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BROADBAND RF ACCELERATING CAVITY FOR TARN II

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Abstract

The rf cavity for TARN II was powered by a final rf power amplifier in frequency from 550 kHz to 8.7 MHz: an rf accelerating voltage thus produced was higher than 1.9 kV. The paper presents recent improvements on the cavity, a feature of the power amplifier, preliminary results of rf power test, and discussions on remaining problems.

Introduction

In a previous paper[1], rf characteristics of the cavity based on low-level rf measurement were presented. Five parasitic resonances possibly affecting the rf accelerating voltage were observed below the frequency of 30 MHz at 580 kHz, 950 kHz, 8.3 MHz, 16.1 MHz, and 29.1 MHz. Origin of them was investigated and an equivalent lumped circuit model of the cavity was proposed to predict three of them and the fundamental resonance.

Further attempts to shift or eliminate the parasites have been continued. At present, parasites are improved to occur at 460 kHz, 950 kHz, 9.0 MHz, and 28 MHz. Because it is known from the measurement that the one at 950 kHz gives no serious distortion on the rf voltage, it has been expected that the cavity is powered in the freqeuncy from 550 kHz to 8.7 MHz without contamination due to the parasites.

A maximum rf accelerating voltage to be produced by a final rf power amplifier was recently decided to decrease to 1.8 kV instead of the original goal of 6 kV, although the cavity itself was desinged and constructed to aim at 6 kV. This change is due to a recent choice for a first construction phase of TARN II: on the basis of the choice, a power supply for bending magnets preceded the power amplifier in construction. The power amplifier consisting of a single tetrode was then designed and constructed to produce an anode rf voltage of 0.9 kV (a half of 1.8 kV).

At an initial period of rf power test, we met with a self oscillation around 180 MHz. After it was eliminated, the cavity has been powered by the power amplifier in the desired frequency range at a maximum rating of a tetrode. In frequency above 1.2 MHz, frequency dependence of the rf voltage well agrees with the low-level rf measurement. However, in frequency below 1.2 MHz, it deviates from the measurement contrary to our expectation: this abnormal behavior possibly relates to the parasite at 950 kHz. Such remaining problems are discussed in the paper.

Improvements on the rf cavity

The parasites observed before at 580 kHz and 8.3 MHz were shifted to 460 kHz and 9.0 MHz, respectively. The one observed before at 16.1 MHz was eliminated. No essential change of the ones observed before at 950 kHz and 29.1 MHz was achieved. This improvement work was made with low-level rf measurement. Schematic electrical configuration of the cavity is shown in Fig. 1 together with the power amplifier.

The parasite observed before at 8.3 MHz arises from a resonance of capacitor banks themselves for rf grounding and dc blocking (denoted by "f" and "e" in Fig. 1, respectively) of the anode choke: it is a parallel resonance having a high impedance. Each bank consists of 90 pieces of capacitors to achieve a large capacitance of 135 nF. We noticed that a resonant frequency depends on arrangement of many capacitors because they work like a distributed circuit. Investigation on the arrangement showed that a double decker capacitor sandwich fixed on squared copper plates is best. We have then succeeded to raise the frequency from 8.3 MHz to 9.0 MHz.

The parasite observed before at 580 kHz arises from a resonance due to co-operation of a proper self inductance of the anode choke and the capacitors described above. In order to lower a resonant frequency, the inductance was increased by the use of an appropriately thin wire for the anode choke instead of the original wide bus bar. The frequency then lowered from 580 kHz to 460 kHz as predicted by the proposed model.

The parasite observed before at 16.1 MHz arises from a resonance associated with an inductive type of rf voltage monitor having a winding. It was abandoned and was replaced by a capacitive divider type equipped at a top of the right half cavity. Consequently, this kind of parasite disappeared.

Because the capacitive divider type of rf voltage monitor was equipped, a frequency of the parasite observed before at 29.1 MHz lowered[1] as predicted by the proposed model. In order to raise the frequency again, a helpful winding in increasing a turn number of windings was equipped inside the cavity. The winding used before for the old rf voltage monitor was used again for such a new winding. Consequently, the parasite remains at the high frequency of 28 MHz.

Rf characteristics of the fundamental resonance based on low-level rf measurement are shown in Fig. 2 together with a preliminary result of rf power test.

Final rf power amplifier

It is known from Fig. 2 that a lowest value of a shunt impedance is 250 Ω at frequency around 5 MHz. Because the value is low in comparison with an output impedance of a tetrode, a tetrode having a high anode dissipation is necessary for the power amplifier although the anode rf voltage of 0.9 kV is rather low. Taking into account of capability of the existing driver amplifier, etc., we chose the tetrode, RS 2012 CJ of Siemens, which is capable of an anode dissipation of 18 kW.

Schematic electrical configuration of the power amplifier is shown in Fig. 1 together with the cavity. An anode dc power supply is of a 6-phase diode rectifier type followed by a filter. Thyristors are equipped to primary ac lines of the power supply and are adequately switched during an initial turn-on period in order to soften a transient phenomenon of the power supply. Dc power supplies for a screen grid and a control grid are of a series transistor regulated type following diode rectifier with a filter.

In our configuration of the anode choke equipped inside the cavity, no more anode choke is equipped outside the cavity. No trouble due to this configuration has been experienced so far.

The tetrode operates in a grounded cathode. An all-pass network, namely a constant-resistance bridge-T network, was chosen for an input circuit of the control grid. In this network, an rf input power is terminated by a resistor (denoted by "R1" in Fig. 1) independently of the frequency while an rf voltage at the control grid shows a low-pass feature in frequency. We added an appropriate capacitor (denoted by "o" in Fig. 1) to the control grid in order to settle a cut-off frequency at about 10 MHz. It is known from measurement that a volt-

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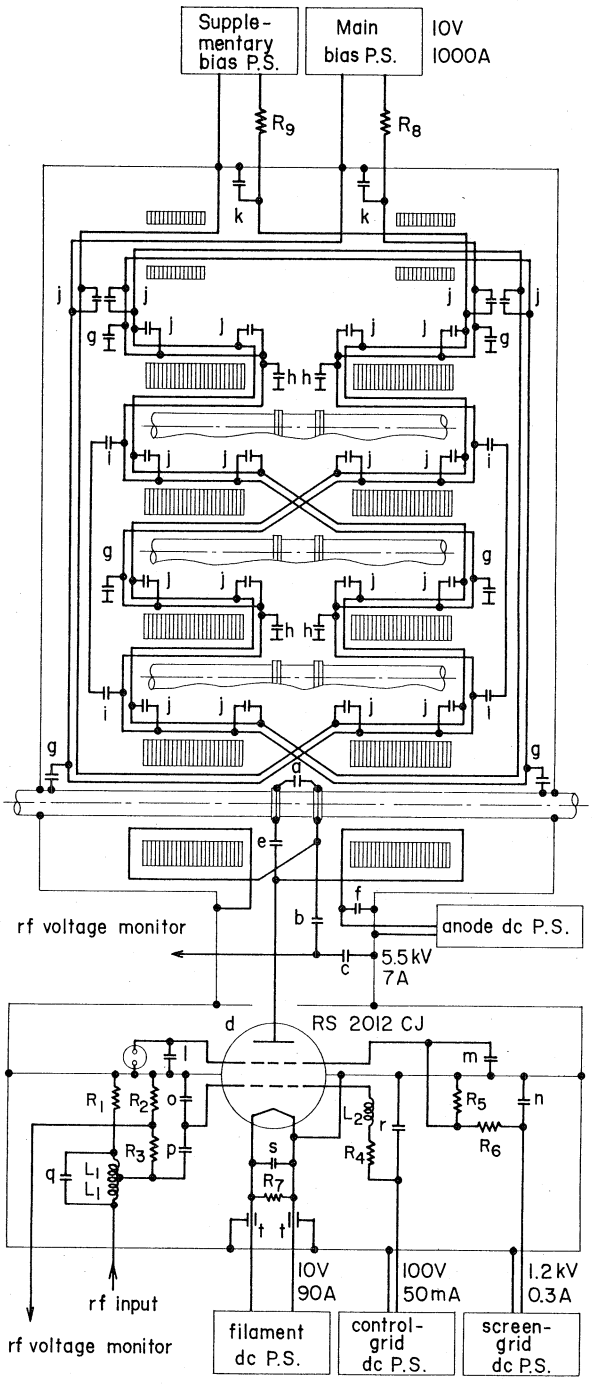

Fig. 1 Schematic electrical configuration of the rf cavity and the final rf power amplifier.
Capacitances: a=150pF, b=100pF, c= 40nF, d= 22pF, e=135nF, f=135nF, g=100nF, h=100nF, i=100nF, j=200nF, k=200nF, l= 12nF, m=127nF, n=100nF, o=645pF, p= 10nF, q=123pF, r=100nF, s= 80nF, and t= 20nF.
Inductances: L1=0.75 μH and L2=30 μH.
Resistances: R1=50 Ω, R2=50 Ω, R3=4.5k Ω, R4=2.5k Ω, R5=40k Ω, R6=10 Ω, R7=85 Ω, R8=2.8m Ω, and R9=300m Ω.
Notes: 1. "d" is the output capacitance of the tetrode.
2. "m" is the screen by-pass capacitor.
3. "o" is the sum of 400 pF and 245 pF: the latter is the input capacitance of the tetrode.
4. A supplementary bias power supply is not a final one at present.

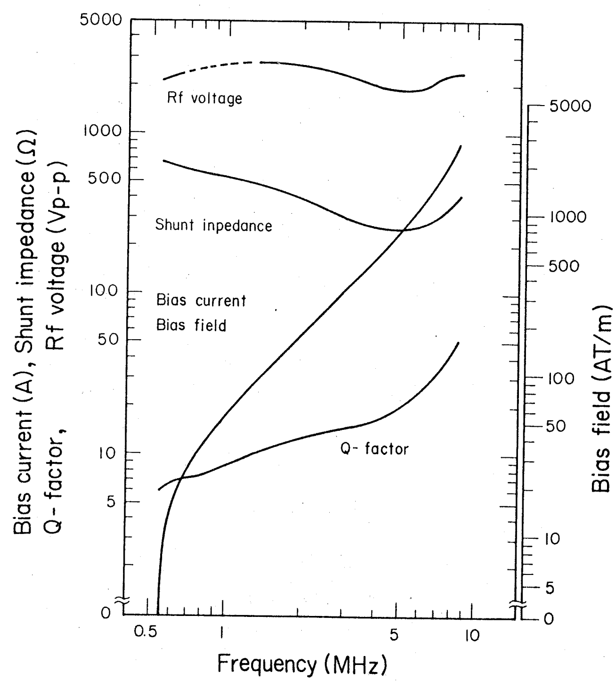

Fig. 2 Rf characteristics of the fundamental resonance of the cavity together with a relation between the ferrite-bias current and the frequency. Q-factor and shunt impedance are reduced from low-level rf measurement. Rf voltage is a peak-to-peak value measured at the right half cavity in preliminary rf power test: a dotted line implies that no clear data has been obtained so far.

age standing wave ratio (VSWR) of the network is better than 1.10 in frequency from 500 kHz to 9 MHz.

A screen grid by-pass capacitor consists of a double decker Kapton sandwich put between an extended screen electrode and two grounding electrodes. It was known from measurement that this capacitor works well because no parallel resonance having a high impedance is observed below 100 MHz.

Rf power test

At an initial period of the rf power test, we met with a self oscillation in frequency around 180 MHz: it happened as soon as all the dc voltages were applied. Because the cavity consists of a great quantity of ferrite materials and the ferrite has a large rf loss in such a high frequency, it was considered that the self oscillation arised from a coupling between a lumped circuit element of the cavity and the power amplifier. When we removed the rf voltage monitor, the oscillation ceased: this fact implies that the lumped element is just capacitors of the capacitive divider type of rf voltage monitor. Here, then, we covered a large hole[2] between the power amplifier and a mid-bottom of the cavity with a copper plate as narrow as possible. After this improvement, the rf power test has been continued without the self oscillation.

The rf power test is made in the frequency from 550 kHz to 8.7 MHz: an rf input power was usually fixed independently of the frequency to produce the rf accelerating voltage of 1.9 kV around 5 MHz where the tetrode operates at a maximum rating. A change of the operating frequency has been manually made: we varied the freqeuncy of a synthesizer and a main ferrite-bias current to tune the cavity at the same time.

It was found that the rf voltage monitor incorrectly worked due to a resonance of the capacitor itself (denoted by "c" in Fig. 1) having a capacitance of 40 nF: it was a series resonance having a low impedance and occuring within the operating frequency range. During the preliminary rf power test, then, the anode rf volatge has been directly measured by a probe which is capable of high rf voltage.

A preliminary result of the rf power test on a relation between the rf voltage and the frequency was taken and is shown in Fig. 2 together with the low-level rf measurement.

It is known from the figure that the rf voltage well agrees with the shunt impedance in frequency above 1.2 MHz as denoted by a solid line but it deviates below 1.2 MHz as denoted by a dotted line.

No clear data was obtainable below 1.2 MHz because it was observed that the fundamental resonance itself was unstable. In the frequency above 1.2 MHz, we measured the rf voltage of the resonance by the following procedure: we fixed the ferrite-bias current and then adjusted the frequency of the synthesizer to obtain a maximum of the rf voltage, or vice versa. In the case of the frequency below 1.2 MHz, however, the maximum itself immediately runs away in spite of the same procedure. In addition, a few peaks in rf voltage are observed contrary to the low-level rf measurement when the operating frequency was swept for the fixed ferrite-bias current. Such abnormal phenomena as instability and a few peaks possibly relate to the parasite at 950 kHz because it is observed that the phenomena shift in frequency when the parasite frequency is shifted. Such a shift can be made by a change in a capacitance of the capacitors (denoted by "h's" in Fig. 1) for rf grounding of the bus bar for the main ferrite-bias current.

Efforts to eliminate the series resonance of the capacitor itself of the rf voltage monitor have been made. Investigation shows that a capacitor has an own inductance relating to a size of the capacitor and thus the series resonance arises from co-operation of capacitance and inductance. Although several kinds of capacitors having the capacitance of 40 nF and being different in size were tested, we have had no nice capacitor so far.

Discussions

The rf accelerating cavity was powered by the final rf power amplifier in the frequency from 550 kHz to 8.7 MHz: the rf accelerating voltage thus produced was higher than 1.9 kV in the entire frequency range.

In the frequency above 1.2 MHz, the entire system of the cavity and the power amplifier works well. In the frequency below 1.2 MHz, however, the cavity shows the abnormal phenomena such as the instability and a few peaks of rf voltage contrary to our expectation based on the low-level rf measurement. The phenomena possibly relate to the parasite at 950 kHz.

Here, in spite of occurence of the abnormal phenomena, it is pointed out from the practical viewpoint that the entire system can operate in the desired frequency range because it can actually produce the rf accelerating voltage of 1.8 kV without a trouble such as heating of circuit elements due to the parasite.

Such a practical use is possible indeed, but a further effort to eliminate the phenomena is being made to achieve better performance of the entire system. An approach is to lower the resonant frequency of the parasite below the lowest operating frequency of 550 kHz: this is made by increase of the capacitors (denoted by "h's" in Fig. 1). In view of our experience, however, such capacitors themselves probably have a parallel resonance having a high impedance at a relatively low frequency; so that the rf grounding probably becomes worse within the operating frequency range. If we meet such a new problem, we will operate the entire system from the practical viewpoint.

Concerning the rf voltage monitor, we suffered from the series resonance of the capacitor itself within the operating frequency range. Because we have had no nice capacitor having the capacitance of 40 nF, we are going to use FET probes measuring an rf voltage at a top of capacitor (denoted by "c" in Fig. 1) having a relatively low capacitance such as 1 nF.

It is pointed out that the remaining problems relate to rf performance of capacitors or capacitor banks having a large capacitance: a series resonance or a parallel resonance possibly occur within the operating frequency range. If nice compact high-rf-power capacitors working in a wide frequency range are available, an rf cavity operating in a wide frequency range will be easy in construction without problems of parasites.

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