A PASS BAND PERFORMANCE SIMULATION CODE OF COUPLED CAVITIES

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Abstract

A simulation code of coupled cavities named PPSC is developed by the solutions of the microwave equivalent circuit equation. It can give the pass band performance of periodic or non-periodic coupled cavity chain, such as the dispersion frequencies and the reflection factor of the cavity, the field distribution of each mode and so on. The natural parameters of the cavity chain, such as the number of the cavities, the resonant frequencies and Q-factors of each cavity, the coupling factor between two cavities and the locations of the couplers, can be changed easily to see the different results of the simulation. The code is written based on MS Visual Basic under MS windows and a user-friendly interface is made. Some simple examples were simulated and gave reliable results.

INTRODUCTION

The tuning of the pass band performance of the coupled cavities is an essential part of the development of a RF linear accelerator. Usually, we need know the pass band performance even on the physical design stage. In general, there are two way to study the coupled cavities. One is to solve the Maxwell equations under certain boundary conditions. The other is based on equivalent circuit model of coupled cavity chain.

For the first way, many codes are developed in recent years, such as URMLT, Superfish, MAFIA, HFSS, ANSYS, etc. These codes can simulate the pass band performance of a RF structure accurately. But for long multi-cell, non-uniform or very complex cavities, the calculating procedure becomes very complicated and time consuming. Sometimes it is almost impossible on a normal PC.

On the contrary, the equivalent circuit method is very simple relatively. It can give the pass band performance of periodic or non-periodic coupled cavity chain, such as the dispersion frequencies and the reflection factor of the cavity, the field flatness, and so on. The natural parameters of the cavity chain that the calculation need are all obtainable by experiments.

During our development of low energy medical linacs and non-destructive inspection linacs, a simulation code (PPSC) based on the equivalent circuit method is written. While designing and tuning a real coupled structure, the information provided by PPSC can be used as a predictive tool to adjust the normal modes and field flatness.

PPSC is a standard Microsoft Windows code. It is written by Microsoft Visual Basic, which allow programmers write large programs easily with user-friendly interfaces by the Object-oriented technology. The idea of this technology is similar to a person's thinking process, so the program is much easier to read.

FUNDAMENTAL PRINCIPLE

The fundamental principle of PPSC is based on the equivalent circuit model of a coupled cavity chain [1] (shown in Figure1).

f_i and Q_i are the resonant frequency and quality factor of the i-th 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. β_1/β_2 is the coupling factor between the waveguide with the input/output coupler respectively.

The equivalent circuit model gives the following matrix:

$$\begin{bmatrix} a_1 & \frac{k_{01}}{2} & \frac{k_{11}}{2} & & & & 0 \\ \frac{k_{01}}{2} & a_2 & \frac{k_{02}}{2} & & & & \\ \frac{k_{01}}{2} & \frac{k_{02}}{2} & a_3 & & & & \vdots \\ \vdots & & & \ddots & & & 0 \\ & & & & & & \frac{k_{1N-2}}{2} \\ & & & & \cdots & a_{N-1} & \frac{k_{0N-1}}{2} \\ 0 & & & 0 & \frac{k_{1N-2}}{2} & \frac{k_{0N-1}}{2} & a_N \end{bmatrix} \bullet \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ \vdots \\ \vdots \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ \vdots \\ \vdots \\ \vdots \\ I_N \end{bmatrix} \quad (1)$$

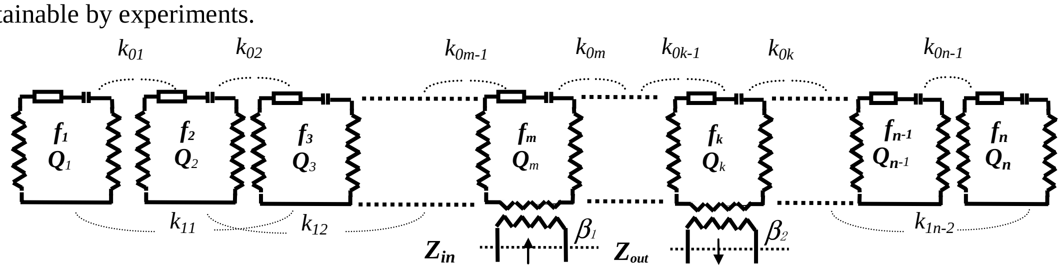

Figure 1: Equivalent circuit model of a coupled cavity chain.

In (1) $I_m = \frac{E_m}{jF\sqrt{2L_m}}$ is the source, $X_i = \sqrt{2L_i}\, i_i$

$$a_m = 1 - \frac{f_m^2}{F^2} - j\frac{f_m(1+\beta_1)}{fQ_m}$$

$$a_k = 1 - \frac{f_k^2}{F^2} - j\frac{f_k(1+\beta_2)}{fQ_k}$$

$$a_i = 1 - \frac{f_i^2}{F^2} - j\frac{f_i}{fQ_i} \quad i \neq m,\ k$$

Here, F is the working frequency.

For a standing wave cavity chain, if the position number of input coupler is *p*, then, from (1) we can get the input impedance

$$Z_{in} = -1 + j\frac{FQ_p}{f_p\beta_1 X_p} \qquad (2)$$

and the reflection coefficient:

$$\Gamma(F) = \frac{Z-1}{Z+1} = 1 + j\frac{2f_p\beta_1 X_p}{FQ_p} \qquad (3)$$

So $|\Gamma|(F)$ can be calculated by solving (1) if f_i, Q_i, k_{0i}, k_{1i}, $\beta_1(\beta_2)$ and the positions of couplers are known, A typical pass-band performance curve $|\Gamma|(F)$ is shown in Fig.2.

IMPLEMENTATION AND USER INTERFACE

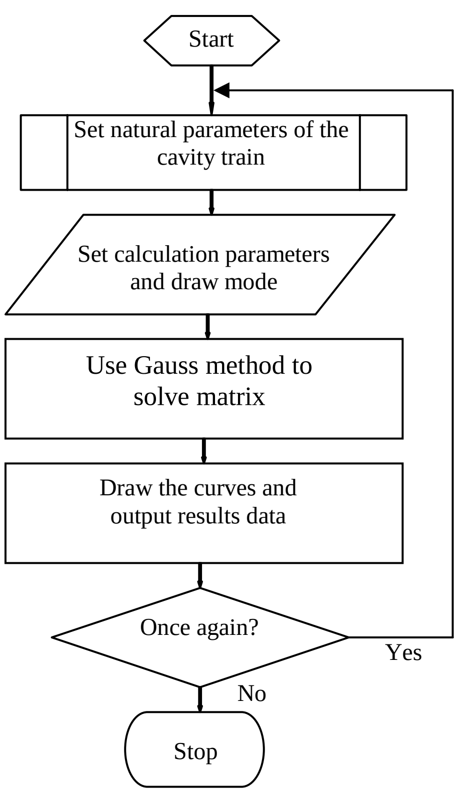

Figure 2: Flow process chart of PPSC.

A step-by-step procedure for the PPSC code with the Gauss method to solve matrix (1) can be described by the flow chart shown in Fig. 2. [2]

First, PPSC initialize a blank window to wait the users' choice: open a new work or a exist work. When open a new one, a dialog interface is shown like Figure 3 to 5. In this interface users can set the natural parameters of the cavity chain, the calculation parameters, the drawing mode, etc.

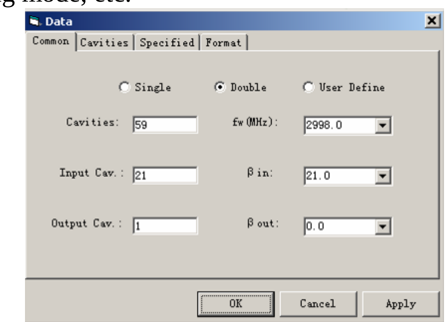

Figure 3: Cavity chain parameters.

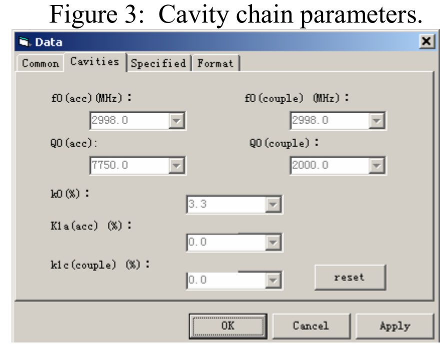

Figure 4: Cell parameters.

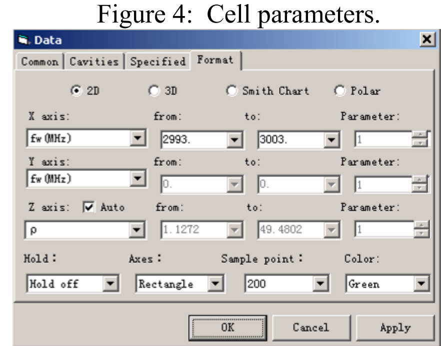

Figure 5: Drawing mode.

After setting the parameters, the main interface shown like figure 6.

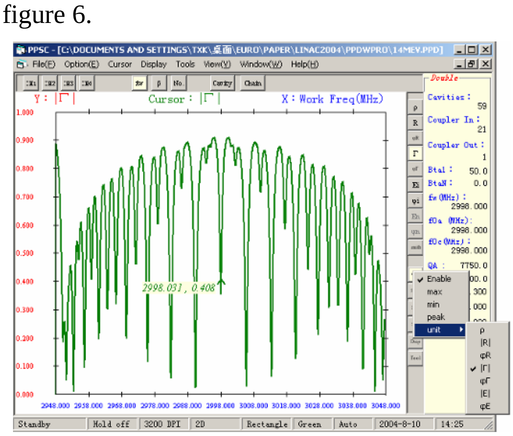

Figure 6: Main interface.

The interface looks just like a front panel of a vector network analyzer. By this interface, the pass band performance curves can be calculated and plotted and the parameters of the calculation and the curves can be change dynamically. A cursor can be displayed on the curve to show the numerical value. The peak and valley points can be found out easily by the cursor. The type, colour, precision and scale of the curve can be changed conveniently, too.

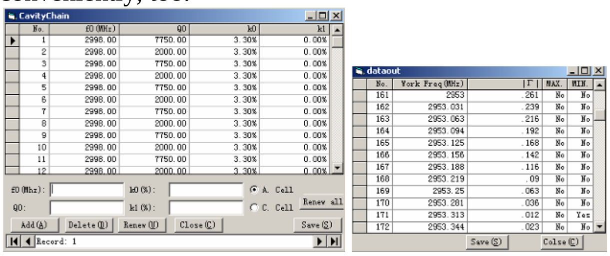

Figure 7: Cavity chain and Output data interface.

Users can also change the parameters of the cavity chain conveniently in a separate window and the calculated result curves can be saved as graphic files or transfer into data files (figure 7).

EXAMPLES

Figure 8 shows a Γ-f curve of a certain SW linac. PPSC can help to adjust the normal modes by finding the best location of the coupler and the tolerance of the detune of each cavity.

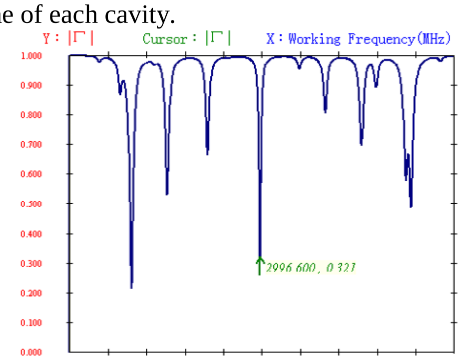

Figure 8: Γ-f curve.

Figure 9 shows the $\pi/2$ mode ρ-β curves of a cavity chain with 3, 11, 19, 29 cavities. By this simulation, the best coupling factor of the 29-cavity chain can be gotten with only 3 cavities. This is very helpful for the linac guide tuning.

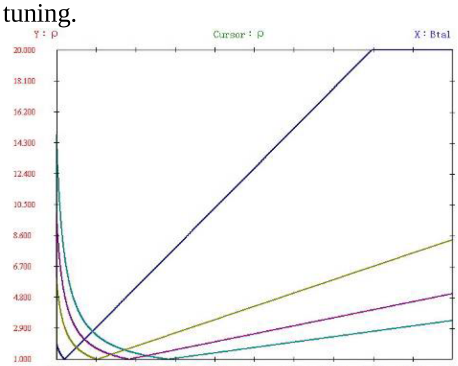

Figure 9: ρ-β curve.

The PPSC code can also help to adjust the field flatness of a cavity chain. Figure 10 gives a simulation result of the test guide of our on-axis coupled standing-wave accelerator energy switch. [3]

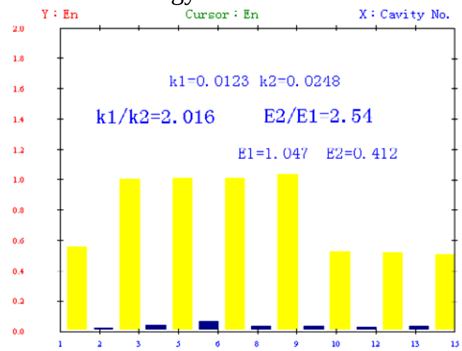

Figure 10: Field flatness.

Smith chart is also a curve type of PPSC simulation result. During the R&D of our S-band 9MeV TW linac for the fixed type container inspection system, PPSC was used as a predictive tool for the tuning of input and output couplers (Figure 11).

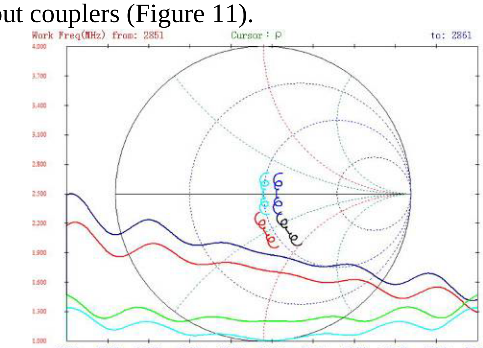

Figure 11: Smith chart.

CONCLUSION

As a powerful predictive tool of the design and tuning of coupled cavity, PPSC has an user friendly interface and is very easy to use. Further improvement of such a simulation code PPSC will be done. A MATLAB version considering the beam loading effect will be completed soon. [4]

REFERENCES

[1] D. E. Nagle, E. A. Knapp and B. C. Knapp, "Coupled Resonator Model for Standing Wave Accelerator Tanks," The Review of Scientific Instruments, Vol. 38, No.11, p1583, Nov, 1967.

[2] Huang Hai, "Study of the microwave performance of a coupled cavity chain," Beijing, 1991.

[3] Tao Xiaokui, "Study on the Energy Switch in an On-Axis Coupled Standing-Wave Accelerator," Beijing, March 1999.

[4] Zheng Shuxin, "Study on a backward travelling wave accelerating structure," Beijing, 2000.