Single-Mode Interference Switches
of High Power Resonant Microwave Compressors

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Abstract – The opportunity of development of single-cavity microwave resonant pulse compressor (RPC) in S-band with the output pulse power of about ~0.5-1 GW containing a single-mode cylindrical cavity with a cylindrical interference switch was examined. Comparative study of energy characteristics of RPCs with single mode rectangular and circular cross section storage cavities was made. For excessive gas pressure insulation the limiting power level of a traveling wave in a single-mode cylindrical cavity was determined experimentally. Configurations of cylindrical interference switches using either waveguide H-tee or symmetrical four port waveguide junction in H-plane or magic waveguide tee were considered and experimentally tested. It was shown experimentally that two – fold increase of each value of output power, efficiency and amplification factor in single cavity RPCs with single mode cylindrical cavities and cylindrical interference switches as against similar RPCs with rectangular waveguide elements was possible.

1. Introduction

At present the obtained output pulse power of single-cavity S-band RPCs with gas insulation is ~150-200 MW [1]. The main obstacle for increasing the power further is the limitation put by the electrical strength of storage cavities and switches usually made from standard rectangular waveguides of corresponding wave bands. A multimode storage cavity if employed solves to some extent the matter of large energy amount accumulation but the problems related to the cavity output element stays. So microwave pulses of higher power ~0.5-1 GW are usually produced by series compression in two or three stages due to getting higher electrical strength of storage systems as the storing time becomes smaller. Efficiency of such a compressor drops perceptibly.

Although there is possibility of rising the limiting power level for single-cavity single-mode RPCs at the same electrical strength by using circular waveguides in cavity and switch designs instead of rectangular ones. This possibility is attributed to larger cross section area of single-mode circular waveguide compared with rectangular one at the same frequency of microwaves. At a certain critical E-field value it will allow to increase the limiting power level of RPC.

The work presents first results of tests of single-cavity RPCs which contain cavities and switches made from single-mode circular waveguides.

2. Comparative study

The comparative study will be made for RPC having the working frequency 2800 MHz and output pulsewidth ~4 ns. The power level value ~200 MW obtained in single-cavity single-mode RPC is taken as a reference point. Let us assume that this power level corresponds to the traveling wave power in the storage cavity i.e. we assume the energy is released without losses. Let us consider two known designs of resonant storage systems: first one with H-plane tee for energy release shown in fig.1a and second – with magic tee geometry unit as an input – output element.
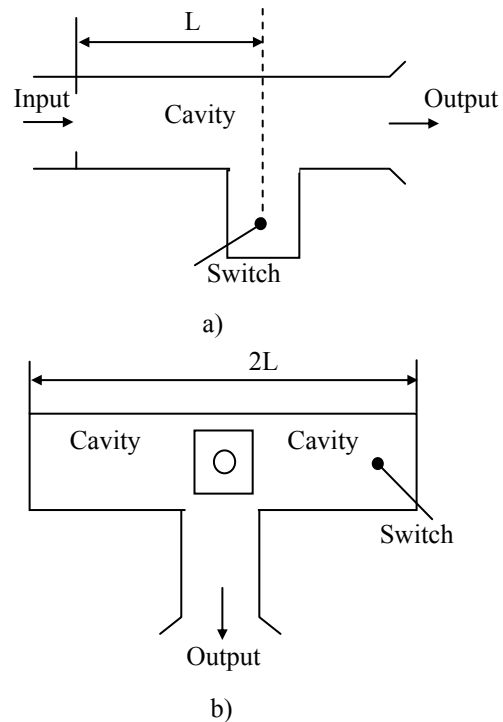

Fig.1. Two storage cavity common designs. a) having H-plane tee as an output element; b) having "magic tee" as an input – output element.

Table 1. Parameters of rectangular cross section 72×34 mm^2 cavities.

System type	Mode	Q_0	M^2, dB	η, %	P_{in}, MW	P_t, MW	P_0, MW	W_{in}, J	W_s, J	ω_s, J/l	E_W, kV/cm	E_V, kV/cm	V, l
H-tee	$H_{10(5)}$	$1.1 \cdot 10^4$	219	21	1.3	200	200	3.8	0.8	0.8	270	270	~1
"Magic tee"	$H_{10(10)}$	$1.15 \cdot 10^4$	22	21	2.5	200	400	7.5	1.6	0.8	270	270	~2

Table 2. Parameters of circular cross section $\varnothing 90$ mm cavities.

System type	Mode	Q_0	M^2, dB	η, %	P_{in}, MW	P_t, MW	P_0, MW	W_{in}, J	W_s, J	ω_s, J/l	E_W, kV/cm	E_V, kV/cm	V, l
H-tee	$H_{10(5)}$	$2.3 \cdot 10^4$	25	39	1.65	530	530	5	1.85	0.8	175	270	2.4
"magic tee"	$H_{10(10)}$	$2.5 \cdot 10^4$	25	39	3.2	530	1060	9.6	3.7	0.8	175	270	4.8

At given lengths of the two cavities L and 2L both systems have practically the same calculated gain factor and form pulses of equal widths. But the system with "magic tee" geometry, fig.1b, can provide two fold increase of the limiting power level due to its storage volume which is large than H-tee cavity's volume by factor of two.

Table 1 presents main calculated parameters of both systems made from standard rectangular waveguides and fed by a microwave pulse of 3 μs width. The cavity lengths were taken 40 cm and 80 cm respectively and they corresponded to the RPC output pulsewidth ~4 ns.

Here Q_0 – intrinsic quality; M^2 – RPC amplification factor; P_{in}, P_t, P_0 – power values of input pulses, traveling wave in a cavity and output pulses respectively; W_{in}, W_s – energy of input pulses and stored in a cavity; ω_s – stored energy density; E_W, E_V – amplitude microwave E-field values on cavity walls and in a volume respectively; V – cavity volume.

Table 2 presents similar parameters for same designs but made from circular waveguides of the diameter 90 mm.

This diameter exceeds a little the cut off one for E_{01} mode and later on the waveguide was used in experiments.

Comparison of data presented in Table 1 and 2 shows more than two fold exceeding of circular cavity RPC energy parameters over similar parameters of rectangular cavity RPCs.

3. Procedures and experimental equipment

Experimental setup contained the magnetron generator, input feeding line, RPC and output line. The magnetron produced microwave pulses of ~(0.8-2.65) MW pulse power and 3 μs pulsewidth at the carrier frequency 2800 MHz. The input feeding line was formed by a phaseshifter, calibrated directional coupler and

circulator with its own phaseshifter and matched load in the reflected signal arm. The circulator and RPC were separated by an air tight microwave transparent window. For energy storing the circular cavities with lengths 375 mm and 750 mm and diameter 90 mm were used. The working modes were $H_{11(5)}$ and $H_{11(10)}$ respectively and measured intrinsic Q-factors $2.3 \cdot 10^4$ and $2.4 \cdot 10^4$. The energy dumping element in the RPC short cavity L = 375 mm was interference switch designed as either the circular waveguide H-tee or the symmetric four – port H-plane junction and in the longer cavity L = 750 mm as the magic tee junction. The external above of the above mentioned symmetrical cavity is shown in fig.2. The output line contained the calibrated directional coupler, matched load and was separated from RPC by an air tight dielectric window. An insulating filling gas in cavities was nitrogen sometimes with admixture percentage of SF_6 ~(2-3)% at excessive pressure (4-6) bar. The input and output lines were filled by pure SF_6 at the excessive pressure (2-2.5) bar.
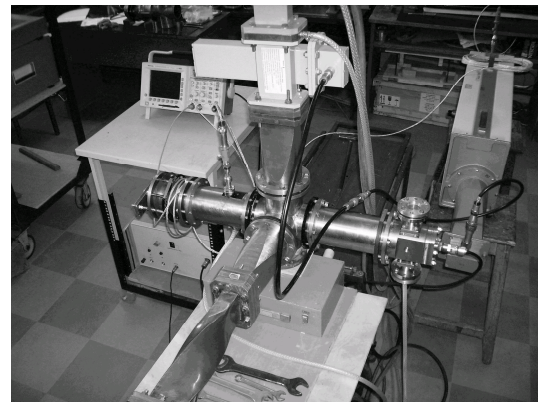

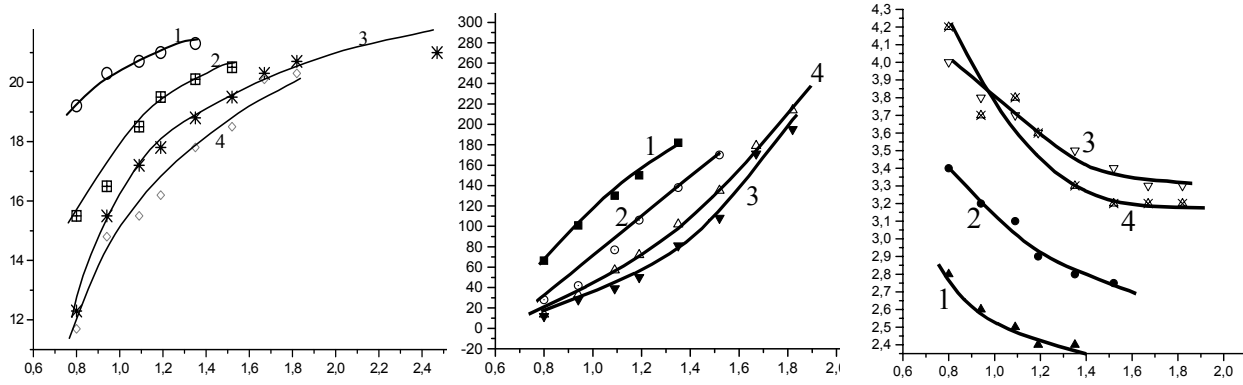Fig.2. External views of the RPC storage symmetrical cavity with magic tee as an input – output element.

Fig.3. Plots of M^2, P_0, t_0 as functions of Pin for the output elements as a H-tee (plot 1), for the four port H-plane junction (plot 2) and for magic tee (plot 3 and 4). Plots 3 for the cavity filling with pure nitrogen and 4 for the SF_6 admixture percentage 3%.

The tests consisted in determination of the amplification factor, output power and output pulsewidth as functions of the input power up to its value which initiate steady breakdowns in a cavity. These relationships obtained experimentally shown that the commutated power level is $P_t/2$ in the H-tee switch, $P_t/4$ in four port H-plane junction, $P_t/4$ in the magic tee and they allow to choose the most suitable switch configuration for obtaining maximum output power value.

4. Experimental results

At the beginning the limiting power level in the circular cavity intended for storing was determined. The cavity operated on $H_{11(5)}$ mode. The input power level when the breakdown began in the cavity was ~1.9 MW at the optimum input coupling factor $\beta \approx 1.64$ and nitrogen pressure in the volume ~6 bar. Estimated P_t value corresponding to $P_{in} \approx 1.9$ MW at the optimum input coupling exceeded 550 MW. Then this type of a cavity was assembled with the circular H-tee which side arm had one or two half-wavelength space variations. It was established that the tee reduced the power value by a factor 0f 1.5, i.e. it was 350-370 MW. The tee reduced the amplification factor of the storage system down to 23 dB at one half-wavelength variation in the side arm and 22 dB – at two variations. The ratio of the factor values is approximately equal to the ratio of corresponding total storage volumes.

It was also ascertained that the commutation in a circular waveguide was not effective. The interference switch opened incompletely and pulses formed at the output had a low power value and a width considerably exceeding the wave double traveling time along the cavity. For this reason during following experiments the commutation proceeded in the section of a rectangular waveguide 72×34 mm². The section was connected to the H-tee arm or to one of the magic tee symmetrical arms via a circular-rectangular waveguide transition.

The plots of the amplification factor M^2, output power P_0 and output pulsewidth to as functions of the input power are presented in fig.3.

The figure shows that at the same limiting commutated power level the output power P_0, M^2 and t_0 depend on the interference switch configuration. At that switched power values in RPCs with H-tee and four port junction are comparable and their maximum values are close to P_t values. In the RPC with four port junction the values M^2 and P_0 are smaller than in the H-tee RPC at the same P_{in} values. It is attributed to the side tee arm having bearing on the cavity gain and to the switched power level determining losses in the switch. The figure shows the lowest switched power is in RPC with the magic tee type of a switch and this RPC shows promise as a one allowing to obtain microwave pulses of the power exceeding 0.3 GW.

5. Conclusion

So the investigation showed that some of proposed and developed designs of RPC circular storage systems are promising for increasing the limiting output power level.

References

[1] Yu.G.Yushkov, V.A.Avgustinovich, S.N. Artemenko, V.L.Kaminsky. *in Proc of the Int Workshop*. Nizhny Novgorod, 1996, p.p.911-925.