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EFFECT OF THE OPTICAL QUALITY AND GAIN CHARACTERISTICS OF THE ACTIVE MEDIUM OF A HF-EXCITATION ELECTRIC-DISCHARGE AMPLIFIER ON RADIATION PARAMETERS IN THE ZONE OF APPLICATION

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The results of investigation of the simultaneous effect of the optical quality and amplifying characteristics of the active medium of a pumped-through HF-excitation CO_2-amplifier are presented. The amplitude front of the light wave was restored by the measured distributions of the small-signal gain and the phase front — from the results of processing the holographic interferograms of gas flow.

The efficiency of the majority of laser treatment processes is determined by the degree of energy concentration in the zone of application. It is known that the provision of the maximum level of energy in the course of focusing depends on the laser source output power and on the divergence of radiation. Both of these parameters are directly connected with the state of the active laser medium, with its amplifying characteristics determining the output power of radiation and the optical uniformity determining the possibility for a beam to be reduced to a spot of minimal size. In view of this it is of interest to investigate their simultaneous effect on the radiation parameters in the zone of application.

The small signal gain of the CO_2-laser active medium with high-frequency (HF) excitation depends on many factors. The most important of these are the level of energy contribution to the discharge and the gas-dynamic parameters of flow. In [1] the results of an investigation of the distribution of the gain coefficient and volumetric energy contribution in a HF-discharge are presented for a model technological laser described in detail in [2]. As is seen from Fig. 1, the gain maximum is displaced downstream practically to the discharge chamber exit. This indicates an increase in population inversion with passage of gas through the region of discharge.

The distribution of the radiation field amplitude in the exit aperture is uniquely related to the distribution of the small-signal gain K_0. In the absence of saturation, it can be calculated in accordance with the Bouguer-Lambert-Beer law. The absence of information on the transverse distribution of gain permits one to present the amplitude front in the aperture selected only in the form of a cylindrical surface (Fig. 2a). This surface is calculated on the basis of the experimentally recorded gains at a inlet gas pressure in the discharge chamber of 55 torr and a specific energy contribution of 103.3 kJ/kg (Fig. 1). Its form is characteristic of virtually all of the operational parameters investigated. In fact, the presence of near-electrode zones will yield a rather complex form of distribution of gain in the lateral direction where relaxational processes will cause a decrease in the level of gain as compared with the flow core with its possible transition into absorption.

The density nonuniformities in the discharge chamber as a result of volumetric energy contribution to a gas moving with a subsonic velocity change the character of the wave front of the radiation passing through the discharge. When the gas moves, the boundary layers on the side wall-electrodes grow. These layers are the main source of nonuniformities [3], with their level increasing downstream. In the flow core, in contrast, the gas density changes virtually linearly, causing a distortion of the type of the "optical wedge" [4] which, as is known, does not alter the divergence of radiation [5] (the phase surface for the discharge chamber is depicted in Fig. 2b). Figure 3 presents the dependence of the integral criterion of optical quality, namely, of the Shtrehl number Sh [6], on

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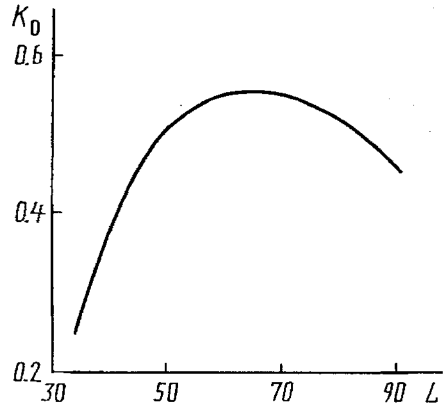
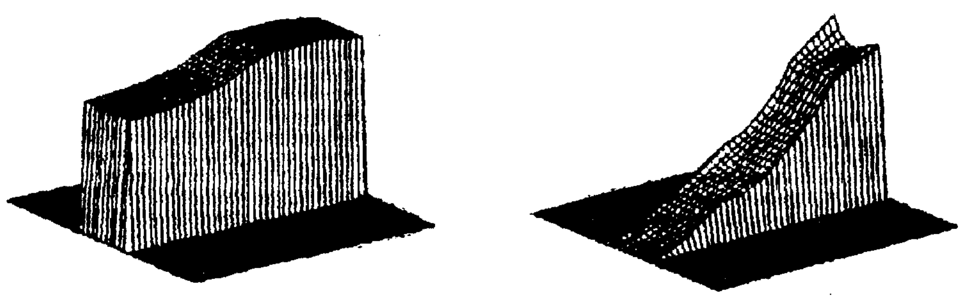


Fig. 1. Distribution of the small-signal gain downstream the discharge chamber [1]. K_0, 1/m; L, mm.



a b

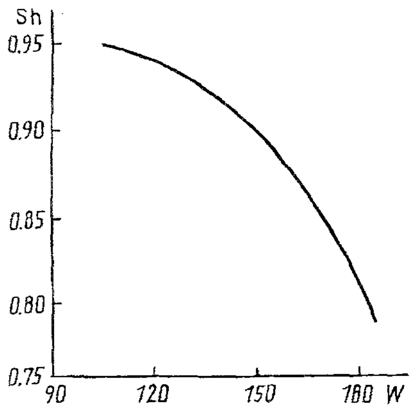
Fig. 2. Isometry of the distribution of the amplitude (a) and phase (b) of radiation when light passes through the discharge chamber.

the power of energy contribution to the HF-discharge. The graph is the result of solution of the diffraction problem for the selected aperture with the wave front recovered from holographic interferograms of flow in the discharge chamber [4] under the same condition present when the small-signal gain was determined. A tendency is clearly seen for a decrease in the optical uniformity of the active medium with an increase in the energy contribution to the discharge, which is associated with the growth of the boundary layers on the side walls.

The presence of the amplitude and phase fronts in the exit aperture restricts the use of the Sh number as an integral criterion of the efficiency of laser operation. It is more reasonable to use for this the maximum brightness (intensity) I_0 from the Fraunhofer pattern, as was done for a laser with a HF-discharge in [7]. This criterion connects both the amplifying and refraction properties of the medium; it also takes into account diffraction effects occurring when focusing radiation into a spot of minimal size with a radiating aperture of a certain configuration [6]. This makes the criterion most appropriate for optimizing the processes of laser treatment of materials.

The aforegoing results show that there are two opposite tendencies in the effect of phase and gain on the maximum intensity of radiation. The increase in gain downstream leads to the possible increase in the output power of the laser facility and, consequently, in the level of intensity in the zone of application, whereas the increase of phase nonuniformities in this very direction leads to a growth in the angle of radiation divergence and to a redistribution of the output laser energy over a larger area than the diffraction limit in the focal spot. The problem arises of finding the optimum place for the location of the axis of radiation output from the discharge chamber to obtain its maximal intensity in the zone of application and thus to ensure the maximum power in the solid angle selected.

As the initial aperture, we took the square one whose size corresponded to the height of the discharge chamber of the model laser, i.e., 30 mm. For a chamber 100 mm in length the center of aperture shifted successively in calculations downstream in the range from 15 to 85 mm. The extension of the gas medium in the direction of the optical axis was assumed to be 1 m. In Fig. 4 the calculated results are presented for the maximum brightness



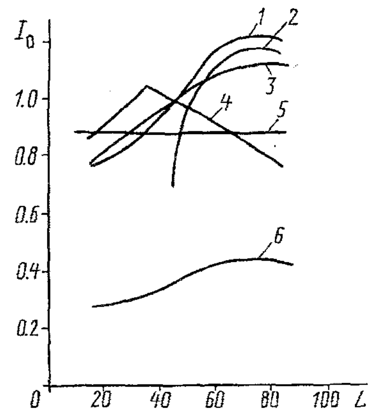


Fig. 3. Dependence of the Shtrehl number Sh on the power of energy contribution W, kJ/kg, to a HF-discharge at a pressure of 85 torr and energy contribution of 131.6 kJ/kg.

Fig. 4. Dependence of the maximum brightness of radiation in the far zone on the location of the aperture center downstream at different pressures and energy contributions: 1) 55 torr and 103.3 kJ/kg; 2) 85 and 131.6; 3) 55 and 73.3; 4) 102 and 136.6; 5) 55 and 103.3 (a three-pass scheme); 6) 55 torr and 103.3 kJ/kg (annular aperture). I_0, 10^{-6} W/m^2.

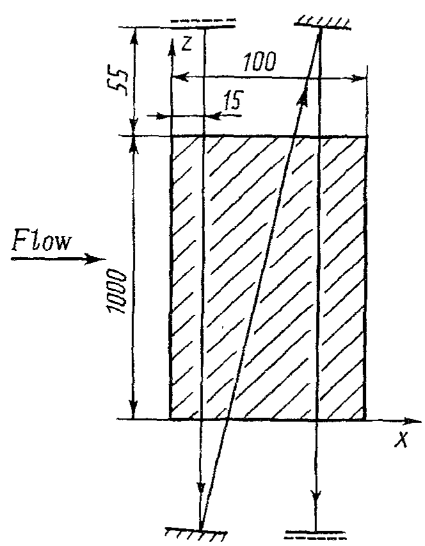


Fig. 5. Scheme of three-pass probing by a radiation beam of square cross section.

of radiation in the far zone depending on the location of the center in the aperture selected along the length of the discharge chamber. This figure also contains information about the operational parameters of the laser. For cases 1, 2, and 3, the maximum brightness of radiation is attained closer to the exit section of the chamber, i.e., at a distance of 75 mm from the beginning of the chamber to the aperture center. Comparison of the axial brightnesses of the first points of each of the graphs in Fig. 4 with the corresponding maximal values point to the possibility of a 50% increase in the intensity in the case of the optimal location of the optical axis. This fact is explained by the growth of the field amplitude along the chamber length whose net effect on the growth of the maximal brightness along the chamber length (Fig. 4) is more important than the increase in phase distortions which in turn lead to a decrease in the absolute brightness. For a given active medium of the electric-discharge laser the influence of its gain characteristics on the distribution of energy will be more substantial than of the phase characteristics and, consequently, the possibility exists for attaining the highest values of energy characteristics of a laser in the course of radiation focusing. It should be noted that the absolute brightness maximum is located in the zone where the gain coefficient (the field amplitude) attains its maximum values along the chamber length (see Fig. 2a) despite the fact that phase distortions in this zone are also maximum (Fig. 2b).

For practical purposes it is of interest to consider the effect of an annular aperture typical of a telescopic resonator with magnifying power $M = 2$. The external diameter of the annular aperture amounted to 30 mm. In Fig. 4 (curve 6) the results of calculation are given for such an aperture with the operational parameters corresponding to curve 1. The trend of the change in the absolute brightness coincides with that for a square aperture, with the only difference that the absolute value of the maximum of brightness for a ring is roughly three times smaller. This is due to the effect of the radiating annular aperture configuration which causes both a decrease in the radiating area and an increase in the angle of radiation divergence as compared with a square aperture.

We evaluated the efficiency of the three-pass scheme of radiation propagation in the active medium (Fig. 5) with the properties considered earlier. The three-pass scheme was compared with the single-pass one (Fig. 4, curve 1), with the extension over the active medium along the direction of radiation propagation being taken identical in the both cases. In the three-pass scheme the beam passed from the beginning of the chamber up to the output aperture located at a distance of 75 mm. In this case it acquired smaller values of gain and distortions as compared with a single-pass scheme for which the extraction of radiation was also made at a distance of 75 mm measured from the beginning of the discharge chamber to the aperture center where the highest amplitudes and phases were observed (see Fig. 2). The maximum brightness for the three-pass scheme will be approximately 1.4 times smaller than for the single-pass one. In Fig. 4 the level of the radiation intensity is indicated for the three-pass scheme (curve 5).

There are physical and design limitations on the increase in the extension of the medium in the direction transverse to the flow. It may therefore be advisable to use a telescopic resonator with a larger number of transits of the beam over the active medium in the zone with maximum gain located closer to the end of the discharge chamber. But then it is necessary to pay special attention to the effect of the decrease of the gain in the medium after the passage of radiation through it, since precisely this effect may suggest the use of three-pass scheme in which the beam passes successively over the entire gas-discharge chamber.

The investigations carried out showed that in an electric-discharge laser we may with good reason permit a reduction in the optical uniformity because of the increase in the energy contribution on condition that the growth in the gain ability of the active medium will lead to maximum power production. At high saturations, in contrast, the exponential character of the growth in intensity may be replaced by a linear one, but then according to calculations the tendency in the behavior of the maximum brightness at the Fraunhofer diffraction spot will remain invariant.

NOTATION

K_0, small-signal gain; Sh, Shtrehl number, i.e. maximum of normalized radiation intensity in the Fraunhofer diffraction zone; I_0, maximum brightness (intensity) of radiation in the Fraunhofer diffraction zone.

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