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THE SPACE-TIME DISTRIBUTION OF LASER EMISSION WITH GENERATION DURATION ON THE ORDER OF 1 ms AND ITS INFLUENCE ON INTERACTION WITH A SUBSTANCE

By

V. I. Aleksandrov, A. G. Solov'yev, P. I. Ulyakov

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В в	*В в*	V, v	Т т	*Т т*	T, t
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Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
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К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh^{-1}
cos	cos	ch	cosh	arc ch	cosh^{-1}
tg	tan	th	tanh	arc th	tanh^{-1}
ctg	cot	cth	coth	arc cth	coth^{-1}
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

0164

THE SPACE-TIME DISTRIBUTION OF LASER EMISSION WITH GENERATION DURATION ON THE ORDER OF 1 ms AND ITS INFLUENCE ON INTERACTION WITH A SUBSTANCE

V. I. Aleksandrov, A. G. Solov'yev, and P. I. Ulyakov

We discuss an experimental study on the space-time distribution of laser emission on glass with neodymium for three cases: free generation, regular mode, and continuous mode. The radiative energy was 100-400 J wth a duration of about 2 ms. We have studied experimentally the dependence of the specific evaporation product recoil pulse on the mean flux of radiation in the region of the threshold of appearance of the recoil pulse for iron and aluminum. Using space-time distribution data we show that at the threshold the maximum local flux (in time and in space) incident on the target has a negative value, 10^6 and $2 \cdot 10^6$0W/cm^2 for iron and aluminum, respectively.

Most of the experiments in the literature (e.g., [1]) on the study of the interaction of powerful light emission with a substance use lasers with time-and-space nonuniform emission distribution. This hinders a comparison of various experiments among themselves as well as with theoretical calculations. In the literature [2, 3, and others] there are data on the dependence of the emission on time and divergence for solid-state lasers operating in the pulsed mode. However, there is little experimental data on the nonuniformity of the space-time distribution of emission (STDE) [3-8], while only two works [3, 7] discuss such research for neodymium-glass lasers with generation duration on the order of 1 ms.

Krylov [7] showed experimentally the spatial heterogeneity of emission in the near zone with free generation. Mak et al. [3] studied features of the excitation of transverse modes in a spherical resonator. Further study along these lines is undoubtedly of interest, since STDE depends essentially on the type of laser, its dimensions, etc. In this work we experimentally study the energy STDE of a neodymium laser in the near and far zones for three different types of generation: random spike, regular spike, and non-spike (smooth) modes. On the basis of the results obtained we give an explanation of certain effects during the interaction of laser emission with metals.

The experiments were conducted using an SFR-2M high-speed camera in the scan mode with I-1070 film. Certain characteristic SFR-grams are shown in Fig. 1. The time structure of the laser emission pulse was recorded by an F-5 photoelectric cell with an OK-33 oscillograph. The divergence of the emission was estimated from the size of the light spot focused on the emission target.

In most of these experiments we used as the active laser element a round rod with diameter d = 25 mm and length l = 0.5 m. In the experiments on free generation we also used a rod with diameter d = 45 mm and l = 0.6 m. Optical pumping in all experiments was constant and considerably exceeded the generation threshold for the resonators used by us. To produce random spike generation a rod of KGSS-7 glass was placed in a plane-parallel resonator with a mirror transmission factor on wavelength 1.06 μm of T = 65 and 10%. The regular and smooth modes were produced in a resonator with spherical mirrors using the method described in [9]. Such modes in a spherical resonator were first produced in [10, 11] using ruby. Bonch-Bruyevich et al. [12] reported on the production of the regular mode on neodymium glass with a radiative energy on the order of 200 J. To produe generation of periodically repeating spikes the active medium of KGSS-7 glass was placed in a resonator with a radius of curvature of 1 m and T = 70%, close to confocal considering the refraction of light in the rod. The smooth mode was produced in the same resonator by replacing the active medium with LGS-28/2. The laser emission duration in all experiments was about 2 ms; the radiative energy was 100-400 J.

The total radiation over the entire pulse for random spike generation is ~0.003 rad, for regular and continuous generation - ~0.05 rad. In the case of free generation the effective spike duration τ_p (with respect to level 0.1) changes within limits 0.5-1.5 μs. The mean time between adjacent spikes is ~2.5 μs. For powerful spikes τ_p on the average equals 0.5 μs, the mean time between spikes is ~10 μs, while the power in the spike is greater than the mean power in the pulse by a factor of about five. The spatial distribution in the near zone consists of individual luminous zones 1-3 mm in size whose position varies arbitrarily from spike to spike. The average distance between centers of luminous spots is approximately twice their size, i.e., the ratio of the area of the entire face to the area from which the laser emission emerges is approximately five.

In the near zone, STDE are identical within limits of measurement accuracy for the active elements used. In the far zone of radiation of a generator with d = 45 mm and l = 0.6 m beams of light are formed that have a divergence of ~10-20 min, corresponding to the various modes. In this case a large quantity of transverse modes are excited right up to the 20th order.

Let us note that between the light zones there are dark zones having approximately the same angular dimension. This indicates that the local intensity in the far zone for one spike associated with the nonuniformity of the spatial distribution exceeds by a factor of five the intensity averaged over the entire divergence angle. Estimates made show that for the studied generators, because of nonuniformity of STDE with free generation, the maximum local (in space and time) radiation intensity in both the near and the far zones is greater than the averaged intensity by a factor of ~25.

For regular generation τ_p was equal to 0.8 μs; the time between spikes is 5.7 μs. The ratio of maximum spike power and the average power is approximately nine. The spatial distribution in the spike was practically continuous in the near and far zones, which was to be expected with considerable excess over the threshold [2], when many high-order modes are excited. Attention is drawn to the certain weakening in intensity (by ~30%) toward the edge of the beam cross section.

The distribution of laser radiation in the case of nonspike generation was also of a space-time and continuous nature in both zones. Let us note that in certain experiments the radiative power in time was sometimes modulated with a period of 3.7 μs; however, in this case the depth of modulation did not exceed 10%.

To determine the influence of STDE on the interaction with a substance we experimentally recorded the dependence of recoil pulse I of the evaporation products from the radiative energy E of the studied lasers incident on the target. The graphs obtained are shown in Fig. 2, where the values of specific pulse I/E are plotted along the ordinate and the mear density of the radiative power q on the target is plotted along the abscissa. From the results based on STDE it follows that in the given experiments in the case of regular and continuous generation the radiation is approximately uniform over the irradiation spot, while with free generation for the values of q used, i.e., with considerable defocusings, the distribution in the spot is similar to that in the near zone.

In the nonspike mode the threshold q* of the appearance of a noticeable recoil pulse exceeds by an order of magnitude the corresponding values of q* for regular and free generation (Fig. 2). Data on STDE for regular and smooth pulses show that in these cases the values of the maximum local flux q_l^* are practically identical and comprise $2 \cdot 10^6$ and $1 \cdot 10^6$ W/cm² for aluminum and iron, respectively. The conclusion as to the start of evaporation with a specific value of q_l^* is qualitatively confirmed by the coincidence of thresholds q* for aluminum with free and regular generation.

The comparative slope of the curves can also be explained by the nature of the STDE. As can be seen, in Fig. 2 curves 1, 3 and 2, 5 increase similarly, i.e., the specific pulse in first approximation in the threshold region is a function of the ratio q/q^* (and, correspondingly, q_1/q_1^*). When $q = (1-5)q^*$ we found $I/E \quad (q/q^*)^{1.6}$. The divergence of dependences 4 and 3 can be explained by the fact that with free generation about the threshold the recoil pulse is created by the most powerful spikes, which include $\sim 1/4$ of all energy in the pulse. In accordance with this, dependence 4 at the threshold should increase approximately four times more slowly than dependence 3, which actually occurs. The abrupt bend in curve 4 is associated with the "inclusion" in the formation of the recoil pulse of spikes having lesser amplitude. Its subsequent sharp rise compared with that of curve 3 is apparently connected with the heterogeneity of interaction of the radiation with the target.

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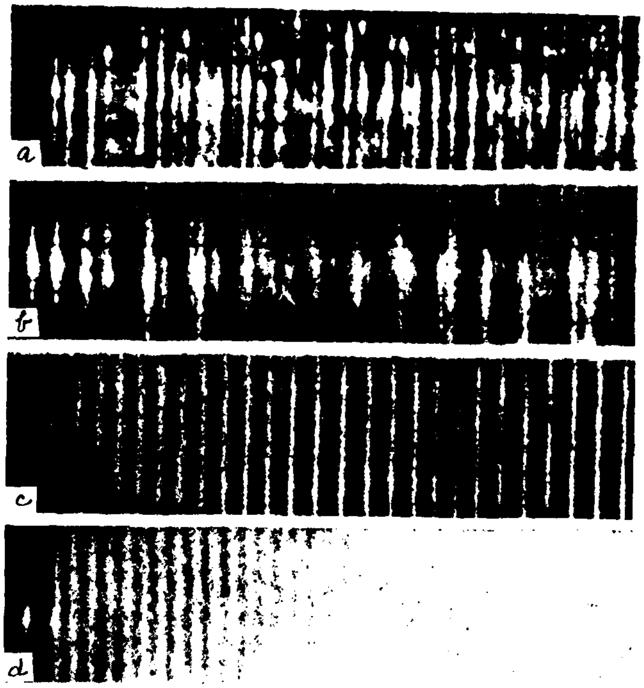
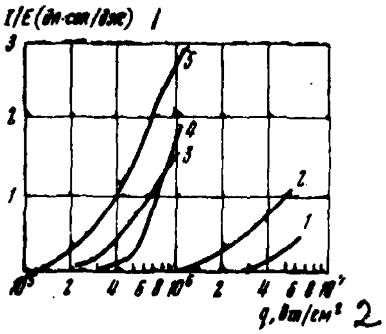


Fig. 1. SPR-grams of laser radiation. a - ditribution in the near zone for free generation (d = 25 mm, l = 0.5 m); b - distribution in the far zone for free generation (d = 45 mm, l = 0.6 m); c - distribution in the far zone for the regular mode; d - distribution in the far zone for the smooth mode.

Fig. 2. Specific recoil pulse vs. mean flux of laser radiation: 1 - in the smooth mode for Al; 2 - in the smooth mode for Fe; 3 - in the regular mode for Al; 4 - with free generation for Al; 5 - in the regular mode for Fe.

KEY: 1 - (dN•s/J); 2 - W/cm².



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