PARAMETRIC ULTRASOUND GENERATOR

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Submitted 25 February 1972
ZhETF Pis. Red. 15, No. 8, 456 - 458 (20 April 1972)

The development of a parametric generator for acoustic oscillations is not only of practical but also of fundamental interest, since coherent sound is generated in such a system by sound, without participation of any electric (as in the case of generation in piezosemiconductors [1]) or electromagnetic (as in Mandel'shtam-Brillouin scattering [2]) energy sources. A theoretical analysis of the parametric interaction of acoustic waves was carried out in a number of papers [3 - 5]. The practical realization of such effects at selected frequencies (specially in liquids or gases), however, is difficult because of the small dispersion of the sound waves. At the present time there are only few known experiments on parametric amplification of hypersound in solids [6, 7]. On the other hand, an experimental investigation of parametric generation in acoustics has apparently never been carried out at all.

We have constructed a parametric ultrasonic generator based on an acoustic waveguide with a liquid. The difficulties connected with the small dispersion of the medium are eliminated by using the interaction between different waveguide modes. A theoretical analysis of the interaction of waves in such systems was presented by the authors earlier [5]. We used in the experiments rectangular waveguide filled with water or alcohol, with thin (approximately 0.5 mm) brass walls, practically equivalent to free boundaries. The waveguide transverse dimensions were 3 × 2.3 cm, the end faces were covered with rigid reflectors forming a resonator 30 - 50 cm long.

The experimental setup is shown in Fig. 1. A pump signal at 84 kHz was fed from piezoceramic radiators P_1 so placed that the p_{13} mode was excited (p is the sound pressure, which is close to zero at the waveguide walls; the subscripts, as usual, denote the number of half-cycles subtended by the cross-section sides). At the chosen ratios of the transverse dimensions a and b of the waveguide walls ($b^2/a^2 = 5/3$), the synchronism conditions were satisfied at the subharmonic frequency (42 kHz) for the p_{11} mode, at which the signal was generated (degenerate parametric generation). The signal and the pump were picked up by a barium-titanate vibration pickup P_2 and fed to a spectrum analyzer.

The pump radiation power was on the order of 0.3 W/cm^2; the Mach number M produced by the pump field in the waveguide was small ($M = 10^{-5} - 10^{-4}$), and the gain of the wave over the resonator length was only 3 - 5 dB, but this sufficed for generation of a rather intense signal at the subharmonic, with an amplitude comparable with the pump amplitude. The phases of the generated signal θ_1 and of the pump θ_2, as expected, satisfied the relation $2\theta_1 - \theta_2 = \pm\pi/2$, i.e., this system can operate in principle as a phase trigger (acoustic parametron).

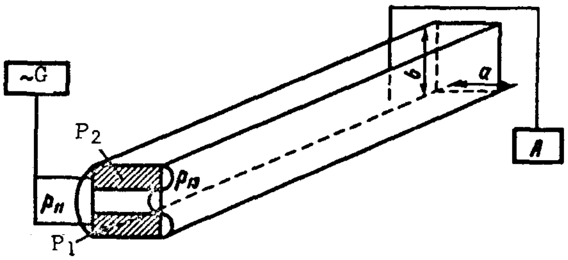

Fig. 1. General setup of experiment: P_1 - pump radiator, P_2 - vibration pickup, G - pump generator, A - spectrum analyzer.

Some results of the experiments are shown in Figs. 2 and 3. It is clear from Fig. 2 that the generation threshold corresponds to $U_p = 35$ V (U_p is the amplitude of the voltage at the radiator P_1), and in this case the Mach number is of the order of 5×10^{-5}. Saturation of the pump and of the signal in the system sets in

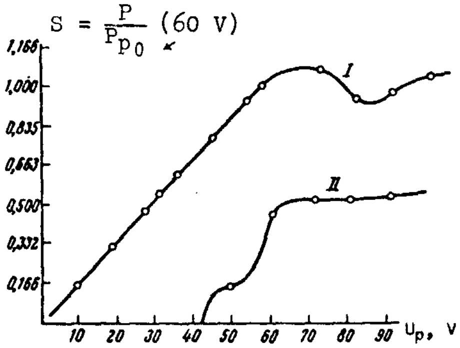

Fig. 2

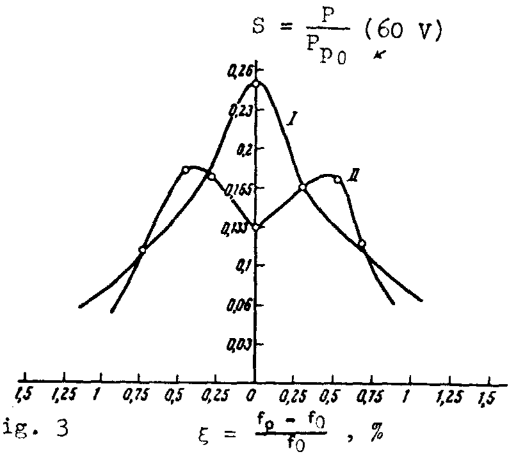

Fig. 3

Fig. 2. Dependence of the relative amplitude (S) of the pressure of the steady-state pump oscillations (curve 1) and of the generated signal (curve 2) in the resonator on the pump voltage amplitude (U_p) at the radiator input. The scale is chosen to be the amplitude of the pressure produced in the resonator by the pump at U_{p_0} = 60 V.

Fig. 3. Resonance characteristic of the system at the pump frequency (f_0 = 83.78 kHz): 1 - below the generation threshold (U_p = 3 V), 2 - at subharmonic generation.

at an amplitude above 2 - 3 times the threshold value. We can therefore conclude that in this case the oscillations are generated by drawing of energy from the pump (the reaction of the signal on the pump).

The generation band is 1 - 2% of the carrier frequency and is determined by the dispersion of the corresponding modes in the waveguide. The resonance curve of the system shows at the pump frequency a characteristic dip connected with the additional load produced by the generated signal (Fig. 3). The transient time of this process is on the order of 1 msec.

Analogous results were obtained for a waveguide filled with ethyl alcohol. In this case the generation threshold was lower by a factor 1.5 - 2, owing to the larger value of the nonlinearity parameter in the alcohol.

We note that the use of a waveguide has made it possible to realize one-dimensional wave interaction at selected frequencies, so that the length of the interaction region is limited only by the very small damping of the waves.

The authors are most grateful to V.A. Zverev for useful discussions and to V. G. Yakhno for help with the experiment.

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