DIAGNOSIS OF INDIVIDUAL CELL FREQUENCIES IN A COUPLED CAVITY CHAIN WITHOUT INTRODUCING OBJECTS INTO THE CAVITY

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Abstract

In this paper, a new method that can diagnose the cell frequencies in a cavity without a perturbing probe is presented. The cell frequencies and couplings between cells are estimated in terms of the measured pass-band performance. This method will simplify the tuning processes and make the tuning of a sealed cavity possible. It has been well checked with some numerical examples.

1. INTRODUCTION

To research and manufacture a linear accelerator, it's necessary to tune the cavity carefully. In order to determine the tuning direction of each cell, the ordinary means is to insert the perturbing probe into the cavity to measure the frequency cell by cell. Therefore, it takes much time and work. It would be more inconvenient to tune a long cavity or a non-uniform one. Moreover, if a sealed cavity is out of shape while sealed or installed, its detuned state can't be dignosed with the perturbing object. On the other hand, for a superconducting cavity, its field flatness is strictly demanded, it requires more careful tuning. But when the cavity is under operating conditions and in a bath of liquid helium, it is much more complicated to measure the field with a perturbing probe. With the development of computer science, numerical computation and intelligent instrument, it will be a signficant task to develope a method that can estimate each cell's frequency without a perturbing probe.

At the early of 1980's, while testing a superconducting cavity in CERN, E.Hable and J.Tuckmantel developed a method based on coupled resonant model that can calculate each cell's frequency through measured resonant frequency of the cavity[1]. Their cavity was a uniform single period one consisting of 5 cells. Because of superconducting, loss of each cell can be ignored. The varying range of each cell's frequency is small, so it was treated as a first order perturbing problem. In article[2], a method using measured resonant frequency and its relevant field distribution to calculate each cell's frequency was described. This method can reduce tuning work, but can not be used to a sealed cavity.

Now a general object is discussed, which has a long or non-uniform chain with loss of each cell considered. The fundamental method is by means of the passband information got from RF network analyzer and computer data acquisition system to calculate each cell's frequency. The method has been well checked by some numerical examples.

2. FUNDAMENTAL METHOD

As shown in Fig.1, the pass-band performance of the cavity is measured from RF network analyzer. The frequency span and step can be adjusted as needed. The measured results are illustrated by the pass-band performance curve $\rho(F)$. And the measured data are analyzed by the PC computer.
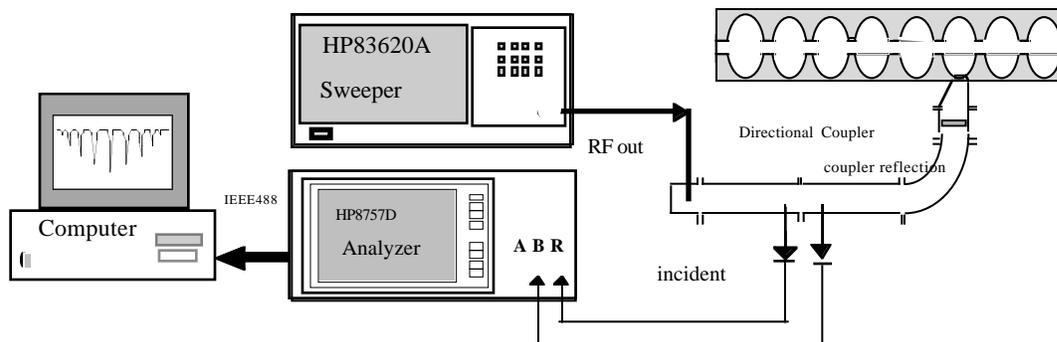

Fig.1 The data acquisition system of the pass-band performance of a coupled cavity chain

In general, each pass-band performance of N-cell accelerating structure consists of N dispersion modes. A typical pass-band performance curve $\rho(F)$ is shown in Fig.2.
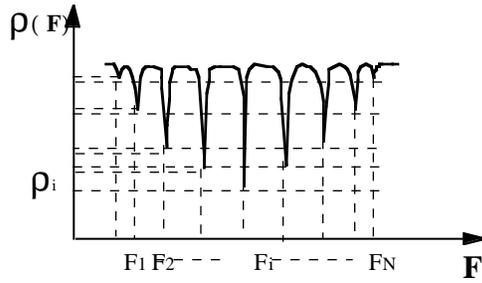

Fig.2 The typical pass-band performance curve $\rho(F)$ of coupled cavity chain

Of course, the pass-band performance $\rho(F)$ can be also calculated directly. The fundamental method is based on the equivalent circuit model of a coupled cavity [3] (shown in Fig.3)
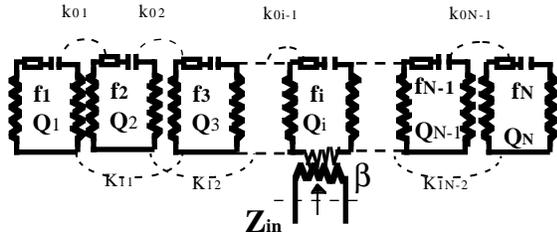

Fig.3 Equivalent circuit of a coupled cavity

f_n and Q_n are the resonant frequency and quality factor in the nth cell $(n=1,2,.....N)$; k_{0n} $(n=1,2,.....N-1)$ and k_{1n} $(n=1,2,.....N-2)$ are the nearest and next nearest neighbour couplings between cells, respectively. β is the coupling factor between the input waveguide and the resonant cavity.

If f_n, Q_n, k_{0n}, k_{1n}, β and the position of coupler are known, $\rho_c(F)$ can be calculated by solving the algebraic eigenvalue equations of the coupled cavity chain. In the following, the letters with the subscript "c" or "m" represent the calculated or measured results, respectively. The letters with bar are used to espress the related row vectors.

$$\bar{f} = (f_1, f_2, ...f_N) \quad \bar{Q} = (Q_1, Q_2, ...Q_N)$$
$$\bar{k}_0 = (k_{01}, k_{02}, ...k_{0N-1})$$
$$\bar{k}_1 = (k_{11}, k_{12}, ...k_{1N-2})$$
$$\bar{F} = (F_1, F_2, ...F_N) \; \bar{\rho} = (\rho_1, \rho_2, ...\rho_N)$$

Now we want to solve the instrinc parameters of each cell from the measured characteristic parameters of coupled cavity chain. In mathmatical sense, this is a reverse problem of matrix's eigenvalue. If the problem can be sovled, diagnosing the cell frequencies of cavity without introducing any objects into cavity is possible.

The previous method to solve the problem was only suitable to a short single- or bi-periodic structure[4]. The cell parameters are (f_0, Q_0, k_0, k_1) or $(f_1, f_2, Q_1, Q_2, k_0, k_{11}, k_{12})$. For a superconducting structure, the quality factor in each cell is very high and the loss can be ignored. If the number of cells (N) is more than that one of the cell parameters in a cavity, the least-squares method can be used to estimate the cell frequencies and couplings between cells from the measured N dispersion frequencies $\bar{F}_m,$. In this paper, a method to be suitable for a more common structure is developed, in which the measured pass-band performance $\rho_m(F)$ and the dispersion modes $\bar{\rho}_m, \bar{F}_m$ are used to estimate the cell frequencies and couplings between cells. A special computer method and program are described in next section.

3. DESCRIPTION OF CALCULATING METHOD

In order to simplify the numerical process and consume less time, at the beginning, it is supposed that $\bar{k}_1$ and $\bar{Q}$ are known, only $2N$ parameters $(\bar{f}, \bar{k}_0, \beta)$ need to be found.

The following goal function is defined,

$$\varepsilon = \sum_{i=1}^{N} (F_{ci} - F_{mi})^2 + w \sum_{i=1}^{N} (\rho_{ci} - \rho_{mi})^2$$

where w is a weighted factor.

In our calculating program Newton[5] and Simplex[6] Methods are combined. Therefore, this program has such advantages as wide initial data, quick convergence and high precision.

First, a set of guess values $\bar{f}, \bar{k}_0$ and β with a wide scale are taken as the initials of Simplex method. According to the error crition ($\varepsilon < EPS1$) or the limit number of iterations (MOF), the solutions that are close to the true one were found and taken as the initials of Newton method. Then the more accurate solutions were determined. If the divergence appear in Newton method, Monte Carlo (MTC) method will be used as a back-up tool. Because different groups of $\bar{f}, \bar{k}_0, \beta$ may get same resonant frequency and SWR, the measured pass-band performance $\rho_m(F)$ was used. If the error $\Delta\rho$ is larger than Err, the Scale and cri in Simplex method will be modified and a new cycle begin. At last, the set of paremeters $(\bar{f}, \bar{k}_0, \beta)$ whose $\rho_c(F)$ satisfy demand are found and printed out. The flow chart is shown in Fig.4.

START

$\vec{F}_m, \vec{\rho}_m, \rho(F)_m$ (measured data)

$\vec{k}_1, \quad \vec{Q}$ (supposed values)

$\vec{f}_{in}, \vec{k}_{0in}, \beta_{in}$ (initial guess)

scale, cri   (initial value for Simplex)

MOF   (the max number of iterations)

SIM search   change SIM

ε<EPS1?   N   NOF>MOF?   N

Y   Y

adjust cri or scale

NEWTON iteration

convergent?   N   MTC

Y

ε<EPS2?   N

Y

$\Delta\rho$<Err ?   N

Y

Print out

$\vec{F}_{out}, \quad \vec{\rho}_{out}, \quad \vec{f}_{out}, \quad \vec{k}_{0out}, \quad \beta_{out}$
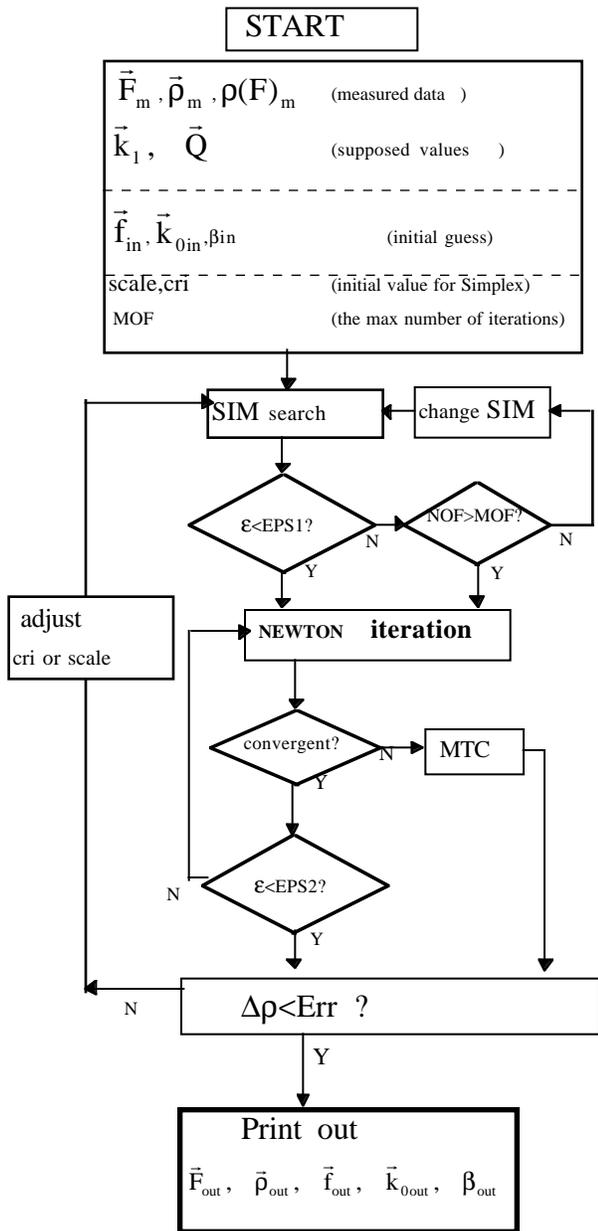
Fig.4 The flow chart of computer program

First, the method is checked by a theoretical value. The cell parameters in a S-band 11-cell non-uniform chain are known. From the matrix of coupled circuit equations consisting of these elements, the pass-band performance, resonant frequencies and related SWR are solved. Then, using these calculated characteristic information to estimate the cell parameters of the cavity, the results were agreement with the given one in advance. The max error of each cell's frequency is 210KHz..

Next, a 6MeV S-band model cavity consisting of 11 cells was analyzed. The cell parameters and the characteristic informance have been measured. Using the method, the cell frequencies and couplings between cells were estimated from the measured characteristic informance. Comparing the estimated data and the measured data, the max error of each cell's frequence is about 900KHz (measuring error<1MHz). If the $\vec{k}_1$ and $\vec{Q}$ are as unknown values and need to be diagnosed, a more precision solution can be obtained.

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