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MICROWAVE TUNING OF DISK-LOADED WAVEGUIDE FOR BEPC

Zhong Shi-Cai, Zhou Xiao-Guang, Yang Hu-Zhi

Institute of High Energy Physics, Beijing, PRC

Summary

Although the microwave tuning of disk-loaded waveguide is well known[1,2] several important considerations relating to precition tuning of BEPC 60 accelerator sections have to be studied.

In order to get the desired phase velocity under actual operating condition of frequency, temperature and vacum, the tuning frequency should be selected correctly. This problem is circumvented in the SLAC accelerator where provision is made for tuning the sections while evacuated and at a temperature of 113±.1°F to simulate operating conditions. But it's expensive on cost and time. In Orsay, the adjustment were made at a frequency which resonated a special reference cavity. This cavity and the accelerator section are held at the same ambient condition duning tuning. But it's difficult due to the tight closing cavity. In order to ensure that a correct phase velocity relationship is maintained for all sections, it's essential that the effect of ensuing environmental change be constantly corrected.This requirement has met by our tuning frequency automatic tracking system.

Second, the phase and VSWR are mearured generally by slot-line. As we know, it's not precise enough and time-consuming. We design and use a Six-port auto-reflectometer to measure the complex reflection coefficients and have got good result.

The main specifications of DLWG which has been tuned for BEPC are following:

VSWR (at $F=F_{2\pi/3}$)	≤1.03
Phase errors	≤±2°
Attenuation	≤4.9 db
Frequency band width (VSWR ≤1.02)	4 MHz

Auto-tracking of The Tuning Frequency

We'll use a accelerator section which has been tuned before as a reference section. The atmospheric condition is not necessary to be precise corresponding to the tuning frequency but is stable during tuning. The system error from this can be compensated by small variation of operating temperature.

The accelerator section to be tuned is located in close proximity to this reference section for over 12 hours and ±0.1°C temperature controlled water is circulated through their interconnected cooling circuts. In this manner, identical environmental conditions are maintained for both sections. The microwave signal from a VCO feed to both sections(Fig.1), these input and output signals from reference section are compared in a phase discriminator(PD). In the correct frequency corresponding to environmental conditions at that time, the phase shifter(PS) is adjusted to make the error signal close to zero. While the environmental conditions change, the phase length of reference section should be varied, the error signal from PD will be used to control the VCO frequency to keep the constant phase length. The Max. limet phase error is:[3]

$$\lim \varepsilon = \pm 2 |S_{22} \Gamma_L| \qquad (1)$$

If $|S_{22}| = |\Gamma_L| = 0.025$, then $\lim \varepsilon = \pm 0.07°$

A double balance mixer is used as the PD. The error signal is modulated and de-modulated to decrease the DC shift. The amplitude control ring (ALC) will avoid the effect of level variation on PD.

Experiment shows that the 42 db open ring gain and 1° phase error has been got for this system.

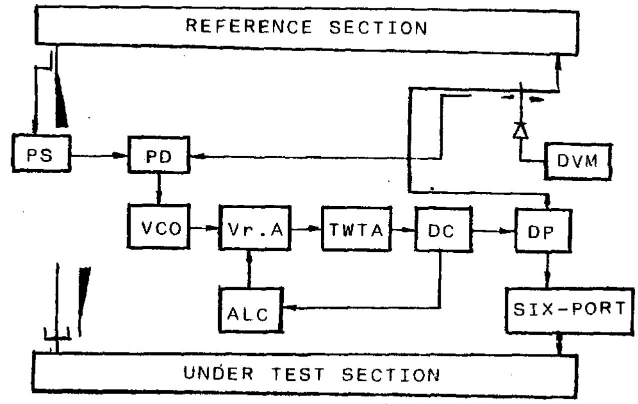

Fig.1 Auto-tracking System of Tuning Frequency

DLWG Tuning by Six-port Reflectometer

A six-port junction is a linear six port microwave network as shown in Fig.2. It was first reported by Engen and Hoer of the NBS, USA in 1972.[4] After over ten years of development work, it has made considerable progress on theory, design, calibration methods and rang of applications of six-port (SP).

Comparing with traditional network analysis techniques, the main advantages of SP for us are that the feature of self-calibration makes possible the calibration of ANA without the need of expensive reflection standard and troublesome adjustment, therefore it is easy to realize the auto-measurements. This just meet the requests for precise and rapid tuning of 60 accelerator sections of BEPC.

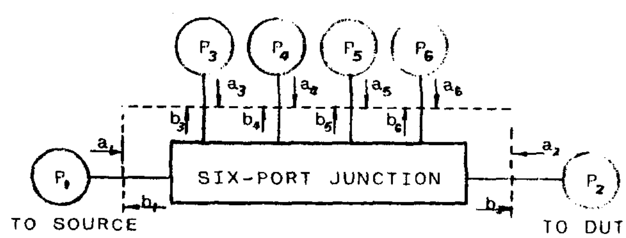

Fig.2 A Six-Port Network

As shown in Fig.2, the SP is an arbitrary linear microwave junction. The microwave signal input to port 1, a device under test (DUT) connected to port 2 and four power detectors are connected to other ports. If the related reflection coeficients of detectors are linear (independent on the power level) and the output voltage are proportional to the respective powers (P B), then a normalized power reading at the i+3 th port is:

$$P_i = \frac{P_{i+3}}{P_3} = q_i \left| \frac{1 + A_i \Gamma}{1 + A_0 \Gamma} \right|^2 \qquad i=1,2,3 \qquad (2)$$

where q_i's are a group of scalar parameters;
A_0 and A_i's are a group of complex parameters;
$\Gamma = b_2/a_2 = x+jY$ is the complex reflection coefficient of DUT.

Equation (2) is called the basic equation.

X and Y can be obtained from (2):

$$X=\frac{\sum R_i P_i}{\sum D_i P_i}\ ;\quad Y=\frac{\sum I_i P_i}{\sum D_i P_i}\ ;\quad i=3,4,5,6 \qquad (3)$$

where R_i's, I_i's and D_i's are a group of new scalar parameters. They'll be found by sutable calibration. Then an unkown complex reflection *coefficient can be calculated by four power* readings of SP reflectometer.

To calibrate a reflectometer, the most popular way is via some reflection standards and these calibration methods have been discussed by many authors. We'll use a precision sliding short (four short posions) to calibrate.[5] It greatly simplifies calibration procedures and increases the accuracy.

The block diagram of our SP reflectometer is shown in Fig.3. The SP junction is composed of a stripline symmetric five port and a directional couper.

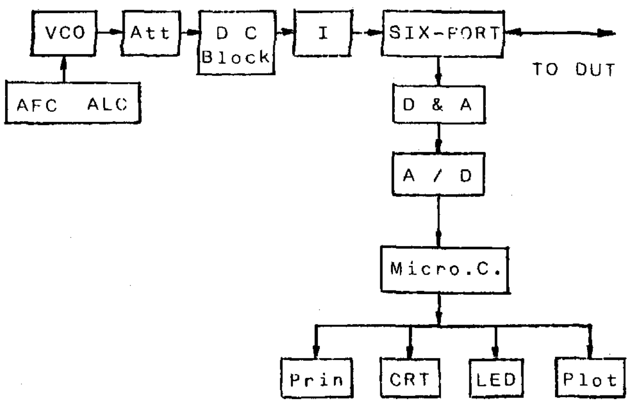

Fig.3. The Block Diagram of SP Reflectometer

Microwave power readings are measured by four Schottky diodes with square detective character. Because the phase of network parameters of SP and accelerator section under test are very sensitive with frequency, the tuning frequency auto-tracking system is used to control the microwave signal source.

For lack of standard load, we can't know the measure precision immediately. The accuracy of measurement is estimated by two means. The first is to measure a preciser sliding short and compare with calculation, the phase difference is no big than ±0.3°. Section, five mismatch loads are measured by SP reflectometer and slot-line. The results are as follows:

load No.	1	2	3	4	5
six-port	1.08	1.29	1.65	2.29	3.53
slot-line	1.09	1.28	1.62	2.20	3.24

40 C.G. sections of BEPC linac have been measured and tuned. Fig.4 is a type result. The measurement results shown that the phase tuning precision of DLWG by SP is more better than slot-line. It's easy to control the error in ±0.5° . The tuning velocity is improved over ten times.

Acknowledgments

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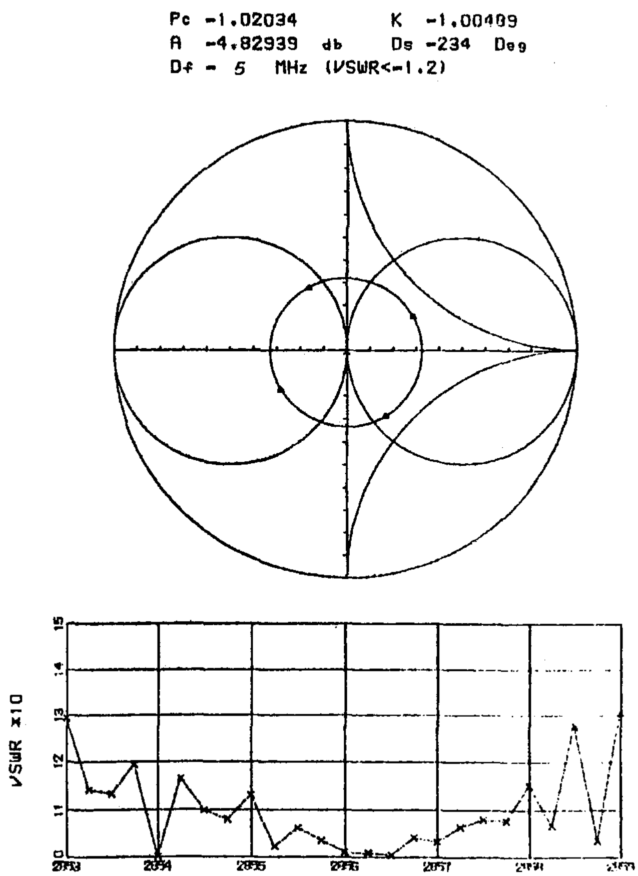

Fig.4 A Type Specification of DLWG