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RESTRICTIONS IN IMPLEMENTATION OF MULTISTAGE LASER AMPLIFIERS

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The results of a simultaneous account of the influence of the amplifying properties of an active medium of a laser amplifier and its inhomogeneities on energy characteristics in an application zone are given. An intensity is described to the approximation of linear and saturated gain. Distortions in the active medium are accounted for by the wave front dispersion. A simultaneous account of inverse indices and optical quality has allowed determination of an optimal number of amplifying stages of a laser unit providing the maximum radiation power density in the application zone.

The most workable arrangement for the design of high-power lasers is a master oscillator–amplifier combination [1]. However the requirement of optical homogeneity of an active medium restricts the amplifier length along a light propagation path. Therefore it is necessary to simultaneously analyze the influence of inverse characteristics of an active medium and the degree of its integrated inhomogeneities on energy indices of laser radiation in the application zone.

In the absence of resonance-free losses in an active medium the light intensity in an amplifier laser may be described [2] as $I = I_0 \exp(kx)$ for the linear gain and $I = I_0 + kx$ for the saturated gain. Inhomogeneities in an active medium exert an influence on the phase characteristics of radiation [1]. When light passes through the active medium with a length L_1 and a wave front undergoes distortions characterized by dispersion D [3], the energy in the central lobe of the radiation directivity diagram in the Fraunhofer diffraction zone is determined as [3]

$$W = \frac{W_{-1}^{+1}}{W_0{}_{-1}^{+1}} = \mathrm{Sh} = \exp(-D),$$

where W_{-1}^{+1} is the power fraction in the central lobe of the directivity diagram for radiation diffraction with a distorted wave front; $W_0{}^{+1}{}_{-1}$ is the power fraction in the central lobe of the directivity diagram for radiation diffraction with a plane wave front (for a square aperture $W_0{}^{+1}{}_{-1} = 0.81$, for a circular one, 0.84); Sh is the Strel number [4].

A single-pass amplifier with length L_1 with k and D for linear gain gives the following power in the far-field zone:

$$W_1 = WSI = SI_0 \exp(kL_1 - D).$$

In order to increase the output power of a laser unit with a preassigned gain of an active medium, it is necessary to increase the amplifier length along the beam or to provide a tandem (multistage) circuit including the necessary number of modules-amplifiers. If the number of stages with the length L_1 is n, then the relative power at the amplifier outlet is

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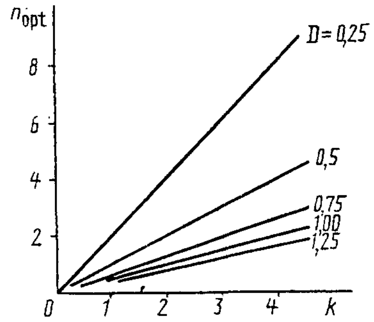

Fig. 1

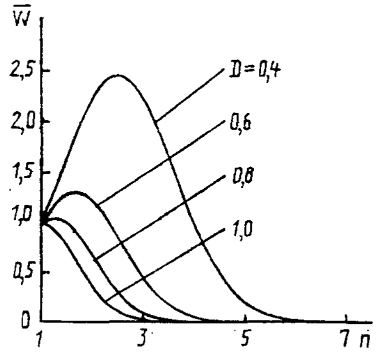

Fig. 2

Fig. 1. Optimal number of amplifying stages versus k for different dispersions of the wave front phase per unit length of the amplifier for linear gain.

Fig. 2. Relative radiation power in the far-field zone versus the number of amplifying stages at different D and L_1 = 1 m and k = 2 1/m.

$$\bar{W} = \frac{W_1}{W_n} = \exp\{(n-1)[kL_1 - D(n+1)]\}.$$

The function $\bar{W}(n)$ at $k > 0$ and $D > 0$ has a maximum at which the far-field zone will have a maximum power

$$n_{opt} = \frac{k}{\left[2\left(\frac{D}{L_1}\right)\right]}.$$

The ratio D/L_1 represents the dispersion of a radiation phase per unit length of the amplifier. Figure 1 illustrates n_{opt} versus k at different D/L_1. For instance, at $n_{opt} = 8$ and $k = 5$ the wave front dispersion per unit length of an active medium must not exceed 0.3, which corresponds to Sh = 0.73. In the case of wave front distortions behind a single amplifier with D = 1 at L_1 = 1 m for $n_{opt} = 8$, the gain in the medium must be ≈ 16 1/m.

Figure 2 shows the dependence of relative power $\bar{W}(n)$ at different D for L_1 = 1 m and k = 2 1/m. In fact this value is the efficiency of energy transfer to the application zone with an account of amplifying characteristics of the medium and its optical homogeneity.

For a saturation mode, a single-pass amplifier having length L_1 with k and D will provide the following power in the far-field zone

$$W_1 = WSI = S(I_0 + kL_1)\exp(-D),$$

while n stages of laser amplifiers will provide the relative power

$$\bar{W} = \frac{W_n}{W_1} = \frac{I_0 + nkL_1}{I_0 + kL_1}\exp[-D(n^2 - 1)].$$

In the case when the output amplifier intensity is much higher than its input value, i.e., $I_0 << kL_1$, the relation above for the relative power may be rewritten in the simplified form

$$\bar{W} = \frac{W_n}{W_1} = n\exp[-D(n^2 - 1)].$$

This function has a maximum at $n_{opt} = 1/\sqrt{2D}$, i.e., for a saturation mode the optimal number of amplifying stages does not depend on the medium gain. Figure 3 depicts n_{opt} versus D. Use of, e.g., eight modules (n = 8) in the amplifier will ensure the maximum power in the far-field zone with a wave front dispersion of not more than 0.0078 on each 1 m long module which corresponds to a Strel number of 0.9922. Figure 4 represents the plot of $\bar{W}$ versus n for different D at k = 1. An inspection of the values of $\bar{W}$ in Figs. 4 and 2 confirms that the single-pass amplifier operating in the saturation mode

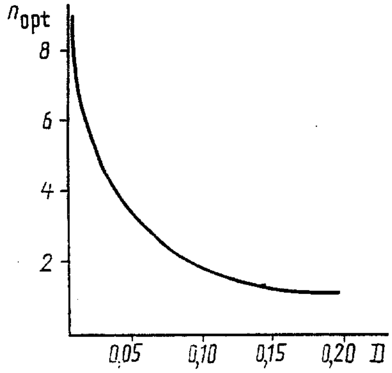

Fig. 3

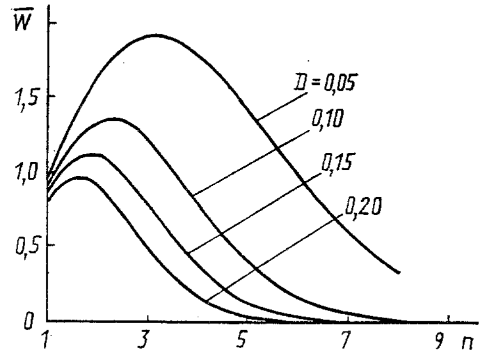

Fig. 4

Fig. 3. Optimal number of amplifying stages versus D for a saturation mode.

Fig. 4. Relative radiation power in the far-field zone versus the number of amplifying stages at different D and $L_1 = 1$ m and $k = 1$ 1/m.

requires rigorous fulfillment of the requirements of optical homogeneity of an active medium, otherwise a simple increase of the laser amplifier length will fail to result in an increase of the radiation power density in the application zone.

Thus, it is found that a simultaneous account of the inverse indices of an active medium and its optical quality allows one to determine the optimal number of amplifying stages of the laser unit to provide a maximum radiation power density in the application zone.

Using the proposed approach we consider, as an example, the active medium of a pumping dc-excited CO_2-electric discharge amplifier. The interferometric flow diagnostics and gain measurements of a weak signal have shown that the density inhomogeneities decrease the Strel number to 0.95 (with wave front dispersion being 0.05) per 1 m of the active medium, while the gain, on the average, is 0.4 1/m. If the amplifier has no saturated gain then it is reasonable to use a four-pass radiation circuit for a medium with its total length of 4 m in order to attain the maximum power density in the application zone on generation of the output radiation. Under the same conditions, the saturation will permit one to provide a maximum power density in the medium with total length of 3 m. An increase of the active medium length up to 5 m causes in both cases a decrease of power in the application zone for the linear gain by a factor of 1.05 and decrease for a saturated gain by a factor of 1.33.

NOTATION

I, intensity of amplified (brought from the amplifier) radiation; I_0, intensity of radiation entering the amplifier; k, gain index; x, amplifier length along a beam; D, wave front dispersion of radiation; W, relative fraction of radiation power in the central lobe of the directivity diagram; L_1, length of the layer amplifier; S, area of an emitting aperture of the amplifier; n, the number of amplifying stages; W_1, power in the far-field zone provided by a single amplifier; W_n, power in the far-field zone provided by n amplifying stages; n_{opt}, the optimal number of amplifying stages; $\bar{W}$, relative power in the far-field zone provided by n stages of amplifiers.

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