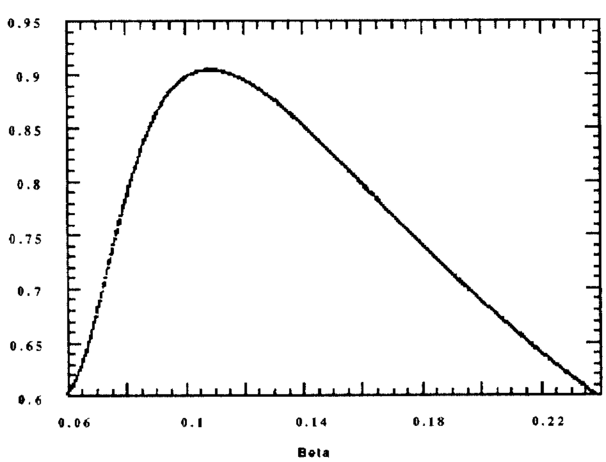

Fig. 4 . ALPI cavity measured T.T.F.

The most useful application of the method is probaly the optimization of the cavity shape in order to reduce peak electrical field. It was sucesfully used to define the inner conductor end of the ALPI 160 MHz resonator. The ratio between surface electrical field measured along the most critical bead path and the accelerating field is presented in fig. 6. The surface fields have not been corrected for image effect of the bead on the metallic surface, but the resulting correction for the surface field is in our case lower than 6%[3].

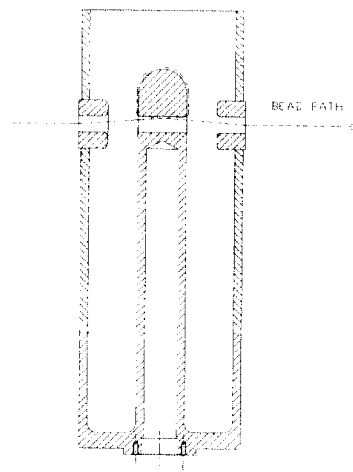

Fig. 5. Bead path used to measure peak electrical field

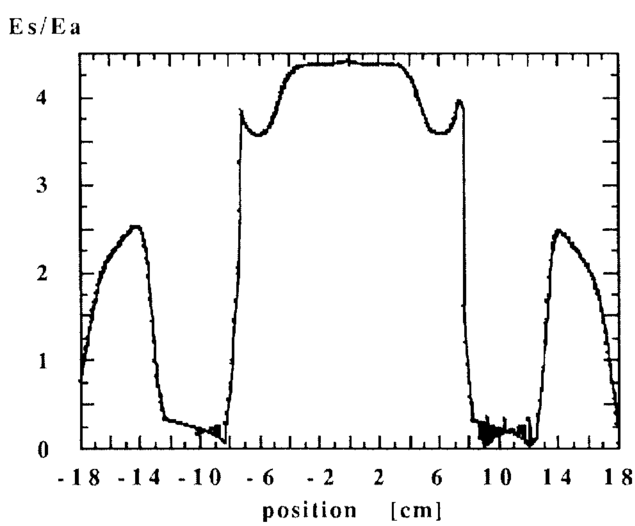

Fig. 6.Ratio between local field, measured along the path indicated in fig. 5, and the accelerating field for the ALPI cavity

References

[1] E. Argence, T. Kakan, Theory of Waweguides and Cavity Resonators (Blackie and Son limited , 1967)
[2] G. Fortuna et al, Nucl. Instr. and Meth. A 287 (1990)
[3] S.W. Kitchen, D. Schelberg, J. of Appl. Phys. 26, 618 (1955)