NON-INTRUSIVE DIAGNOSIS OF INDIVIDUAL CELL FREQUENCIES IN A CAVITY CHAIN

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Abstract

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

1. INTRODUCTION

To research and manufacture a linear accelerator, it is necessary to tune the cavity carefully. In order to determine the tuning direction of each cell, the ordinary means is to insert a pair of perturbing probes into the cavity to measure each cell frequency cell by cell; therefore, it takes much time and work. It would be inconvenient to tune a long cavity or a non-uniform one. Moreover, if a sealed cavity becomes out of shape in the course of sealing or installing, its detuned state can not be diagnosed with perturbing objects. On the other hand, for a superconducting cavity, field flatness is strictly demanded, thus more careful tuning is required. But when the cavity is under operating conditions and in a bath of liquid helium, it is much more complicated to measure the cell frequencies with perturbing probes. With the development of computer science, numerical computation and intelligent instruments, an important task is to develop a method that can estimate each cell's frequency without perturbing probes.

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

In this paper, a general objective is discussed, which concerns a cavity that has a long or non-uniform chain, and loss of each cell is considered. The fundamental method is by means of the passband information obtained from an RF network analyzer and computer data acquisition system to calculate each cell's frequency. A special calculating program is designed and has been well checked by theoretical values. Some experimental results are also given.

2. FUNDAMENTAL METHOD

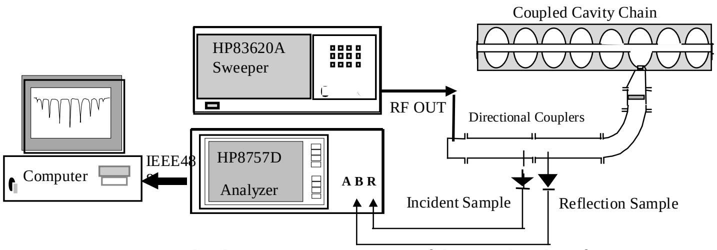

Fig.1 The data acquisition system of the pass-band performance of a coupled cavity chain

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

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

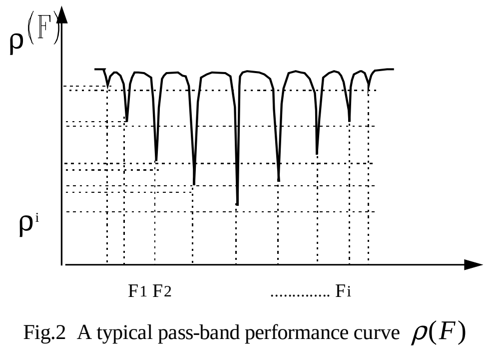

Fig.2 A typical pass-band performance curve $\rho(F)$ of coupled cavity chain

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). The matrix equations of coupled circuit consists of such elements as f_i, Q_i, k_{oi}, k_{1i} and β. f_i and Q_i are the resonant frequency and quality factor

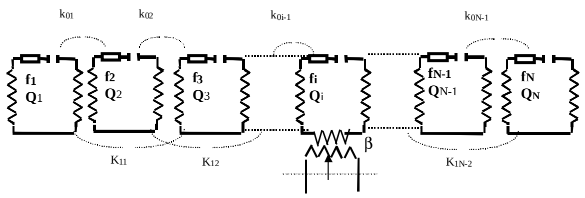

Fig.3 Equivalent circuit of a coupled cavity

in the ith cell *(i=1,2,.....N);* k_{0i} *(i=1,2,......N-1)* and k_{1i} *(i=1,2,.....N-2)* are the nearest and next nearest neighbour couplings between cells, respectively. β is the coupling factor between input waveguide and coupled cavity chain.

If f_i, Q_i, k_{oi}, k_{1i}, β and the position of coupler are known, $\rho_{ci}(F_i)$ can be calculated by solving the matrix's eigenvalue equations of the coupled cavity chain. In the following, the letters with the subscript "c" or "m" represent calculated or measured results, respectively. The letters with bars are used to express the related row vectors.

$\vec{f} = (f_1, f_2, ...f_N)$, $\vec{Q} = (Q_1, Q_2, ...Q_N)$,

$\vec{k}_0 = (k_{01}, k_{02}, ...k_{0N-1})$, $\vec{k}_1 = (k_{11}, k_{12}, ...k_{1N-2})$,

$\vec{F} = (F_1, F_2, ...F_N)$, $\vec{\rho} = (\rho_1, \rho_2, ...\rho_N)$

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

The previous method to solve the problem was only suitable for a short single- or bi-periodic structure[4]. 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; therefore, only a few cell parameters need to be determined. 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 $\vec{F}_m$. In this paper, a method to be suitable for more common structures is developed, in which measured pass-band performance $\rho_m(F)$ and dispersion modes ($\vec{\rho}_m, \vec{F}_m$) 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 $\vec{k}_1$ and $\vec{Q}$ are known and equal to their designed data. Only *2N* parameters ($\vec{f}, \vec{k}_0, \beta$) need to be found.

The following goal function is defined,

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

w is a weighted factor

In our calculating program, Newton and Simplex Methods are combined; therefore, this program has such advantages as wide initial data, quick convergence and high precision. The calculating method is as follows.

First, a set of guess values $\vec{f}, \vec{k}_0$ and β with a wide scale are taken as the initial data of Simplex method. According to the error crition ($\varepsilon < EPS1$) or the maximum number of constraints expected (MOF), the solutions that are close to the true one are found. Then taking the solutions as the initial data of Newton method, the more accurate solutions are determined. If divergence appear in Newton method, Monte Carlo (MTC) method will be used as a back-up tool. Because different groups of $\vec{f}, \vec{k}_0, \beta$ may get same dispersion frequencies $\vec{F}_c (= \vec{F}_m)$ and $\vec{\rho}_c (= \vec{\rho}_m)$, the measured pass-band performance $\rho_m(F)$ is used. If the

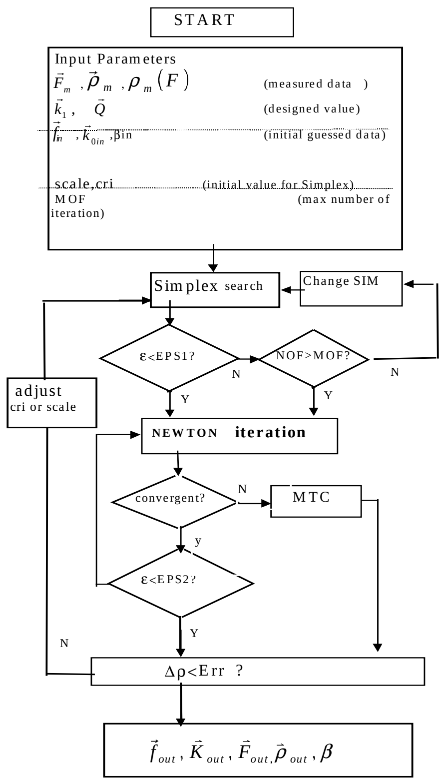

Fig.4 The flow chart of program

error $\Delta\rho$ is larger than Err, the scale and cri in Simplex method need to be modified and a new cycle begins. At last, the set of parameters ($\vec{f}, \vec{k}_0, \beta$) with satisfactory

$\rho_c(F)$ are found and printed out. The flow chart is shown in Fig.4

4. NUMERICAL RESULTS AND DISCUSSION

First, the method is checked using theoretical values. The cell parameters in a coupled cavity chain are given. Solving its matrix eigenvalue equations, the pass-band performance $\rho_t(F)$, dispersion frequencies $\vec{F}_t$ and related $\vec{\rho}_t$ are obtained easily. Here, the parameters with subscript "t" represent the given or theoretical values. The calculated characteristic parameters are assumed to be measured ones and used to estimate the cell parameters of the cavity. Several S-band 11-cell bi-period cavity chains are discussed. $\vec{f}_t$, $\vec{k}_{0t}$ and β_t are taken random in the range of 2960-3020MHz, 0.0195-0.0395 and 7-20, while the initial guessed data are all taken as the ones of its tuned state, 2998MHz, 0.0215 and 15. A set of typical calculated results are listed in Tab.1. From Tab.1, we can find that the estimated data are in agreement with $\vec{f}_t$, $\vec{k}_{0t}$ and β_t very well. The max error of each cell frequency is less than 123KHz, and the max relative error of $\vec{k}_{0t}$ and β_t is less than 5.e-3 and 9.e-4

F_t	ΔF	ρ_t	$\Delta\rho$	f_t	Δf	K_{ot}	ΔK_0
2964.76	0.004	2.275	4E-3	2983.00	0.123	0.0213	0E+0
2968.02	0.005	20.07	3E-3	2999.02	0.085	0.0212	5E-3
2973.30	0.003	25.91	3E-3	2997.14	0.014	0.0219	0E+0
2979.29	0.002	3.339	5E-3	3000.15	0.019	0.0220	0E+0
2985.85	0.007	54.71	6E-3	2996.17	0.102	0.0219	5E-3
2995.05	0.002	1.035	2E-3	2998.86	0.060	0.0218	5E-3
3004.20	0.003	67.58	3E-3	2996.07	0.019	0.0217	5E-3
3011.83	0.000	3.495	2E-3	2988.60	0.060	0.0219	0E+0
3020.70	0.001	3.175	8E-3	2998.90	0.019	0.0219	0E+0
3026.38	0.002	20.89	8E-3	3002.03	0.036	0.0218	0E+0
3029.28	0.002	4.713	4E-3	2996.11	0.032	9.0000	9E-4

Tab.1 S-band 11 cells bi-period cavity
($Q_{2i-1} = 15000, Q_{2i} = 2000$, k_{1i}=0, k_{01}=0.0395)

Then, a 6MeV S-band model cavity consisting of 11 cells is analyzed. Both the cell parameters and characteristic informance are measured. Using the method, the cell frequencies and couplings between cells are estimated from the measured characteristic informance. All these data are shown in Tab.2. The initial guessed data $\vec{f}_{in}$, $\vec{k}_{0in}$ and β_t are taken as the ones of its tuned state. Comparing the estimated data and measured data, the max error of each cell's frequency is less than 900KHz. It is in our measuring accuracy. The difference between the calculated and experiment data is larger than that one between the calculated and theoretical data in Tab.1. The main factors are the inaccuracies of known $\vec{Q}$, $\vec{k}_1$ and the error of experimental data. If $\vec{Q}$, $\vec{k}_1$ are treated as unknown values and are diagnosed too, a more precise solution can be obtained.

F_t	ΔF	ρ_t	$\Delta\rho$	f_t	Δf	K_{ot}	ΔK_0
2962.19	0.03	99.90	0.14	2997.47	0.02	0.0403	0E+0
2968.03	0.03	2.50	0.28	2997.90	0.51	0.0221	5E-3
2972.82	0.03	95.88	0.44	2997.89	0.10	0.0217	9E-3
2980.20	0.03	2.51	0.25	2998.44	0.01	0.0225	2E-2
2988.90	0.03	300.0	0.03	2997.83	0.02	0.0216	1E-2
2998.34	0.03	1.67	0.27	2998.43	0.06	0.0219	5E-3
3008.04	0.03	81.13	0.02	2998.10	0.34	0.0216	5E-3
3016.90	0.02	2.58	0.23	2998.60	0.06	0.0222	1E-2
3024.29	0.03	44.56	0.48	2997.52	0.90	0.0217	9E-3
3029.56	0.01	2.18	0.16	2998.23	0.07	0.0217	5E-3
3034.37	0.03	42.18	0.00	2999.07	0.04	11.000	7E-2

Tab.2 6MeV 11 cells S-band model cavity
($Q_{2i-1} = 15000, Q_{2i} = 2000$, k_{1i}=0, k_{01}=0.0395)

5. CONCLUSIONS

In this article, a new method that can diagnose the cell frequencies in a cavity chain without perturbing probes is described. The fundamental method is by means of the measured pass-band informance to calculate each cell's frequency. A special computer program is designed and has been well checked by some examples. In order to obtain more precisise solutions, we are treating $\vec{Q}$, $\vec{k}_1$ as unknown values; therefore more cell's parameters need to be diagnosed. Now we are working on it.

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