CASCADE INTERFERENCE SWITCHES IN ACTIVE MICROWAVE COMPRESSORS*

S.Gorev, S.Artemenko, V.Avgustinovich, V.Igumnov, V.Kaminsky, S.Novikov, Yu.Yushkov#,
Tomsk Polytechnic University, Tomsk, 634050, Russia

Abstract

The switching element is usually located in the area of maximum electric field strength and the desire to put it in the area of lower field strength, but keeping the same efficiency and steadiness, of operation is quite understood. Presumably a cascade switch might provide the required way of operation. Two designs of cascade switches were examined. The first one was formed by waveguide tees connected in a way when a direct input arm of a next tee is connected to a side arm of a preceding tee. The second was a set of tees connected in series through their direct arms. It was shown that the considerable decrease of the switched power value and the increase of the output power and stability of the output pulse parameters can be provided.

INTRODUCTION

Requirements applicable to high power microwave sources are diverse. The sources in particle accelerator technique should have high efficiency, beside high pulse power values, steady phase and oscillation frequency and also rectangular envelope of output pulses. The possibility of meeting most of requirements in resonant microwave compressors [1] is strongly influenced by operating quality of the switch controlling the coupling between a cavity and a load and being, factually, a device of energy extraction. Precisely this device determines the output power level, repetition rate and steadiness of output pulse parameters. Taking strict requirements for switch operation into account it is one of the most troubled elements of a compressor. The trigatron type of a gas-filled microwave switch is usually used as the energy extraction device. Its electric strength is normally lower than one of the cavity volume as it is located in an area of high electric field strength. Therefore the electric strength of the switch determines the compressor limiting output power and steadiness of output pulse power.

The way of a power increase and output pulse steadiness improvement when the energy is extracted through the H-tee waveguide interference switch is considered in the report. The main idea of the element operation is that the switched power is distributed between several switches connected by a certain manner [2,3]. The cascade of tees connected as "side arm – direct arm" and series connection "direct arm – direct arm" may serve as main designs. Conditions enabling the considerable electric field strength decrease in arms of the switching tees along keeping field strength in the volume of the storage cavity are considered as well.

CASCADE OF TEES IN SIDE ARM

In the cascade of tees in the side arm of the switch a direct arm at each sequential tee is connected with a side arm of the proceeding one. Other direct arms of tees are short circuited. The switching arm is the side short circuited arm of the last tee. In this arm the microwave switching gap is located at quarter of the waveguide wavelength from the short circuiting end plate. Input direct arms of the tees have lengths equal to half wavelength in a waveguide and output short circuited ones – quarter of the wavelength. This configuration of tees provides mode "closed" to the switch. The tees are opened in sequence starting with the lost tee. Once the microwave switch gap for the lost tee is closed this tee is getting opened and the half wavelength of its input arm changes into the quarter wavelength of the total section of input direct arms. This results in sequential opening of all tees.

The power decrease is obtained due to matching each tee from the side arm. It is well known the power in the side arm in tees of this type is half as much as the power fed by the direct arm [4]. This means the switched power is decreased by the factor of 2^3, which is equal to eight times, when three tees are used in the circuit design.

The main switch characteristic – the transition attenuation in storage and extraction modes of operation and the wave amplitude amplification in the cavity volume and the side tee arm of the storage mode – can be easily obtained by using of scattering matrix method. The results of calculation are presented as plots on Fig.1.

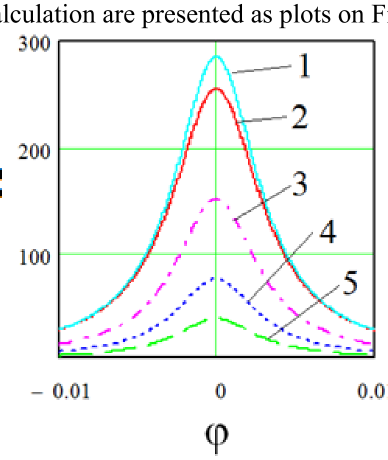

Figure 1: wave amplitude amplification A in the cavity volume and side arms of tees against the phase shift at discharge gap operation.

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#yuyu@tpu.ru

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Following marks are used in Fig. 1: 1 – cavity amplification factor with the ordinary switch; 2 – three sequential tee switches; 3,4,5 – amplification in the volumes of side arms of consecutive tees. The curves are plotted for the compressor tested experimentally with the attenuation constant along the cavity $\alpha \approx 1.5\times10^{-3}$ and for other elements 5×10^{-4}. The attenuation constant values here derived from the Q-factor value determined experimentally. As the comparison of curves 1 and 2 shows the amplification of the cavity with the ordinary switch is higher than one for the cavity with the cascade switch by 0.5dB. The reason of the difference is the additional energy losses for field excitation the cascade of tees. Obviously the cascade switch is suited in a greater degree for compressors with cavities of large volumes. The plots of Fig.1 prove that the switched power can be decreased by the factor of 2^3 in the switched combined of three tees and so, if the amplification in the cavity volume is 24dB, the amplification in the switching tee arm does not exceed 16dB.

The experimental tests were made with the microwave S-band compressor at the operational frequency f_0 of 2800MHz. The energy was extracted through different interference switches – through the ordinary switch with one tee only, through cascade switches with two and three tees. The tees were made of circular waveguides of 90mm cross section diameter. The copper cylindrical cavity with the diameter of 120mm and length of 55cm was used as an energy accumulator. The cavity was matched with the switch by the smooth matching transition. The total length of the cavity was 710mm. The working oscillation mode was $H_{11(8)}$, its measured intrinsic Q-value Q_0 was 3×10^4, the estimated time T_1 of H_{11} wave mode round trip along the cavity was about 5ns. The maximum estimated amplification factor G of the compressor with the output pulse width equal to T_1 was $G = Q_0/2\pi f_0 T_1 \approx 25$dB. Two perspectives of the external view of the microwave compressors with the two tees incorporated into the switch by connecting to side arms are shown in Fig.2.

Figure 2: Microwave resonant compressor with the cascade switch based on two H-tees in side arms.

The microwave magnetron generator with the pulse power of 0.8..2MW and the pulse width of 3μs was used as a source of input pulses. The estimated efficiency of storing reached 0.47 and the amplification factor 24.5dB. So the estimated maximum output power of the compressor was 480 MW at the output pulse width of 5ns. The electric field strong in the switching arm of the ordinary switch was close to the value 185 kV/cm. In the cascade switch with two tees it decreases down to the value 130 kV/cm and with three tees – down to the value 90 kV/cm.

Before the characteristics of the cascade switch were determined the pilot experiment with the compressor including the ordinary switch was made. The blown through quartz tube was used to confine the discharge area of the microwave switch. The tube was positioned diametrically along the electric field line of the working H_{11} mode and had the triggering spark gap at one of the ends [5]. The compressor with such a switch provided pulses of 300MW pulse power at the amplification factor 22dB and pulse width of 4.8ns. The typical envelope of the output pulse is presented in Fig.3. When the tube was filled with argon steady spontaneous breakdowns occurred at the input pulse power of 1MW and corresponding output power of 150MW. The occurrence of steady spontaneous breakdowns was the sign of reaching the limiting working power of the switch.

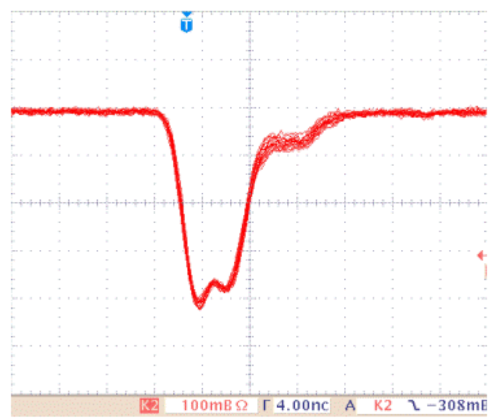

Figure 3: Oscillogram of output pulse envelopes of microwave compressor with the ordinary switch.

There were three stages of experimental tests of the cascade switch. The first stage was investigation of the tee cascade when tees were mismatched from directions of the side arms. The wave power values in the storage volume and the switching arm are practically equal for this type of design. The tees wave matched from the direction of side arms at the second stage but that mismatched the compressor output. The third stage involved matching the compressor output line with the cascade switch having tees matched from the directions of side arms. That required installing the additional matching element at the output. The principal result of the experiments is presented by the oscillogram in Fig.3 displaying the figure of output pulse envelope of the compressor with the two tees switch. The amplification was lower than 21dB and that is 1dB less than the amplification value of the compressor with an ordinary switch. But the discharge area of the tube was filled with argon only at the excess pressure at 0..0.5bar, the input

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pulse power could be increased to 2MW, the output pulse power reached 250MW and all that proved the decrease of the switched power and potential opportunity for the further output power increase.

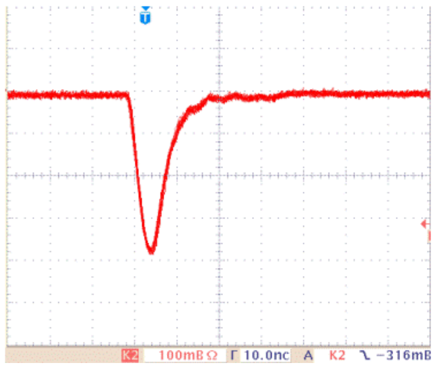

Figure 4: Oscillogram of output pulse envelopes of microwave compressor with the cascade switch including two tees.

The three tees cascade switch was tested at the final stages of the experiments. The experiments exhibited the stored energy exerted the noticeable effects on the output parameters such as steadiness, shape, pulse width and amplitude. So it should be perspectives of these type of switches in microwave compressors with big volume cavities.

SIERIES DIRECT ARM CONNECTION

Experimental studies of the compressor with a serial cascade switch were performed at the same laboratory bench. The difference was only in design of the cascade switch. The cascade of two tees was used. External view of the compressor with the switch is presented in Fig.5.

Figure 5: External view of the cascade with "direct arm – direct arm connection.

The formation of two types of pulses due to precedence in acting of switches was observed. One of the switches was controlled by external triggering, the other switch acted spontaneously. Therefore, in both cases, the main pulse is usually preceded by a pre-pulse. The prepulse associated with either energy extraction of the waveguide section between the tees when the second switch was externally triggered or by leakage of the second tee and the delayed of starting of spontaneous breakdown this tee when the first tee switch is controlled. This is the reason the main pulse is shorter in the first case and has higher power while the second is longer. Alternating triggering tees alternately generates pulses of both types. When the spontaneous breakdown formation time coincides with the transmission time of the line between the waveguide tees the output pulse is short and has maximum amplitude. Significant prepulse amplitude due to the comparability of the lengths of the side shoulder tees and a segment of the waveguide between the tees with long storage cavity. A consistent cascade switches allowed to increase the working capacity of the compressor switched in argon in half, bringing it to a level of about 150 MW. A lower power level compared to the power compressor cascade tees lateral shoulder due to the use of the cascade tees not approved by the lateral arm, and energy losses due to the pre-pulse. To reduce losses in the pre-pulse is necessary to use a larger cumulative cavity.

CONCLUSION

Possibility of making the output parameters higher in the microwave compressor with the energy extraction through the waveguide H-tee was proved. Practically it can be brought about by making the switching side arm as a cascade of H-tees. This design is especially effective in compressors when the energy extraction period is bigger than the time of wave travelling along the storage microwave structure. The cascade switches could be useful for compressors with solid state switches which level of the switched power is considerably lower than one of the gaseous switches and electron beam switches. It is seems quite possible to decrease the switched power to the level acceptable for a semiconducting switch. The cascade switches will be functionally operative if they are made of oversized tees [4] or in the figure of a packet of standard tees with the oversized switching arm [5].

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