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BALANCING SMALL ENGINES-FLYWHEELS

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When you create a small spacecraft there is the problem of redressing the imbalance of the rotor-flywheel of the small engine flywheel with the selection of weights, while the mechanical contact method leads to elastic deformation in the supports of rotation, which has a negative impact on their work especially at high speeds of rotation of the flywheel.

From this perspective, there is a need to study other ways of balancing of rotors, flywheels, namely contactless balancing of rotor of flywheels with the help of concentrated energy fluxes of laser and electron-beam evaporation of the metal.

The technology of balancing with an electron beam has a number of advantages over the laser technology of balancing for the realization of balancing of rotors of flywheels. For example, it is possible to implement the process of redressing of imbalance in the vacuum that brings the balancing conditions to real operating conditions. Also the reflectance of energy in the processing of electron beam is much lower than during laser processing, which demonstrates the efficiency of the process.

The dependences of the intensity of evaporation from the settings of the laser and electron beam are defined.

Contactless balancing of rotors of flywheels with the help of concentrated energy fluxes evaporation of metal is currently possible, but it is necessary to have special equipment with the required capacity of operation.

Keywords: engine-flywheel, balancing, laser, electron beam.

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БАЛАНСИРОВКА МАЛОРАЗМЕРНЫХ ДВИГАТЕЛЕЙ-МАХОВИКОВ

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При создании малых космических аппаратов возникает проблема устранения дисбаланса ротора-маховика в малоразмерном двигателе-маховике. Использование подбора грузов ограничено их массой, а механический контактный способ (высверливание отверстий) приводит к возникновению упругой деформации в опорах вращения, что отрицательно сказывается на их работе (особенно на больших частотах вращения маховика).

Исходя из этого, необходимо исследовать другие способы, в частности, бесконтактную балансировку роторов-маховиков с помощью концентрированных потоков энергии, лазерное и электронно-лучевое испарение металла.

Технология балансировки электронным лучом обладает рядом преимуществ перед лазерной: коэффициент отражения энергии при обработке электронным лучом значительно ниже, чем при обработке лазером, энергоэффективность процесса выше, устранение дисбаланса выполняется в вакууме, что приближает условия балансировки к реальным рабочим.

Установлены зависимости интенсивности испарения от параметров режима лазера и электронного луча.

Бесконтактная балансировка роторов-маховиков с помощью концентрированных потоков энергии испарения металла в настоящее время возможна, но необходимо иметь специальное оборудование с требуемой мощностью работы.

Ключевые слова: двигатель-маховик, балансировка, лазер, электронный луч.

Introduction. A number of problems arises during manufacturing of an engine-flywheel. One of them is imbalance of a rotor of a flywheel that leads to vibrations. There are 2 methods of redressing of imbalance in instrument engineering: the mechanical one (metal removal, fig. 1, *a*) and selection of weights – balancing screws (adding of mass, fig. 1, *b*).

During the process of metal removing mechanical pressure on the bearing unit appears through a flywheel rim and arms. Under emerging stress elastic deformation occurs in the bearing unit that causes displacement of the rolling elements (balls) from their raceways. When exceeding the admissible load elastic deformation moves to the stage of irrecoverable deformation that leads to hidden defects in the bearing unit.

While balancing the rotor of the flywheel with screws they make several bores equidistantly located on the girth of the rotor rim, where they place screws of certain mass. However, this method of balancing has some problems caused by small size of the rim itself and is limited with technological capabilities to produce screws and screw holes. Those screw holes in the rim of the flywheel reduce its total mass that leads to increase of mass in the other places of the rotor system that makes the required moment of inertia secure kinetic moment of the flywheel. In designing the structure of the engine-flywheel that increases its weight and size [1–3].

Both methods of implementation of above-mentioned balancing are labour-intensive, demand high skills of performer and expensive cutting tools and equipment and special arming for each appliance.

While using small engines-flywheels the problem of balance correction of the rotor of the flywheel because of its small measures and other peculiar features.

Due to this fact the need to study different methods of balancing of rotors of flywheels appeared, namely the method of contactless balancing with the help of concentrated energy flows in laser and cathode-ray metal evaporation [4].

The cathode-ray balancing technology has several advantages over the laser one. For example, the process of imbalance redressing takes place in vacuum that creates almost-real life operating conditions of engine-flywheels. The energy reflection coefficient when the electronic beam is used is much lower than when we use lasers. So the former technology appears to be more energy efficient than the latter one. The cathode-ray technology has an advantage of lower price as well, for example, having the power of 12 kW it is the third of a price of laser technology complex. The other drawback of laser technology is that the material of flywheel rotors would react with gases of air during heating and melting. Consequently, we have to create protective atmosphere in a work volume [5; 6].

To balance the flywheel rotor using concentrated energy flows the following tasks were set up:

- the study of dependence of evaporation on characteristics of laser and electronic beam action;
- receiving data of changes in metal structure in the area of local weld penetration;
- defining the possibility of balancing flywheel rotors by means of concentrated energy flows.

Defining the optimal regime through experiments. The process of evaporation was carried out with a fine-focused electronic beam and a laser on samples, made of steel 30X13H2CM, that is used in production of flywheels.

During the experiment the distance between samples and focusing system, the beam current, the number and duration of impulses were modified [7–9].

Before the experiment the samples were weighed up on laboratory scales with a precision of 1 mg. After each stage of the process they were weighed up again, this way an amount of removed material was determined.

Necessary characteristics were calculated according the following formulas:

- power flow density

$$P = \frac{P_{\text{п}}}{S_{\text{п}}},$$

where $P_{\text{п}}$ is beam power; $S_{\text{п}}$ is beam area on the surface of the sample;

- evaporation rate

$$V_{ev} = \frac{m}{tS_{\text{п}}},$$

where m is mass of evaporated material; t is impulse duration.

The experiment studied the influence of the distance between the irradiated sample and focusing system of electronic beam. Concentration of electrons in the beam depends on a focus distance. If the distance is long while vacuum is not deep enough (less than 10^{-1} Pa) than electrons would lose energy and change direction of movement because of dispersion in particles of environment, therefore, the impact on the material surface would be less efficient (fig. 2).

a *b*

Fig. 1. Balancing the rotor-flywheel:
a – removing the metal on the rim of the flywheel; *b* – balancing with screws

Рис. 1. Балансировка ротора-маховика:
а – удаление металла на ободе маховика; *б* – балансировка винтами

The maximum evaporation occurs when the distance is 20–25 sm. If to increase or to decrease the distance to the focusing system then the beam diameter increases and it becomes less concentrated as well as the process of treatment becomes less efficient. The higher the concentration of electrons is, the more intense the metal removal is.

All the further experiments were carried out at the estimated distance of 20–21 cm to the focusing system. It corresponds the beam diameter of 250 µm under 50 mA and accelerating voltage of 30 kV.

To define the possibility of evaporation it is needed to set the laser and electronic beam at minimum power.

Due to the studies it is known that the minimal current value of the beam allowing evaporation is 35 mA, while the maximal one is 52 mA. There is no reason to use current of greater power because of unfavorable effects, such as explosive melt ejection, overheat of processed material.

The duration of impulses also had limits (fig. 3, 4). The maximal was 1000 ms for it is a threshold value for the used installation. The minimal is 100 ms, because at lower values the energy of electrons is spent on their runaway as a result of surface reflection, the sample warms up slightly, but the material removal does not happen [10].

Fig. 4 shows us that the mass of the metal evaporated from the surface of the sample with laser is very small. That is why we take the cathode-ray method as the basis of studying possibilities of balancing rotors of flywheels.

When metal is treated with electronic beam, the process of evaporation depends greatly on the impulse duration. The longer duration is, the more metal is removed, because much more energy affects the sample. In this case energy spreads far beyond the processed area due to its thermal conductivity. It makes structural changes of the metal. The long impulse duration leads to appearance of vapours of processed material over the sample surface that causes waste of the beam energy [11; 12].

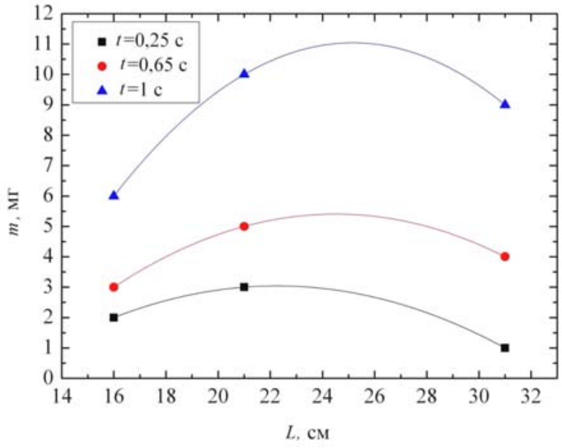

Fig. 2. Dependence of the mass of the vaporized metal on the distance to the focusing system at a beam current $I = 52$ mA

Рис. 2. Зависимость массы испаренного металла от расстояния до фокусирующей системы при токе луча $I = 52$ мА

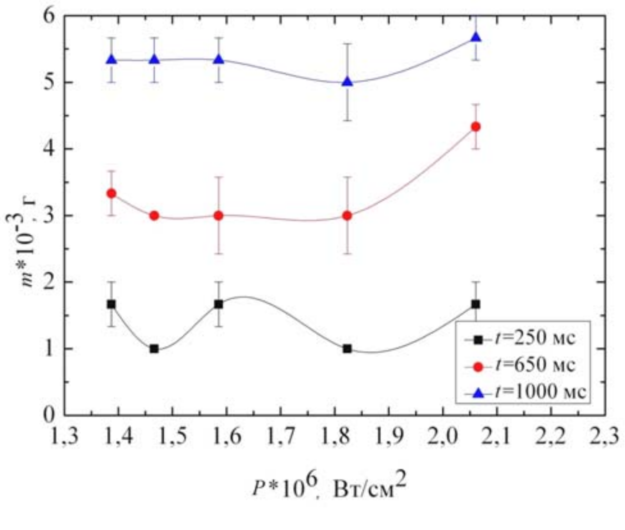

Fig. 3. Dependence of the mass of the material removed on the electron beam power density (with a diameter of $D = 250$ µm and a voltage $U = 28$ kV)

Рис. 3. Зависимость массы удаляемого материала от плотности мощности электронного луча (при диаметре $D = 250$ мкм и напряжении $U = 28$ кВ)

The short impulse duration (250 ms) makes the evaporation process unstable. One can see that at this duration and power density of about $1.4 \cdot 10^6$ W/cm^2 1,5 mg of material is removed, whereas at power density of $1.45 \cdot 10^6$ W/cm^2 only 1 mg of material is removed. The graph is periodical that can be accounted for auto wave processes that are present when the electronic beam treatment is carried out.

We studied evaporation rate at different values of current of electronic beams (fig. 5).

At initial energy $U = 28$ keV (the output of secondary emissions is very small) and power density of 10^6 W/cm^2 (there is no expansion of the metal due to the powerful waves of compression and unloading) almost all energy is spent on warming up the sample. It can be seen (fig. 5) that the maximum rate of material removal appears at a pulse duration of 0.15–0.3 s. Then the process of evaporation passes stably regardless of the fact that the pulse duration increases [13]. This can be explained by the fact that as the pulse duration is increased, the energy of the electrons is mainly spent on heating the processed material and is carried away as a result of its thermal conductivity.

Experimental results. During the experiment the microstructure of area melted at different impulse duration of the electronic beam was changed (fig. 6–8).

Presented photos show us that the depth of passage of the electron beam depends strongly on the pulse duration. The zone of thermal action at the maximum pulse duration (1 s) is 6.7 mm wide and 4.4 mm deep, which should be taken into account when designing the flywheel rim in the balancing zone [14; 15].

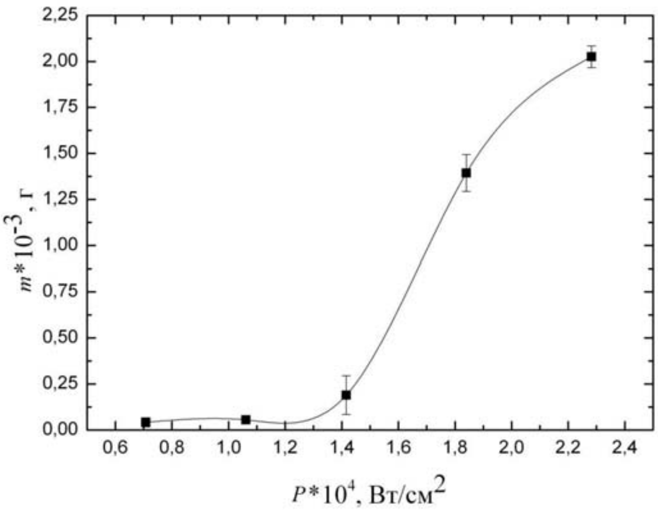

Fig. 4. Dependence of the mass of the material removed on the laser power density (at time $t = 20$ ms)

Рис. 4. Зависимость массы удаляемого материала от плотности мощности лазера (при времени $t = 20$ мс)

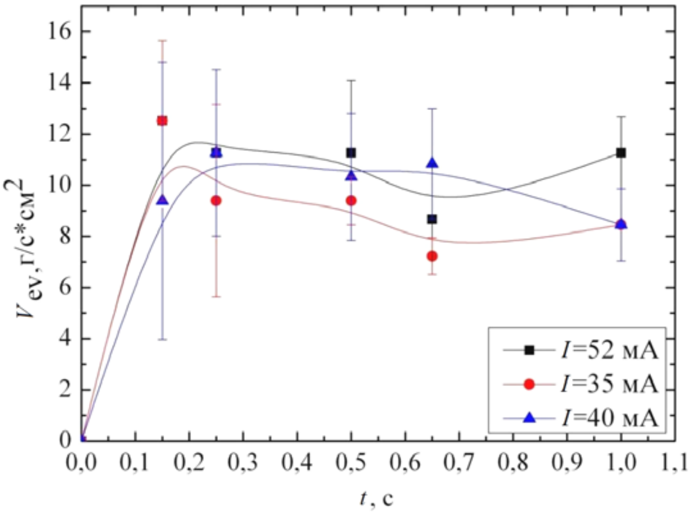

Fig. 5. Dependence of the evaporation rate on the duration of the electron beam pulse ($L = 21$ cm, $U = 28$ kV)

Рис. 5. Зависимость скорости испарения от длительности импульса электронного луча ($L = 21$ см, $U = 28$ кВ)

Hardness of samples, measured by the Vickers method, is distributed depending on the zone (fig. 7).

In the process of research work, a significant shortage of the equipment on which the experiments were performed was revealed: the low power of the electron beam device, and, accordingly, the low accelerating voltage. Consequently, the energy of the beam necessary for evaporation was reached by increasing the current, which led to a considerable overheating of the samples and an increase in the lifetime of the liquid phase prior to the onset of the evaporation process.

The high cooling rate caused by the large temperature gradient in the body of the sample causes the appearance of hardening stresses, which leads to the appearance of cracks (fig. 8).

a *b*

c

Fig. 6. Microstructure of the melted zone at different time of exposure:
a – at $t = 0.1$ s; *b* – at $t = 0.65$ s; *c* – at $t = 1$ s

Рис. 6. Микроструктура проплавленной зоны при разном времени воздействия:
а – при $t = 0{,}1$ с; *б* – при $t = 0{,}65$ с; *в* – при $t = 1$ с

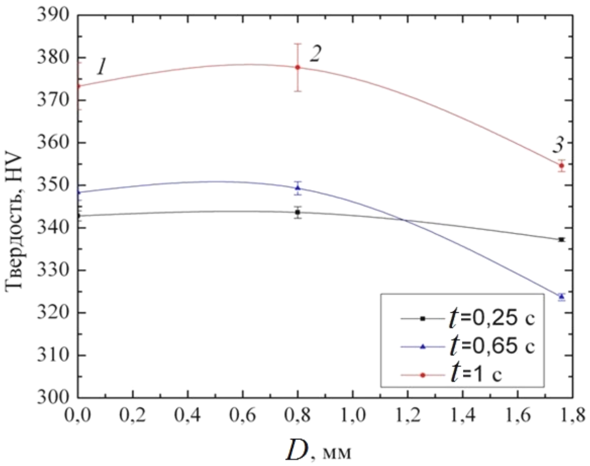

Fig. 7. The distribution of hardness in sample:
1 – the treatment area; *2* – heat affected zone; *3* – steel

Рис. 7. Распределение твердости по образцу:
1 – зона обработки; *2* – зона термического влияния; *3* – сталь

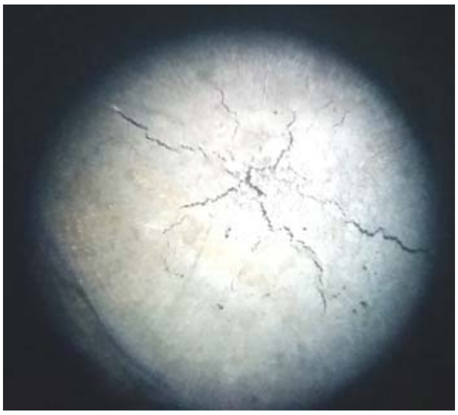

Fig. 8. Cracks in the bath of molten metal samples
of steel 30X13H2CM when exposed to the electron beam

Рис. 8. Трещины в ванне расплавленного металла образцов
из стали 30Х13Н2СМ при воздействии электронного луча

Conclusion. The process of evaporation of a metal under the influence of an acute-focused pulsed electron beam and a laser is studied. The dependence of the evaporation intensity on the parameters of the laser and electron beam modes is established (fig. 3–5).

In the course of the work it was established that when the electron beam is exposed to samples of steel 30X13H2CM due to the long existence of molten metal, recrystallization cracks form at the site of the beam action.

With the use of these parameters and the increase in the number of pulses, it is possible to remove from 1 to 100 mg of substance per process cycle on materials not prone to cracking, or where such cracks are not critical.

Contactless balancing of flywheel rotors with the help of concentrated energy fluxes of laser and electron-beam evaporation of metal is currently possible, but it is necessary to have special equipment with the required output power.

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