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# Application of strongly focused pulsed electron beam for the reaction wheels balancing

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**Abstract.** In the given work the material removing possibility by the strongly focused pulsed electron beam was investigated. The optimal mode of flywheels balancing was found. At this mode the power density is 1.6 MW/cm$^2$ and pulse duration is 0.65 s. At such parameters the evaporation rate is equal to 11 g/s·cm$^2$. It is possible to vary the amount of remote material from 1 to 100 mg, that is sufficient to balance flywheel. It is found that treatment by an electron beam does not change the material structure.

## 1. Introduction

One of the satellite main systems is orientation system which lets stabilizing the position of its axes relative to the specified destinations. Attitude control system includes reaction wheel which allows controlling satellite movement around the center of mass. Wheel rotates on the high speed; thereby creates internal moments that allow changing the angular position of the satellite relative to the base reference system, without changing the center of mass. Usually three wheels are established in satellite. Their axes are aligned with the satellite major axis of inertia. Fig. 1 shows the structure of the reaction wheels.

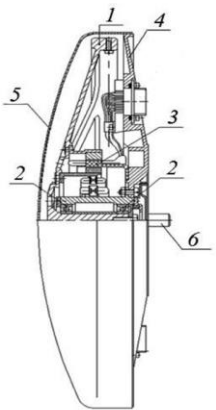

**Figure 1.** The construction of reaction wheels: 1 - ring of wheel, 2 – supports, 3 - electromotor, 4 - a base on which the rotor is fixed, 5 - protective cover, 6 – spindle.

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In the reaction wheel manufacturing process there is a number of problems, one of which is its mass unbalance. This problem can lead to the satellite avoidance from its orbit. Currently, there are several techniques for flywheel unbalance correction: mechanical technique and treatment by concentrated energy fluxes (precision work).

**Figure 2.** The mechanical method of the flywheel balancing.

The first method involves holing in the flywheel, and, if necessary, balancing it by placing the particular weights in the form of small bolts inside the holes (Fig. 2). Such laborious technique requires heavy expenses of time and money. Therefore there is a need to develop other flywheel balancing methods, for example treatment by concentrated energy fluxes that includes laser and electron beam technologies. In this case the main mechanism of material removing is evaporation, because metal temperature riches a high magnitude under the influence of high-energy particles. This technique is more precise and can be more effective than the mechanical method.

Nowadays, laser technology of balancing is developing, but there are some disadvantages such as high energy reflection coefficient (~80%) and liquid melt ejection. Electron beam application allows to avoid these problems, because the energy reflection coefficient of the electron beam is much lower (~15 %) than for the laser beam, consequently the process efficiency is higher. Varying the electron beam parameters the liquid melt ejection can be avoided.

In the present study the electron beam treatment is suggested as the method for flywheel balancing. Application of strongly focused pulsed electron beam allows local and short-time metal treatment.

## 2. Experimental

### *2.1. Electron beam treatment*

Electron-beam evaporation was carried out on the EBU - 0,5 - 6 electron-beam unit with plasma cathode (Fig.3). This unit is fitted out by a two-lens focusing system which gives an opportunity to reduce the beam divergence angle. The maximum diameter of the beam can reach the value of 0.8 mm, considering that the distance between the focusing system and the sample can be ~0.5 m. Such system allows producing a beam with the diameter less than 300 microns [1].

The investigated samples were made from steel AISI 321. Their thickness was 5 mm and diameter was 20 mm.

During the experiment the acceleration voltage was 28 kV; working pressure was $10^{-1}$ Pa. The distance to the focusing coil was 200 mm that corresponds to the beam diameter equal to 0.32 mm [1]. Such parameters as beam current, duration and number of pulses were variated to determine the optimal mode of evaporation.

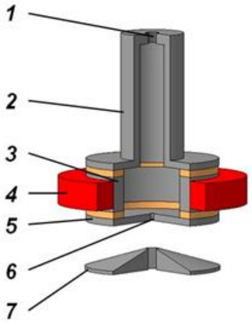

**Figure 3.** The electrode system of plasma cathode gun: 1 – the gas flow channel, 2 - the hollow cathode, 3 - the anode, 4 - the permanent magnet, 5 - the emitter cathode; 6 - the emission channel, 7 - the extractor (accelerating electrode) [2].

### *2.2. Methodology*

The amount of removed material was measured using the PA413 laboratory analytical weighing scales OHAUS Pioneer. The macrostructure was investigated by the TRIO -1044 microscope. The samples hardness was measured by Vickers method with the load of 50 grams by the KB 30S Pruftechnik GmbH Hardness tester.

## 3. Results and discussion

Experiments show that the minimum of the beam current while the evaporation process was 35 mA; maximum magnitude was 52 mA. Above this value there are some negative effects, such as liquid melt ejection and energy beam expenditure on the thermal conductivity, i.e. overheating of samples (Fig.4). The evaporation rate at different current (35, 40, 52 mA) was investigated (Fig.5). Almost all energy was used to heat the sample in case when the initial energy was equal to 28 kV (the secondary radiation yield is very small), and the power density was $10^6$ W / cm$^2$. Fig. 5 shows that the removal rate of material reaches the maximum at the pulse duration of ~ 0.15...0.3 s. However, at these pulse duration magnitudes, the evaporation process is non-stationary and the curve nature is periodic (Fig.4). It can be explained by the auto oscillations, which are presented during the electron beam treatment.

When the pulse duration is 1 s a large amount of energy is coming to the sample consequently heats it. There is vapor formation near samples surface, which leads to loss of beam energy, and evaporation process becomes energy intense. From these observations it can be seen that the optimal pulse duration is 0.5…0.65 s.

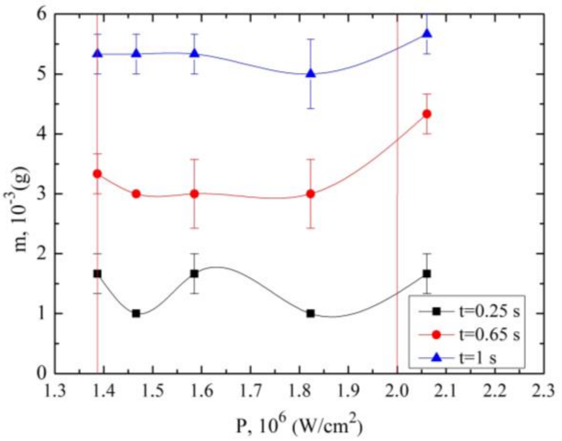

**Figure 4.** The removed material mass versus the electron beam power density.

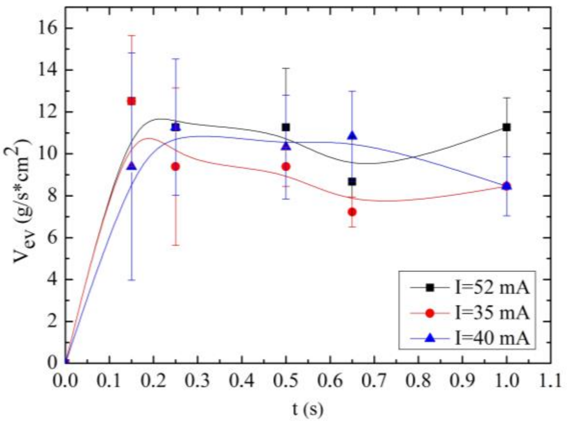

**Figure 5.** The dependence of the evaporation rate on the electron beam pulse duration.

Besides, it can be seen from Fig.5 that the evaporation rate at 52 mA almost equals the rate at 40 mA, therefore it can be noted that the more energetically effective current beam is 40 mA.

In addition, in this work it was necessary to investigate the macrostructure and mechanical properties of treated samples, because the presence of defects can lead to the reaction wheel damage in the process of operation. Hardness investigation shows that electron beam treatment does not affect the mechanical properties of material (Fig.6). It was shown that the depth from the beam thermal effect significantly depends on the pulse duration. When it was 1 s, the depth of molten zone was 5 mm (sample thickness), but at the value of 0.65 s the maximum width of the molten zone was 6 mm, and the depth was 4.4 mm (Fig.7). Such dimensions are negligible for the flywheels treatment, because its diameter varies from 30 to 35 cm. Also it can be seen that there are not any bulk defects (pores and cracks).

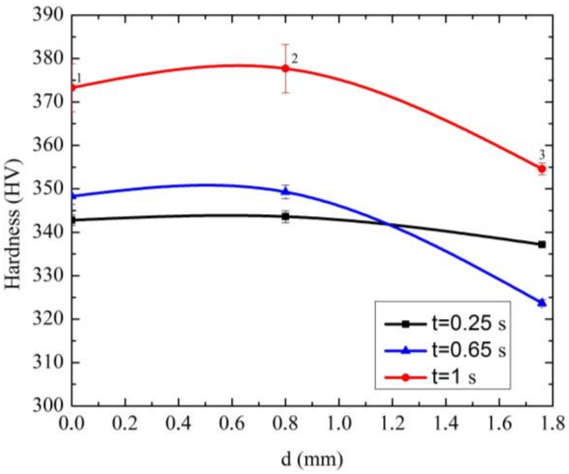

**Figure 6.** Samples hardness distribution: 1 – area which was treated by electron beam 2 - between the treatment zone and steel, 3 – steel.

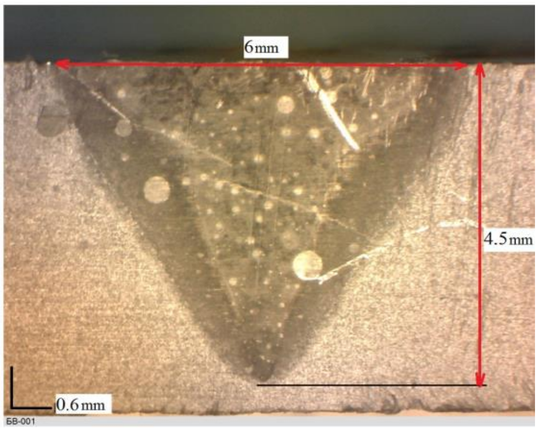

**Figure 7.** The macrostructure of the molten zone at t = 0.65 s.

From these results it may be concluded that the treatment by strongly focused pulsed electron beam does not lead to the defects appearance.

## 4. Conclusions

It was shown that strongly focused pulsed electron beam can be apply as the method of gyroscope flywheel balancing. The optimal mode for material removing from the steel surface includes following parameters: beam power density of $1.6 \cdot 10^6$ W/cm$^2$, pulse duration of 0.65 s, evaporation rate of 11 g/s·cm$^2$. The amount of removed metal may be varied from 1 to 100 mg per a cycle.

The investigation of the samples macrostructure and hardness showed that the electron beam treatment does not change the metal structure significantly.

## References

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