THE 3D ANALYTICAL CALCULATIONS OF THERMAL RADIATION FIELD IN SPHERICAL BOX WITH CIRCULAR CONVERTERS HEATING UP FROM OUTSIDE BY LASER BEAMS OF MEGAJOULE FACILITY

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The paper [1] published the results of 3D modeling of laser radiation conversion into X-rays in a spherical box designed to compress indirect irradiation targets. These calculations were performed for the project parameters of the Russian megajoule laser facility under the assumption that 48 laser beams will be introduced into the spherical box through 6 holes while maintaining full cube symmetry [1]. When modeling the operation of this design, serious problems were discovered associated with the occurrence of unwanted absorption of laser radiation by plasma near the holes in the walls of the box [1]. The difficulties in ensuring the conditions for thermonuclear ignition of both direct [2] and indirect irradiation [1] targets for the design parameters of the Russian megajoule laser facility stimulate the search for alternative ways to achieve this goal.

The report presents the results of analytical calculations of the thermal X-ray radiation field inside a spherical box with circular converters heated from the outside by laser beams of megajoule facility. The converters, symmetrically inserted into the walls of the box, are disks made of foil or low-density material (foam) with a high Z number, which are semitransparent for their own thermal radiation. A spherical target placed in the center of the system should be irradiated uniformly by X-ray radiation from the inner surfaces of the converters and the walls of the box. The main advantage of the new design of the box with converters is the absence of problems associated with the entering of laser radiation into the box through holes. Essentially the new variant of a direct-indirect drive approach to ICF is suggested. Note, that the term "direct-indirect drive" was introduced for the first time in work [6] where it is offered to surround a spherical target through a vacuum gape by a thin shell made from the gold foil irradiated outside with laser radiation with intensity $\sim 2 \cdot 10^{15}$ W/cm^2 and a wavelength $\lambda = 0.35$ μm. Calculations and experiments specify that the efficiency of energy conversion of a laser radiation into an unilateral flux of thermal radiation from the rear side of the converter can reach $\nu_{-} \approx 30$–40% [3]. Note that in [4] it is proposed to use low-density composite materials as a converter-absorber rather than thin foils.

When carrying out analytical calculations of the radiation field inside the box of the new design, the spherical harmonic method was used, the methodology of which for ICF problems and for solving a stationary linear problem of heat exchange by radiation in a spherical system is described, for example, in [5]. For this problem from the energy conservation law it follows that the unilateral flux of the radiation falling on a target, placed in the center of spherical box with circular converters heated outside by laser radiation, is given by the formula:

$$q_T = \sigma T_{RAD}^4 = \frac{\nu_{-} P_L}{4\pi R_B} \times \frac{1}{1-\left(1-\left(1-\alpha_T\right)k^2\right)\left[\alpha_B - S_C\left(\alpha_B - \alpha_C\right)\right]}, \tag{1}$$

where P_L is the power of the laser light irradiates the outer surface of the circular converters, σ – Stefan-Boltzmann constant, ν_{-} – coefficient of laser radiation conversion into X-ray, α_T, α_B, α_C – albedo of target, box and convertor respectively, $k = R_T / R_B$ – ratio target radius to box radius, S_C – the ratio of all convertors area to box area.

It should be noted that the second factor on the right in formula (1) takes into account the multiple reflection of radiation from the inner walls of the box, which significantly increases the efficiency $\left(\eta \equiv q_T / P_L\right)$ of target irradiation compared to the direct-indirect irradiation scheme proposed in [3].

The calculations discussed in the report were performed under the assumption that 48 laser clusters are focused on the outer surface of 6 (8 clusters each) or 12 (4 clusters each) circular converters inserted in the walls of a spherical box. Both configurations of laser beam focusing are feasible for 48 lenses placed on the target chamber of the Russian megajoule laser facility.

The calculations of the radiation field inside the box and on the target surface were performed at constant values of the $\alpha_B = 0.85$, $\alpha_T = 0.25$ parameters, while the number of converters (N_C) and the parameters k, S_C and α_C described above were varied. Figure 1 illustrates the high symmetry of target irradiation in two variants of the calculations performed. The efficiency of target irradiation in these calculations is $\eta \approx 10\%$ by $k = 1/4$ and $\eta \approx 15\%$ by $k = 1/3$ for efficiency of converters $\nu_{\_} \approx 35\%$.

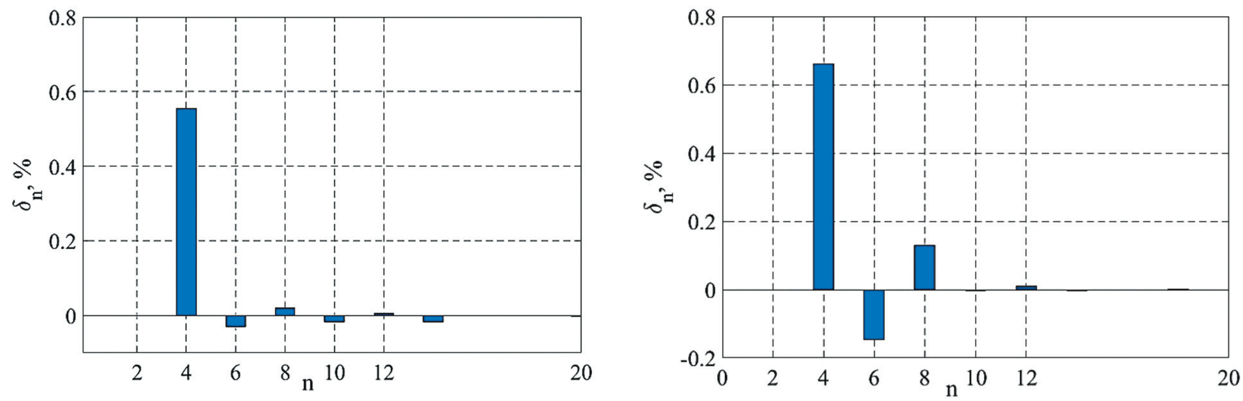

Fig. 1. Harmonic composition of radiation non-uniformity on target:
for $N_К = 6$ and $k = 1/4$ (left), for $N_К = 12$ and $k = 1/3$ (right); other parameters for both configuration is same: $S_К = 16\%$; $\alpha_М = 0{,}25$; $\alpha_Б = 0{,}85$; $\alpha_К = 0{,}7$

Since for the proposed design the efficiency of laser radiation conversion ν– into the X-ray flux entering the spherical box is ~2 times lower than in the classical design of a cylindrical converter box with two holes, the radiation temperature T_{RAD} achievable in the box will be 15% lower. Thus, with a laser radiation power of $P_L = 450$ TW and the considered parameters of the problem, a temperature value $T_{RAD} \approx 0.26–0.28$ keV can be achieved in the box and it is confirmed by calculations carried out using a two-dimensional program of radiation hydrodynamic [6]. Apparently, the proposed design of a box with circular converters is most suitable for studying the physics of compression of double shell targets, which require such values of radiation temperatures for their operation [7].

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