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PULSED PERIODIC GAS DISCHARGE IN A CHAMBER WITH A HELMHOLTZ RESONATOR

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It was pointed out in [1, 2] that thermal energy released in a gas discharge chamber of a pulsed periodic CO_2 laser with a Helmholtz resonator might be used to excite nonlinear oscillations in the resonator, and consequently to realize wave self-pumping of a gas mixture. This suggestion was based on practical realizations of pulsed air-breathing jet engines and a pulsating combustion chamber with a Helmholtz resonator [3, 4], and also on theoretical estimates and direct numerical experiment [1, 2]. Since the flow discharge of a pulsed periodic CO_2 laser requires rather uniform parameters of the gas in the discharge chamber, relatively low specific energy inputs etc., the conclusions in [1, 2] require direct experimental verification. In the present article we report preliminary results of such an experiment.

The experiments on wave pumping of a gas mixture by exciting nonlinear oscillations in a Helmholtz resonator were performed on the arrangement shown schematically in Fig. 1. The $0.5 \times 0.3 \times 0.3$ m sealed chamber 1 contained a Helmholtz resonator with a rectangular neck 7, 0.035×0.07 m in cross section and 0.3 m long, and the 1000-cm^3 vessel 9. The discharge chamber 14 with electrodes 5 and 15 was located in the neck of the resonator in the immediate

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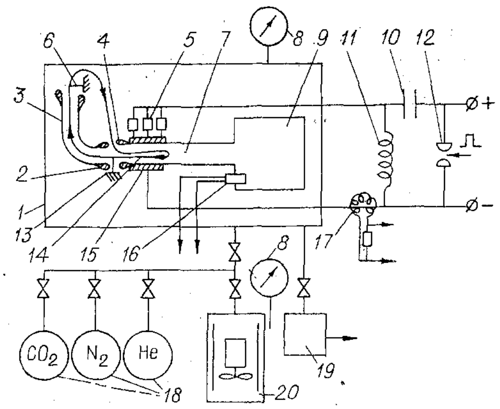

Fig. 1

vicinity of its entrance. At some distance from the mouth 4 was the gas collector 2 (not used in all the experiments) connected with the reversing tube 3. A sensitive element 6 in the form of a Lavsan film ~10 μm thick was mounted in the exit section of the reversing tube. The same kind of sensitive element 13 was placed at the mouth exit. The volume of the discharge chamber was ~84 cm^3, the interelectrode distance was ~3.5 cm, and the length of the electrodes along the neck was ~4 cm. The ratio of the area of the smallest cross section of the mouth to that of the neck was varied, and was 40% in the optimum case.

The beginning of the circulation of the gas (in Fig. 1 the approximate path of the gas is shown by the closed line with arrows) could be determined by the deflection of the sensitive film 6. The mass of gas drawn into the neck of the resonator through the gap between the mouth and the gas collector was determined by measuring the amplitude of the pressure fluctuations of the gas in the vessel with the pressure indicator 16. A uniform gas discharge was obtained by employing an electrode system with a pin cathode 5, each electrode of which was connected to the working capacitor 10 through a type TVO-0.5 ballast resistor with $R = 480\ \Omega$. The electrode pins were spaced ~3 per cm^2.

The power supply system included a capacitor, an inductor 11, and a type TGI-1000-25 thyratron 12. The current was measured with a Rogowski loop 17. The gas supply system consisted of tanks 18 of CO_2, N_2, and He, a forevacuum pump 19, and a mixing chamber 20. The pressure in the vacuum and mixing chambers was measured with the vacuum gauge 8.

The repetition rate of the discharge pulses was set by a G-5-54 oscillator. The capacitance of the capacitor was varied from 10^{-8} to 1.5×10^{-8} F, depending on the pressure of the gas mixture. The experiments were performed for gas mixture pressures from 5×10^3 to 1.1 10^4 Pa. Air and a mixture of air and helium in the ratio 1:1 were used as the working gas. The width of the current pulse was $\sim 5 \times 10^{-7}$ sec.

The results presented below were obtained with an air—helium mixture at a pressure of $\sim 6 \times 10^3$ Pa. The natural frequency of the acoustic system, including the mouth, neck, and vessel, was ~180 Hz.

First the natural frequency f_0 of the acoustic system was determined experimentally by using an electrodynamic radiator located on one wall of the vessel, and a pressure indicator.

The experiment was begun by filling the chamber with a gas mixture of the specified composition. The G-5-54 oscillator set the triggering frequency of the thyratron equal to the natural frequency f_0. Then the voltage across the working capacitor was increased gradually. Starting from a certain voltage across the interelectrode gap, a constricted discharge (Fig. 2) was initiated. This discharge was constricted to the middle of the anode in the form of a narrow band across the axis of the neck. The sensitive films began to vibrate, and film 6 was displaced from its neutral position in the direction of the assumed motion of the gas indicated by the arrows in Fig. 1. With a further increase in voltage the contraction became more pronounced, and the amplitude of the vibrations of film 13 increased. Starting from a certain threshold voltage across the capacitor, the character of the discharge changed abruptly: It became uniform over the whole volume of the discharge chamber, a steady hum arose, strong acoustic vibrations were produced, and the displacement of the film from its neutral position was increased. Wave pumping of the gas began with complete venting of the discharge chamber. A photograph of the discharge under these conditions is shown in Fig. 3.

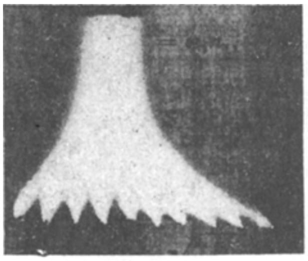

Fig. 2

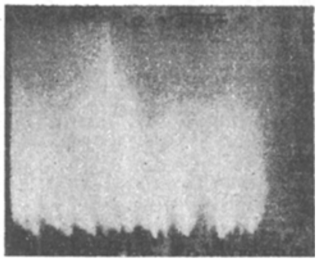

Fig. 3

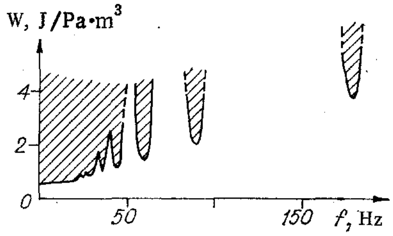

Fig. 4

A further increase in the voltage across the capacitor had practically no effect on the nature of the gas discharge, but the amplitude of the pressure fluctuations of the gas in the vessel increased. When the repetition rate of the gas discharges was changed from the natural frequency f_0 by ± 5 Hz, a constriction of the discharge (Fig. 2) was again observed. Films 6 and 13 returned to their neutral positions.

Reliable operation of the device (without constriction of the discharge) was obtained at all frequencies $f = f_0/n \pm 5$ Hz, where n is an integer, and at all intermediate frequencies a constricted discharge was observed (Fig. 2) over the whole range of variation of the voltage across the capacitor. The characteristics of the operation of the device noted above are illustrated in Fig. 4, where the shaded regions correspond to a uniform discharge (Fig. 3), and the unshaded region to a constricted discharge (Fig. 2). The magnitude of the threshold voltage at frequencies $f = f_0/n$ at which the constriction of the discharge disappears decreases with increasing n.

The mean square flow velocity in the discharge chamber can be estimated from the obvious relation $\tilde{u} \approx 2l\alpha f$, where l is the length of the discharge chamber along the flow, and $\alpha \geq 1$ is a factor which depends on the rate at which fresh gas is sucked into the neck. In the experimental device $l = 0.04$ m and $\alpha \sim 2$. Thus, for $f = f_0$, $\tilde{u} \approx 25$ m/sec. The average flow velocity in the neck was also determined from the relation $\tilde{u} \approx 4mf/\rho F_n$, where the mass m of gas sucked into the vessel during a period is determined from the amplitude of the pressure fluctuations in the vessel, ρ is the density of the gas, and F_n is the cross-sectional area of the straight section of the neck.

Thus, we have obtained wave pumping of a gas through a discharge chamber (flow velocity ≈ 25 m/sec) for admissible specific energy inputs in a rather large-scale device. In our opinion this indicates a practicable way of producing pulsed periodic CO_2 lasers operating on this principle.

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