Technical Physics, Vol. 45, No. 11, 2000, pp. 1475–1477. Translated from Zhurnal Tekhnicheskoĭ Fiziki, Vol. 70, No. 11, 2000, pp. 105–107.

RADIOPHYSICS

Energy Extraction from an Oversized Cavity through a Package of Interference Switches with Summation of the Output Signals

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Received December 30, 1999

Abstract—It was shown experimentally that the pulse power output of a resonant microwave compressor with an oversized cavity and an interference switch used for energy extraction could be increased using a package of interference switches with summation of the output signals instead of a single switch. The use of two switches for energy extraction provided an almost twofold increase in the output signal power and a corresponding (almost twofold) decrease in the signal duration. It is shown that energy extraction through four switches with signal summation is possible. © *2000 MAIK "Nauka/Interperiodica".*

1. It is well known [1] that the density of electromagnetic wave power flux through waveguide transmission lines with gas insulation can reach 1–5 MW/cm^2. Therefore, the traveling wave power in oversized cavities with gas insulation and a cross section of ~10^2–10^3 cm^2 can reach 0.1–1 GW. The use of such cavities in resonant microwave compressors holds much promise. In addition to the high power of the traveling wave in the oversized cavity, resonant microwave compressors have advantages such as simple design, rather low weight, small dimensions, and the possibility of operation at a pulse repetition rate exceeding 1 kHz [2].

However, the lack of effective methods and devices for rapid energy extraction from a capacious energy storage is one of the main obstacles to the development of compressors on the basis of oversized cavities. The best known device for energy extraction (an interference switch based on rectangular waveguide tees [3]) does not provide sufficiently rapid energy extraction because of rather loose coupling between the tees and a capacious energy storage. So far, the search for more effective methods and devices for energy extraction has not met with any considerable success [4, 5].

The results of the well-known parallel compression experiment should be noted in this context [6]. In this experiment, energy was extracted from two synchronously excited resonant microwave compressors. Then, the output signals from the two compressors were summed up. The results of this experiment thus provide hope that the problem of rapid energy extraction from oversized cavities can be solved through the use of several identical switches for synchronous extraction of energy. It can be easily shown that the total peak power P of the output signal is determined in this case by the equation

$$P = nP_1 = n\beta_1 P_2/M_0^2, \qquad (1)$$

while the signal duration τ is

$$\tau = \tau_1/n \approx TM_0^2/\beta_1 n, \qquad (2)$$

where n is the number of switches; P_1 and τ_1 are the peak power and duration of the output signal for a single switch, respectively; β_1 is the switch–cavity coupling factor for a single switch; and P_2 and M_0^2 are the traveling wave power and power gain provided by the cavity, respectively.

As seen from Eq. (2), the number of switches providing maximum rate of energy extraction (i.e., extraction within the time interval comparable to the cavity round-trip time T) is determined by the expression

$$n \approx M_0^2/\beta_1. \qquad (3)$$

The typical power gain M_0^2 provided by oversized resonators is approximately 10^3, whereas the attainable switch–cavity coupling factor β_1 is about 10^2. Thus, approximately ten switches are required to provide the maximum rate of energy extraction. According to Eq. (1), the total output signal power P is comparable in this case to the power of the traveling wave in the cavity.

The goal of this work was to describe the results of experimental study of synchronous energy extraction from an oversized 3-cm-range cavity through two and four switches with further summation of the output signals.

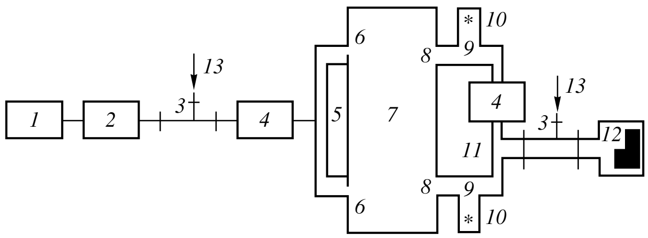

Fig. 1. Diagram of the experimental setup used for studying synchronous energy extraction from an oversized cavity through two interference switches.

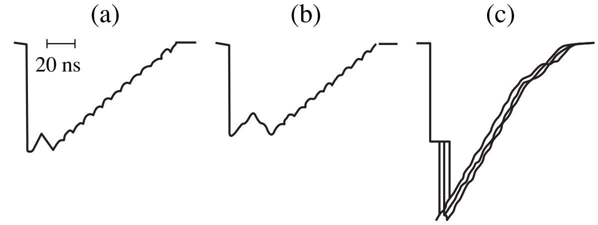

Fig. 2. Output pulse envelopes in the cases of (a, b) separate energy extraction through each of the switches, and (c) synchronous energy extraction through the two switches with further summation of the output signals.

2. A cylindrical cavity 90 mm in diameter and 200 mm in length was used in the experiment. A cavity operating at a frequency of 9.28 GHz was tuned to the $H_{01(11)}$ oscillation mode. To decrease the effect of intermodal interference at the coupling windows, the cavity was excited through two windows in one of the cavity lids. The windows were arranged on the same diameter at a half-radius distance from the center of the lid. The power from a microwave generator was delivered to the cavity through rectangular waveguides via a matched *E*-tee (Fig. 1). The intrinsic *Q*-factor of the cavity without switches was about 10^5.

The connection of two more waveguide switches to the other lid of the cavity through coupling windows with diameters of 10 mm (these windows were also arranged on the same diameter at a half-radius distance from the center of the lid) reduced the *Q*-factor of the system. The reduction in the *Q*-factor depended on the mutual arrangement of the input and output windows and the reach of the arm of the switches. To minimize the reduction in the *Q*-factor, the optimum reach of the arm was selected, and the windows were placed in the same longitudinal cross section of the cavity. Thus, a *Q*-factor value of $\sim 7 \times 10^4$ was attained. Optimization of the reach of the arm also provided the identical action of the separately opened switches and additive action of the switches during their synchronous opening. In tuning the system with two switches, the basic challenge was to select an optimum reach of the input arm and ensure equal field intensities in the switches. To assess the accuracy of the field intensity equalization, the signals at the output of switches with known coupling losses were compared in the amplitude accumulation mode. It was found that the field intensities in the switches were equal to each other with an accuracy of ~25%.

3. In the high-power operation mode, the system was powered by a magnetron generator with an output pulse power of ~60 kW and a pulse duration of ~1 μs. The diagram of the experimental setup used for studying synchronous energy extraction through two switches with further summation of the output signals is shown in Fig. 1: (*1*) microwave generator, (*2*) circulator, (*3*) directional couplers, (*4*) phase shifters, (*5*) matched waveguide *E*-tee, (*6*) input coupling windows, (*7*) oversized storage cavity, (*8*) output coupling windows, (*9*) interference switches, (*10*) spark gaps, (*11*) summing waveguide *H*-tee, (*12*) matched load, and (*13*) detector heads.

Synchronous operation of the switches was provided by applying high-voltage pulses from the same source to the gas-filled spark gaps of the switches. This induced microwave breakdowns in the switches. The output signals were summed up using the waveguide *H*-tee.

Oscillograms of the output pulse envelopes, obtained in the cases of separate energy extraction through each switch and synchronous energy extraction through the two switches with summation of the output signals, are shown in Figs. 2a–2c, respectively. As seen from Fig. 2, the output pulse duration in the case of energy extraction through one of the switches, the other one being turned off, was 60 and 80 ns for the first and second switches, respectively; in the case of synchronous energy extraction through two switches with further summation, the output pulse duration was ~35 ns, while the time spread of the signals to be summed up did not exceed 10 ns. The gain in the cases under consideration was 8, 7, and 10 ± 1 dB, respectively. Thus, synchronous extraction of energy provided almost a twofold decrease in the output pulse duration and a corresponding (almost twofold) increase in the summed up signal power.

4. The results of experimental study of energy extraction from the cavity through a package of four switches are similar to those considered above. As in the case of two switches, tuning of the system with four switches consisted in selecting an optimum reach of the arm, equalizing the field intensities in the switches, and determining optimum mutual arrangement of the input and output windows. In the cases with both two and four switches, the optimum reach of the arm was found to be approximately a quarter-wavelength. The output windows were arranged on two mutually orthogonal diameters at angles of 45° with respect to the diameter parallel to the line passing through the centers of the input windows. Upon tuning, the intrinsic *Q*-factor of the system with four switches was $\sim 6 \times 10^4$.

It should be noted that synchronous energy extraction through four switches with a further summation of signals could be performed even in the case of a considerable (two- to threefold) difference between the field intensities in the switches. In this case, however, an increase in the time spread of the summed up pulses was observed, while the amplitude and duration of pulses at the output of the switch with minimum field intensity varied with time. This was due to the fact that this switch came into action last, when the majority of energy had already been extracted through the other switches. Summation was performed separately for two pairs of the switches. The fact that the signal duration at the output of a given switch decreased as the other switches were sequentially turned on was used for monitoring the extraction synchronism.

It should also be noted that the process of energy extraction from the compressor through four switches was not completely additive. The signal amplitudes at the output of synchronously operating switches differed from the output signal amplitudes obtained in the case of the isolated operation of the switches. Presumably, this was caused by the switching-induced disturbance of the field in the cavity and corresponding changes in the switch–cavity coupling factor. Therefore, in contrast to energy extraction systems with a single switch [7], the optimum reach of the arm for systems with energy extraction through a package of switches is a quarter-wavelength. In this case, the symmetric arrangement of the switches about the cavity axis allows strong intermodal interference near the coupling windows to be compensated, whereas the invariability of the field structure in the cavity in changing from the storage mode to the extraction mode provides stability of the switch–cavity coupling.

5. Thus, it was shown that synchronous energy extraction from an oversized cavity through a package of interference switches allowed the energy extraction rate to be increased. Synchronous energy extraction with further summation of the output signals provided an increase in the total output signal power proportional to the number of switches, whereas the total output signal duration was found to be inversely proportional to the number of switches. In our opinion, this method for increasing the extraction rate can be used not only in conventional microwave compressors, but also in self-excited oscillators with pulse compression in the oscillatory system. These oscillators have relatively low Q-factors. Therefore, to provide effective operation of an oscillator in the compression mode, the extraction time should be comparable to the oscillatory-system round-trip time. It is also our opinion that compressors with energy extraction through a package of switches can be used in phased arrays.

ACKNOWLEDGMENTS

We are grateful to V. L. Kaminskiĭ for expert assistance. This work was supported by the Russian Foundation for Basic Research, project no. 97-02-16461.

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Translated by K. Chamorovskiĭ