FURTHER STUDY ON A NEW TYPE OF A TUNING-FREE CAVITY WITH AN ALL-PASS NETWORK

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Abstract

A new type of a tuning-free cavity with an all-pass network has been suggested for an ion synchrotron. The idea has been confirmed experimentally with a proto-type cavity. [1]

The new cavity has several merits and further study for them is proceeding.

For example it can achieve high accelerating efficiency up to several hundreds (Ohm/m) with band width ratio as up to 1:8. The proto-type is improved for higher voltage and installed to HIMAC synchrotron for beam acceleration tests.

Also it can produce voltage over super wide frequency range of 1:30-100 and some experiments have been performed to realize them. Such a super wide band cavity is expected to produce great opportunity to accelerate super heavy ions and also molecular ions.

The results and details are presented.

1 INTRODUCTION

Research study has been proceeding for a new type of a tuning-free cavity with a bridged-T type all-pass network. The study began theoretically with circuit simulations and several unique merits were prospected.

The tuning-free cavity can, nevertheless to say, produce accelerating voltage at wide frequency range without feedback control of ferrite bias current. In addition, it obtains higher accelerating voltage because most of input RF power is extracted to an external resistor and only voltage is generated at an accelerating gap parallel to the resistor.

The other important merit of the tuning-free cavity is that users can select the external resistor arbitrarily for their purposes. In case of the higher external resistor more than 450(Ω), it produces high shunt impedance as much as a conventional bias-tuned cavity. While it can also generate accelerating voltage through very wide band frequency range with the lower external resistor as 50(Ω) or less. By equivalent circuit analyses, the bandwidth reaches up to 1:30-100, which any other type of cavities cannot obtain. Such a wide band cavity is attractive for synchrotrons of very heavy or molecular ions.

In order to verify the new concept, a proto-type of the tuning-free cavity with the 200(Ω) external resistor was designed and constructed. The experimental result was that the gap voltage of 550-700(V) was generated at the frequency range of 1-8(Mhz) by 1(kW) RF power input, successfully. [1]

Consequently, for the research of super wide band, the proto-type cavity is re-designed with a 50(Ω) external resistor to get the 1:94 wide frequency range from 0.29 to 27.4(Mhz).

The design and the experimental results are shown below.

2 BASIC CONCEPT

A bridged-T type all-pass network is a circuit with impedance Z_1,Z_2,Z_3 and a terminating resistor R connected as shown in Fig.1(a). The all-pass conditions,

$$Z_2 = \frac{R^2}{2Z_1}, \quad Z_3 = 4Z_1, \qquad (1)$$

keep the whole circuit impedance V/I is equal to external resistor: R at any frequency, where V and I are the input voltage and current.

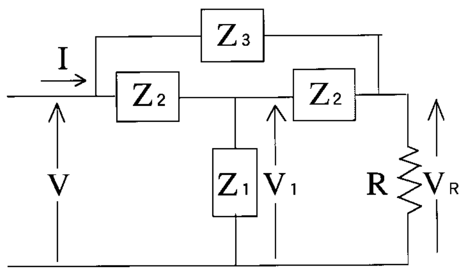

Fig.1(a) A bridged-T type all-pass network (Z expression)

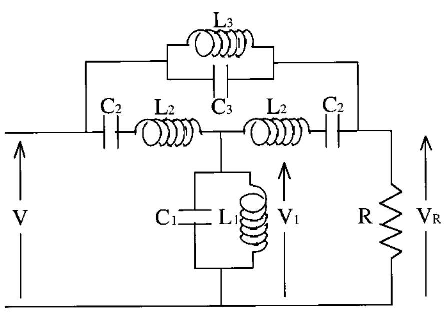

Fig.1(b) A bridged-T type all-pass network (LC expression)

It was known that the circuit works as a low-pass filter if Z_1 is a capacitance and that as a high-pass filter with Z_1 as an inductance. Inductively, it should be a band-pass filter with Z_1 as an LC parallel circuit. In this case,Z_2 and Z_3 should be an LC series and an LC parallel, respectively, to fulfill the eqs.(1). The all-pass network is rewritten as Fig.1(b) and the all-pass conditions are as

$$C_2 = \frac{2L_1}{R^2}, L_2 = \frac{C_1R^2}{2}, C_3 = \frac{C_1}{4} \text{ and } L_3 = 4L_1 \quad (2)$$

Thus Z_1,Z_2 and Z_3 have a same resonance frequency: f_0, where Z_1 and Z_3 behave as resistance and Z_2 is a short. So the all-pass circuit turns to be a simple parallel of R_1 (parallel resistance of Z_1) and R at f_0.

From circuit analyses, V_1(Z_1 voltage) normalized by V (source voltage) has a band-pass feature as Fig.2, while the circuit has a constant impedance without tuning. Therefore a new type of a tuning-free cavity can be realized with Z_1 as a ferrite LC resonator with an accelerating gap.

The curve on Fig.2 is symmetric at f_0, where $|V_1/V|=1$, with the log scale horizontal axis. If the other frequencies where $|V_1/V|=1$ are called f_L and f_U, a bandwidth parameter σ is as;

$$\delta \ldots \frac{\omega_0}{\omega_L} = \frac{\omega_U}{\omega_0} = \sqrt{1+\alpha^2} + \alpha, \quad (3)$$

where the parameter α is decided by L_1, C_1, R or f_0 as;

$$\alpha = \frac{\omega_0 L_1}{R} = \frac{1}{R}\sqrt{\frac{L_1}{C_1}}. \quad (4)$$

σ is larger with larger L_1 and smaller R, though smaller R obtains lower source voltage V with same input power and accordingly lower cavity voltage V_1. Thus the value of R is decided by requirement from synchrotrons, e.g. wide bandwidth or high voltage.

The gap voltage V_1 exceeds the source voltage; $V = \sqrt{2PR}$, where P is input rf. power, at the frequency region $f_L<f<f_U$.

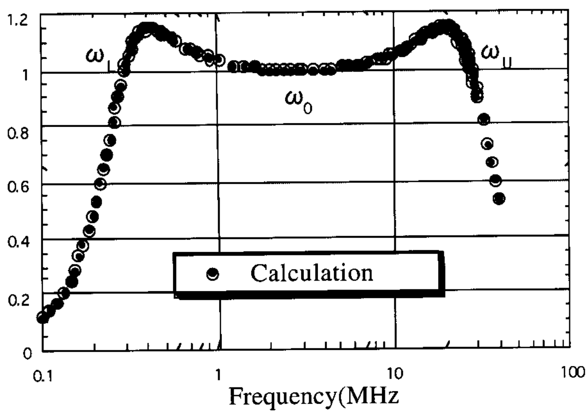

Fig.2 The Frequency dependence of $|V_1/V|$

It is a unique merit of the new type tuning-free cavity that the external resistor R can be arbitrarily selected according to the users' option. Furthermore, as the relation between Z_1 and Z_3 is independent of the resistor, it is quite easy to modify R only by changing the R, the impedance transformer for input matching and the Z_2's.

3 EXPERIMENTS

3.1 Improvement of the Tuning-Free Cavity

Since the precise description about the cavity design is done at the previous paper[1], only the summary of the cavity design is presented here. The cavity applies new ferrite SY-20, not an advanced type, whose relative permeability is ~200.

The proto-type cavity with the 200(Ω) external resistor applies the all-pass network with variable vacuum capacitors: two C_2's and a C_3, a ferrite inductor L_3 and coil inductor L_2's. For the study of the super wide band cavity, the L_3, the C_3 and the main cavity inductance are kept constant and only the C_2's and the L_2's are exchanged with the 50(Ω) resistor. Therefore the design and the improvement are very easy.

Designed all-pass circuit is in Fig.3. From the equations (3) and (4), the characteristic frequency f_L and f_U are 0.29 and 27.4(Mhz), respectively.

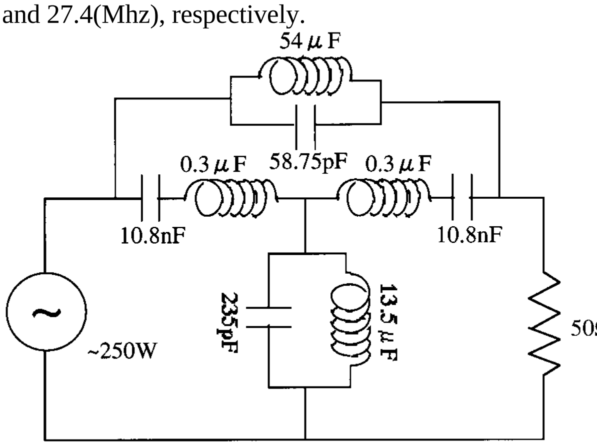

Fig.3 Designed all-pass network

3.2 Experimental Results

Firstly, low-level RF tests with 0dBm input are performed. As the input power is 1(mW) and the all-pass network is designed to be 50(Ω), the voltage at the power source: V is 0.32(V). Input RF frequency is changed from 0.1 to 40(MHz) and the cavity voltage: V_1 specified by V is in Fig.4. The real line in the Fig.4 is corresponding to the line in Fig.2. From the design calculation, V_1/V exceeds 1 at the frequency rang 0.29-27.4(Mhz) but the experimental result indicates the lower voltage gain. Especially at nearly 9(Mhz), a strong dip appears on the V_1/V curve.

The dip is more obvious at high-power input test up to 250(W), which is shown in Fig.5.

In the experiment, not the input power from the RF amplifier but the read value of the synthesizer output display before the amplifier is kept constant as -4dBm.

Both the synthesizer output voltage and the amplifier output voltage are varied against frequency in spite of the constant display value of the synthesizer. But the cavity voltage is almost kept constant.

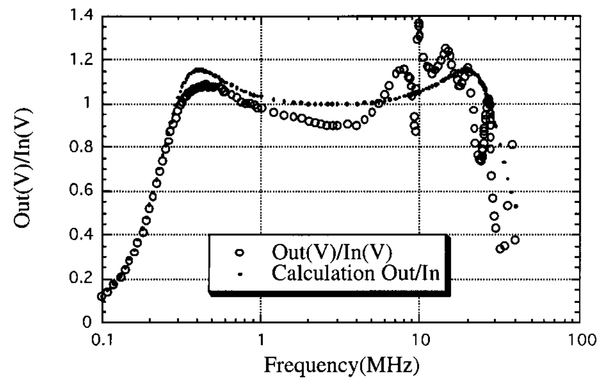

Fig.4 Low-level RF test results of the cavity (Cavity voltage/Source voltage)

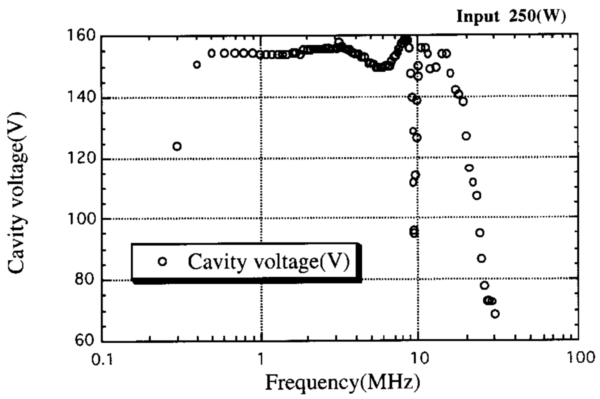

Fig.5 High power input test results
(with the same display value of the synthesizer output)

From the results on Fig.4 and 5, the test cavity can produce voltage at 0.3-9(Mhz), whose bandwidth ratio is 1:30. And if the dip at 9(Mhz) is avoided, it will spread to 0.3-30(Mhz), 1:100 ratio.

4 DISCUSSION

The improved model cavity generates the voltage from 0.3 to 9(Mhz), whose bandwidth ratio is 1:30. It is fur wider than conventional cavities but narrower than the theoretical prediction, because the cavity voltage has a dip at 9(Mhz). The voltage is produced again at more than 9(Mhz) until 30(Mhz). It means that the dip determines the bandwidth of the cavity and that it is thought to be possible to obtain super wide band up to 1:100 if the cavity get rid of the dip.

Thus it is very important to find out what causes the mismatching at 9(Mhz). The study has been performed both analytically and experimentally.

It is experimentally found that the ferrite stack of the main body of the cavity itself has a weak resonance at around 9(Mhz). The resonance is known to be different from the normal one of a coaxial cavity, because the resonant frequency is far away from the calculated one of the higher-order mode. It is not much difficult to estimate the resonance frequency of the coaxial cavity even for the higher-order modes.

A new numerical method is developing to analyze the cavity characteristics by a transmission line approximation with the effect of radial modes. By the method, a resonance at 8-9(Mhz) is expected for one of the periodic unit of the ferrite cavity, which consists of a ferrite torus with two copper cooling plates at both size and short at the outer side. It is quite possible because the results of the method have other good agreements with some other behavior of the cavity. Further analyses have been continued, while the way to increase the resonance frequency is suggested.

The cavity generates the voltage from 10 to 30(Mhz) without any big problem, which shows Snoek's limit does not cause a fatal effect to the wide band cavity. One of the reasons is an LC parallel circuit acts almost as a capacitor at far higher frequency range than the resonance frequency. For example the LC parallel: L_1-C_1 and L_3-C_3 has a same resonance frequency of 2.83(Mhz), which is fur lower than the frequency range as 10-30(Mhz).

5 CONCLUSION

A new concept of the tuning-free cavity with an bridged-T type all-pass network is improved for super wide band up to 1:100. Because of the parasitic resonance, the voltage is generated from 0.3 to 9(Mhz), 1:30 ratio. The cause of the resonance is now on studying and the ways to avoid it are suggested. Wider frequency range seems to be obtained.

On the other hand, the super wide band cavity was re-constructed again for higher voltage with the 450(Ω) external resistor. It can generate 1.5(kV) accelerating voltage with 2(kW) input power at the frequency range of 1.5-6(Mhz). The high impedance tuning-free cavity has already installed to HIMAC (Heavy Ion Medical Accelerator in Chiba) and will perform beam acceleration tests from April, 1998..

6 REFERENCE

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