Tests of RF Windows in the Resonant Ring

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Abstract. Klystron output window testing was performed with the help of traveling wave resonator. Two versions of windows were tested. After design modifications, maximal power transmitted through the window increased up to 40 MW.

1. Possibility of indirect estimation of the TWR amplification coefficient

Installation of directional coupler in the ring of traveling wave resonator would be desirable for definition of power circulating in it but this element causes additional reflection and attenuation, and reflections inside the ring decrease the amplification drastically.

However, measurement with two couplers installed out of the ring (Fig. 1)

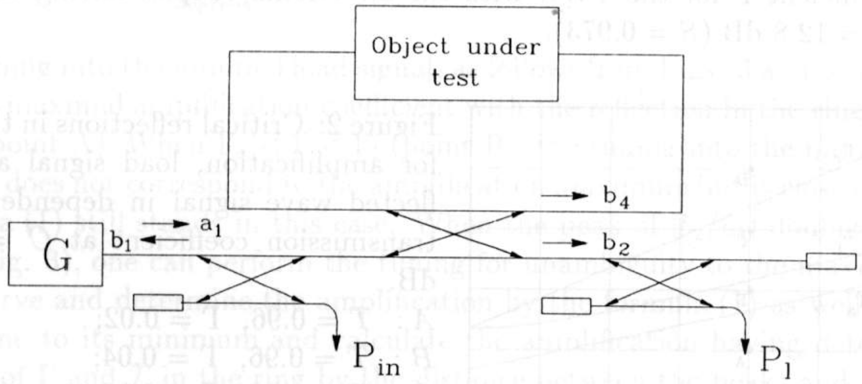

Figure 1: TWR scheme for measuring the gain from without the ring.

gives possibility to determine its power amplification coefficient K because it is related to the incident wave amplitude at the TWR input (a_1) and the amplitude of the wave passing into load (b_2), by the relationship [1]

$$K = \frac{1}{C^2}\left(1 - S \cdot \frac{b_2}{a_1}\right)^2,$$

where C is coupling coefficient of the directional coupler between the waveguide transmission line and the resonant ring, and by S the wave portion passing into the load is designated: $S = \sqrt{1 - C^2}$. If the quantity of C is less than its optimal value, i.e.

$$S > T,$$

where T is the ring voltage transmission coefficient, then the b_2 and a_1 waves are inphase at resonance, and tuning to the resonance corresponds to the tuning into minimum of ratio $|b_2/a_1|$. In this case the amplification is

$$K = \frac{1}{C^2}\left[1 - S \cdot \sqrt{\frac{P_l}{P_{in}}}\right]^2, \quad (1)$$

where P_l is power passing into the load, and P_{in} is power at the TWR input.

So, one can perform the tuning into maximum of amplification in the ring by changing the input signal frequency in such a way as the ratio P_l/P_{in} becomes minimal.

If the reflection in the ring exceeds some critical value then the graphs of amplification, reflected signal and of the passing into the load signal in dependence on frequency become two-peaked. These critical values are different for said dependencies. They are presented in Fig. 2 as functions of the transmission coefficient T for the TWR with the directional coupler having coupling ratio $C = 12.8$ dB ($S = 0.973$).

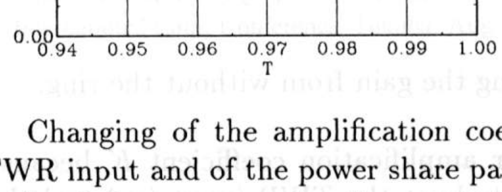

Figure 2: Critical reflections in the ring for amplification, load signal and reflected wave signal in dependence on transmission coefficient at $C = 12.8$ dB.

$A: \ T = 0.96, \ \Gamma = 0.02;$
$B: \ T = 0.96, \ \Gamma = 0.04;$
$C: \ T = 0.96, \ \Gamma = 0.06;$
$D: \ T = 0.96, \ \Gamma = 0.08.$

Changing of the amplification coefficient, reflection coefficient from the TWR input and of the power share passing into the load against the detuning angle of the resonator for the points indicated in Fig. 2, is shown in Figs 3, 4, and 5.

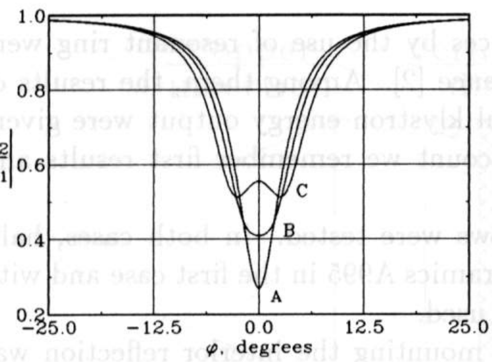

Figure 3: Share of input wave passing into the load for points A, B, and C of Fig. 2 vs resonator detuning.

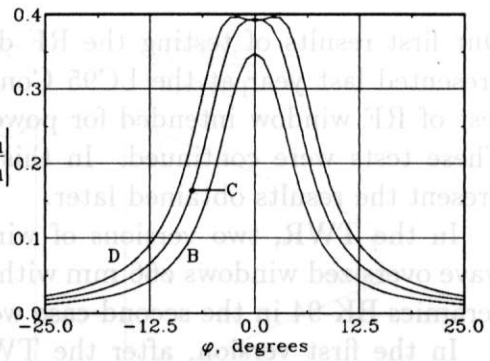

Figure 4: Coefficient of reflection from input for points B, C, and D of Fig. 2 vs resonator detuning.

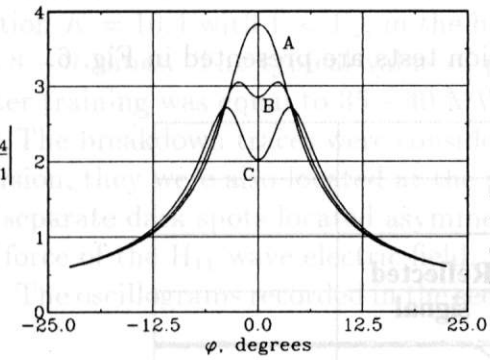

Figure 5: Voltage amplification coefficient for points A, B, and C of Fig. 2 vs resonator detuning.

Tuning into the minimal load signal, as follows from Figs. 3 and 5, allows to obtain maximal amplification coefficient with the reflection in the ring $\Gamma < \Gamma_a$ only (point A). When $\Gamma_a < \Gamma < \Gamma_l$ (point B), the tuning into the minimum of $|b_2/a_1|$ does not correspond to the amplification maximum but is close to it, the formula (1) still stands in this case. When the peak of $|b_2/a_1|$ doubles (curve C in Fig. 3), one can perform the tuning for unambiguity to the maximum of this curve and determine the amplification by the formula (1) as well, or one can tune to its minimum and calculate the amplification having determined values of Γ and T in the ring by the distance between the peaks and value of the minimum. With Γ, T and detuning angle φ the amplification can be found using the corresponding curve of Fig. 5.

The control of the signals of reflected from the input wave and of the wave incident to the load gives possibility to determine the value of discontinuity in the ring and the ring transmission coefficient if the coupling ratio is known.

2. Experimental results

Our first results of testing the RF devices by the use of resonant ring were presented last year at the LC95 Conference [2]. Among them, the results of test of RF window intended for powerful klystron energy output were given. These tests were continued. In this account we remember first results and present the results obtained later.

In the TWR, two versions of windows were tested. In both cases, half-wave oversized windows ø66 mm with ceramics A995 in the first case and with ceramics BK-94 in the second case were used.

In the first version, after the TWR mounting the interior reflection was greater than the critical value Γ_l that was reflected in the fact that frequency characteristic of the wave in the resonator load doubled. The work was done at the right-hand peak of this curvee. The calculated amplification in the ring with account of detuning was found to be about 5. Breakdown limitation occurred at the level of 10 – 12 MW that corresponds to the earlier obtained limitation [3] when at the klystron output the window of the same design but with ceramics BK–94 was installed.

The signals obtained in the first version tests are presented in Fig. 6.

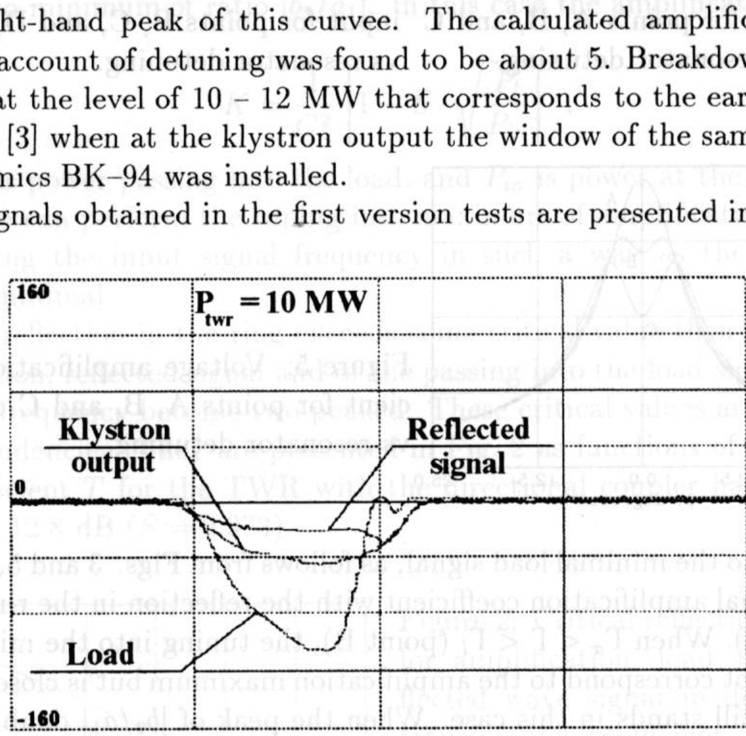

Figure 6: Shape of TWR pulses. First version window test.

After disassembling the window, the breakdown traces were revealed at the perimeter of the ceramic disk. They had an appearance of black spots around all the periphery of the disk and of separate lines directed along the electric field vector of the round waveguide H_{11}–mode, and were grouped mainly near the opposite walls corresponding to the field.

There were modifications in the design of the second version with the aim to prevent multipactor discharge, Fig. 7.

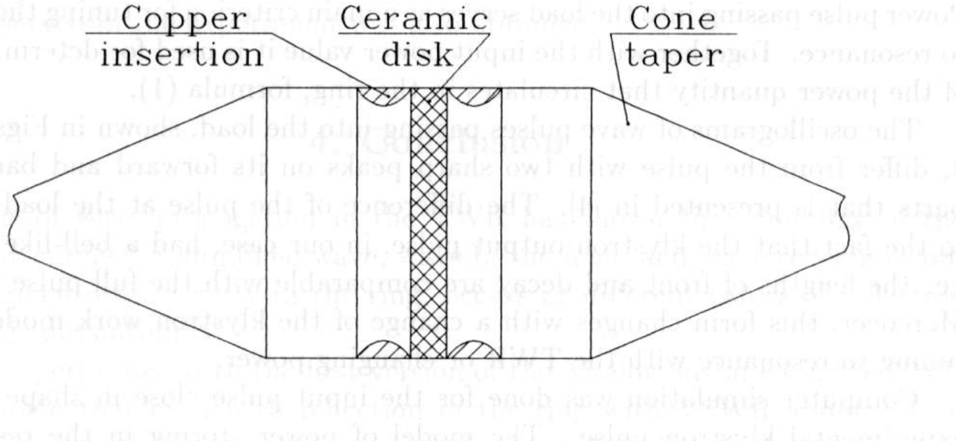

Figure 7: Sketch of the second version window design.

We succeeded to set the resonator in the cold measurements at the amplification $K = 10.4$ with $\Gamma < \Gamma_a$, in the hot testing the power amplification came to 8 – 9 times. The typical value of power transmitted through the window after training was equal to 35 – 40 MW, and up to 50 MW in separate pulses.

The breakdown traces were considerably weak in comparison with the first version, they were also located at the periphery of the disk and had an aspect of separate dark spots located asymmetrically on both sides of the central line of force of the H_{11}-wave electric field.

The oscillograms recorded in the second version tests are presented in Fig. 8.

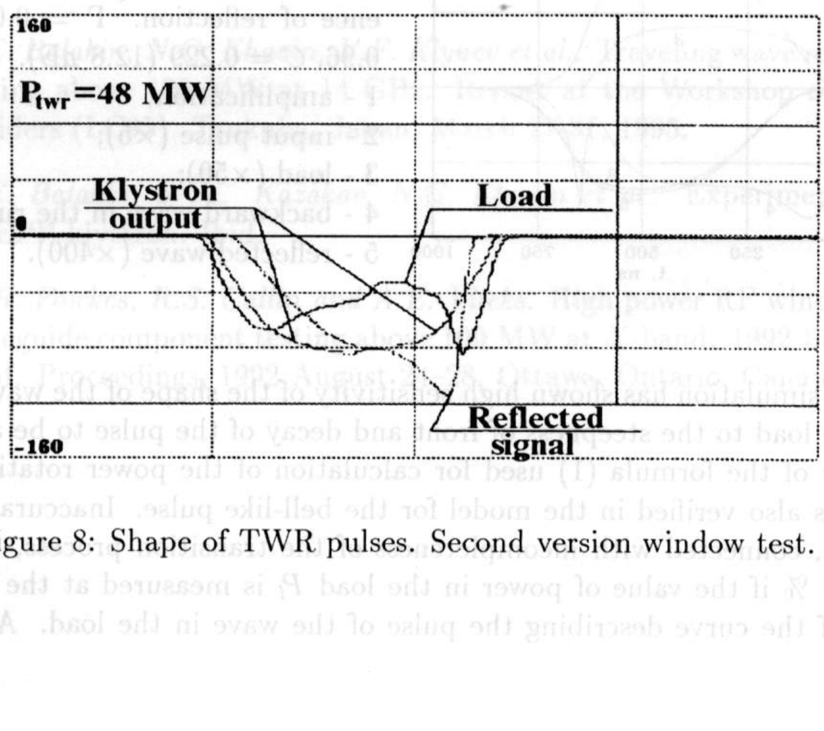

Figure 8: Shape of TWR pulses. Second version window test.

3. Computer simulation

Power pulse passing into the load serves as a main criterion for tuning the TWR to resonance. Together with the input power value it is used for determination of the power quantity that circulates in the ring, formula (1).

The oscillograms of wave pulses passing into the load, shown in Figs 6 and 8, differ from the pulse with two sharp peaks on its forward and backward parts that is presented in [4]. The difference of the pulse at the load is due to the fact that the klystron output pulse, in our case, had a bell-like shape, i.e. the lengths of front and decay are comparable with the full pulse length. Moreover, this form changes with a change of the klystron work mode when tuning to resonance with the TWR or changing power.

Computer simulation was done for the input pulse close in shape to the experimental klystron pulse. The model of power storing in the resonator considers wave amplitudes at the TWR input, at the load, in the ring near the discontinuity with the step in time equal to the half of time of wave revolution in the ring. The discontinuity was suggested to be at the point of the ring most distant from the directional coupler. The simulation has shown qualitative agreement with the experiment. Results of simulation are presented in Fig. 9 for one of parameters sets. The scale along the ordinate axis is different for all the pulses. Relative scales are indicated in the figure by multiplier near the designation. The klystron pulse width at half-height is 500 ns.

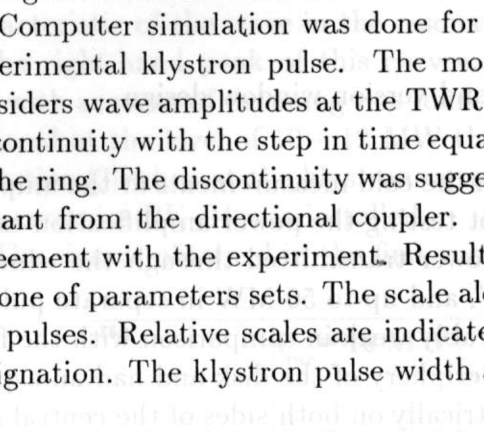

Figure 9: Results of simulation of TWR pulses at resonance in a presence of reflection. $\Gamma = 0.015$, $T = 0.96$, $C = 0.229$ (12.8 дБ).
1 - amplification;
2 - input pulse (×5);
3 - load (×50);
4 - backward wave in the ring (×20);
5 - reflected wave (×400).

The simulation has shown high sensitivity of the shape of the wave passing into the load to the steepness of front and decay of the pulse to be amplified. Validity of the formula (1) used for calculation of the power rotating in the ring was also verified in the model for the bell-like pulse. Inaccuracy of this formula, connected with incompleteness of the transition process, comprises about 1 % if the value of power in the load P_l is measured at the inflection point of the curve describing the pulse of the wave in the load. A decrease in the amplification coefficient in comparison with cold measurements (with a pulse of 100 mks), connected with incompleteness of the transition process and observed in the experiment was also obtained.

4. Conclusion

Analysis of wave propagation in the TWR has shown that doubling of the resonant curves for amplified wave, wave in the load, and wave reflected from input, given discontinuity in the ring, occurs at different values of reflection from this discontinuity.

Tests performed with the first version of the window installed in the TWR have shown that even with reflection in the ring with VSWR about 1.3 an acceptable amplification can be achieved, about 5 under these experimental conditions.

After modifications of the window, the level of power in the TWR transmitted through the window ranged up to about 40 MW.

Computer simulation of the power storage process in the TWR has shown strong effects of the input power pulse form on the form of pulses in other points of the ring and explained a drop in amplification in connection with incompleteness of transition processes.

References

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