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Laser engine based on the ablative-reactive effect in films

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The operation principle and design of a solid-fuel laser pulse jet engine are proposed. An experimental confirmation of the proposed operation principle of the laser engine has been obtained.

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A laser ablative-reactive effect was found in our experimental studies on laser cleaning of thin film surfaces [1]. It consists in the appearance of a reactive recoil momentum, which is capable to cause a spatial displacement of the entire film or its section during ablation of a transparent film coating by laser pulses. Among other parameters, the recoil force depends on the film coating material. It can be significantly increased if materials rapidly evaporate under the influence of laser radiation heating, fuel mixtures or even brisant substances are used as the coating material.

In the present article, we propose to use this effect in a laser jet engine. The proposed laser engine belongs to the class of ablation engines [2] that use lasers to produce high-temperature gas or plasma by evaporating or igniting a working agent (fuel) with subsequent production of reactive thrust. The key feature of application of the laser ablative-reactive effect in the proposed engine is that the working agent forms a discrete film coating, which has the form of capsules containing the working agent and secured to the surface of a moving film, rather than a continuous one. Each capsule is essentially a fuel cartridge.

The schematic diagram of the proposed engine is shown in the figure (the proportions of elements are arbitrary). The engine case (1) has an axial channel (2) for transmissing the laser beam, which exits the channel through the focusing lens (3). Upper channel exit (2) is covered by transparent protective disk *4*. Solid working substance *5* is contained in capsules *6* which are in a rigidly one-piece way attached to a flat thin tape *7*. Capsules are arranged along the longitudinal centerline of the tape at regular intervals. The tape is tightly pressed to the upper face of the engine case and can move along its surface along the guides *8*.

Each capsule has a cone-shaped recess *9* at the top that serves as a small-size nozzle increasing the thrust. The lower part of the capsule filled with a working substance is closed by a thin protective cover *10* at the transition of its cavity to the nozzle. Capsules and the tape are made of durable heat-resistant materials capable of withstanding the combustion of a fuel portion contained in the capsule without significant destruction. The tape material must be transparent to used spectral range of laser radiation. The tape serves as a capsule conveyer. It also protects the upper face of the engine body from contamination by products of combustion of the working substance and provides additional protection of output window *4* against thermal and mechanical damage.

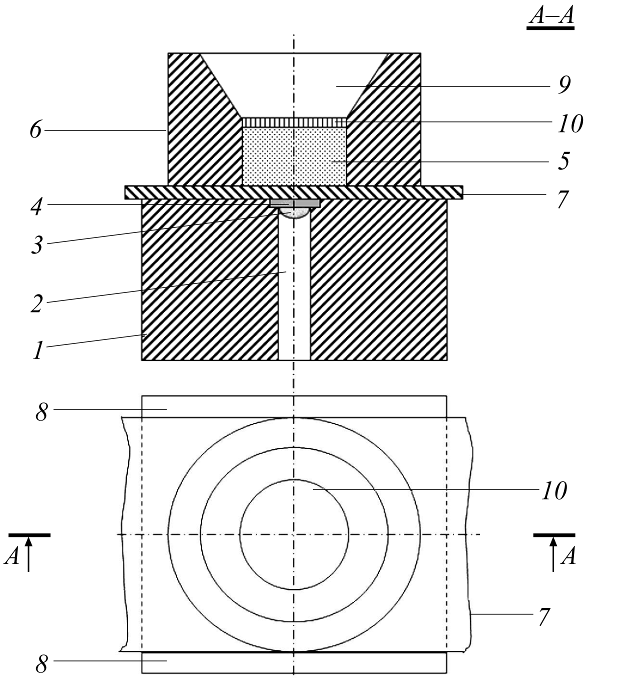
Structurally, the capsules can be either rigidly attached to the tape, or integrated with it representing shaped protrusions on its upper surface and made of the same material with it (for example, from heat-resistant plastic by hot stamping). The tape with capsules in a rolled-up form can be stored in replaceable cassettes, from which it is fed to the engine during its operation. Solid materials evaporating under the influence of high temperature, solid rocket fuels, explosives can be used as a working substance filling the capsule.

Pulsed diode lasers [3] or a diode-pumped solid-state laser [4] including those with a fiber output, are well-suited in the proposed laser engine. These classes of lasers are characterized by high efficiency, compactness, reliability and long operating time. Laser radiation can be injected into channel *2* either directly, when the laser output aperture is positioned on the axis of channel *2* near the lower face of the case, or via an optical fiber (in this variant the laser can be mounted in any suitable place in a spacecraft). The energy parameters of a laser (pulse energy and duration) depend on the type of the working substance in capsules. Rocket fuel and explosives are the least energy-consuming options, in these cases pulse energy is required just to ignite them.

The engine operates according to the following algorithm.

1. The tape drive shifts the tape and positions a capsule so that its longitudinal axis is aligned with the optical axis of focusing lens *3*. The tape is fixed in this position.

2. A laser pulse is emitted, after passing through transparent tape *7*, it is absorbed in the bulk of the working substance *5*. Due to the absorbed laser pulse energy evaporation or thermal ignition of the working substance occurs. High-temperature gas formed in the capsule, being



Scheme of the proposed laser engine. *1* — engine case, *2* — laser input channel, *3* — focusing lens, *4* — protective disk, *5* — solid working substance, *6* — capsule, *7* — tape, *8* — tape guides, *9* — nozzle, *10* — capsule cover..

under high pressure in it, burns (or tears off) the upper capsule cap *10*, and a gas jet exits out of the nozzle, imparting the capsule a reactive impulse in the direction opposite to the gas outflow. This impulse presses the tape tightly against the enjine case and is transferred to the case through it. The engine generates reactive thrust as a result.

3. After the gas outflow completion the cycle repeats.

The time between steps, repetition rate, duration and number of cycles can vary and are set by an automated engine control system. The reactive impulse energy can be controlled by changing the laser pulse energy and duration.

The efficiency of the proposed engine operation principle was confirmed in model experiments with powder tablets glued to a lavsan tape. The same technique as in [1] was used for measurements - deflection of a weight hanging at the tape end by a reactive impulse. A pulsed YAG:Nd laser with $\lambda = 1.064\,\mu$m, a pulse energy of 10 mJ, a pulse duration of 20 ns, and a repetition rate of 10 Hz was used in experiments. The mean mass of powder pellets was 0.12 and 0.24 g. No more than two pulses were enough to ignite a tablet. The mass of weights varied from 1 to 10 g, and the tape length was 50 cm. Depending on the parameters the values of the horizontal deviation of the tape were recorded in the range approximately from 7.5–34 cm. It is important to consider that the effectiveness of the resulting reactive pulses was significantly reduced due to the non-directional expansion of powder gases, but despite this the measured efficiency averaged $7-9\%$. When using capsules with a built-in nozzle (*9* in the figure) it should be significantly higher. Also these experiments demonstrated, compared to the ablation of the metal oxide tape coating used in [1], the high-explosive coating provided a 50-fold increase in reactive thrust.

The proposed laser jet mini-engine should be at its most efficient when used in-flight to adjust the orientation and correct and stabilize the position of small spacecraft in space. Its advantages are simplicity of design, flexible adjustment of the operating mode and large fuel resources compactly stored in tape cassettes.

Conflict of interest

The authors declare that they have no conflict of interest.

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