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ASTRONOMY, ASTROPHYSICS, AND COSMOLOGY

Using an Artsimovich Railgun for Return from the Moon

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Abstract—Nonstandard techniques to deliver a payload from the Moon to Earth are explored. Two approaches are compared, which are based on using a space elevator and an acceleration device, the Artsimovich railgun. The energy needed to launch a payload to a low lunar orbit and the L_1 libration point in the Earth–Moon system is estimated. We conclude that the railgun is economically advantageous compared to the space elevator and standard jet technologies.

Keywords: development of the Moon, railgun, space elevator.

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INTRODUCTION

To realize the Russia long-term plans related to the exploration of the Moon, Mars, and outer space bodies, many challenging issues should be resolved, among which the return of crewed lunar missions and delivery, in the future, of lunar minerals and raw materials to Earth are of special importance.

At the first phase of lunar and interplanetary programs, the existing Russian space facilities (provided they are restored and upgraded) seems to be adequate to maintain communications and navigation of single flights of automated spacecraft to the Moon or to deep space. However, the large-scale development of the Moon and exploration of other solar-system bodies will significantly extend the scope of studies and the instrumental base, to provide reliable and quality support to crewed missions.

Flights to the Moon of both automated and piloted spacecraft that will perform more profound studies are planned for the next decades. This involves their movement on the lunar surface and the return of the spacecraft to the Earth. It is very timely in this context to initiate research and studies of the approaches to design and development of new promising technologies and techniques that will facilitate exploration and development of the Moon by space missions.

One challenging problem in the exploration of the Moon is the high cost of delivery of a payload to the lunar surface and its return with lunar rock specimens to Earth. The cost of launching a kilogram of payload to a near-Earth orbit exceeds $ 30 000. The delivery of a payload to the Moon, not to say returning to Earth, is significantly more expensive. One reason is that along with payload the fuel to launch the return vehicle should also be delivered to the Moon.

New technologies enable the last stage to be eliminated. Such options have been discussed in [1]. This study suggested rekindling the concept of the orbital elevator, which was proposed more than 100 years ago by K. Tsiolkovskii and has been developed in detail by Yu. Artsutanov [2]. While the concept of the elevator for launching spacecraft from Earth to space is not fully feasible, it may be implemented on the Moon using modern or near-future technologies [3–6]. A disadvantage of this concept is the small weight of the payload, that is, no more than ∼100 kg per launch [1, p. 6] which will result in a low throughput capacity of the orbital elevator.

We will discuss the concept of the railgun proposed by Artsimovich [7], which is intended to accelerate spacecraft for the return from the lunar surface to the Earth. This was discussed earlier in relation to possible usage of such "electromagnetic guns" to launch small spacecraft to a low Earth orbit [8–12].

The principle that underlies this technique is as follows. The railgun consists of parallel electrodes, which are referred to as rails, that are connected to a powerful DC source. The accelerated current-conducting mass is located between the rails and closes the electric circuit. It is accelerated by the Ampere force that acts on the closed conductor with

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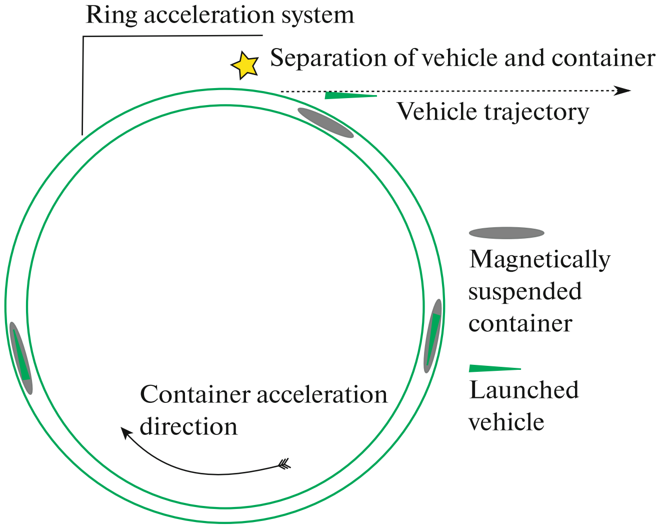

Fig. 1. A ring accelerator intended to launch a payload from the Moon's surface. The payload with the carrier container is accelerated in a giant cyclotron to the required velocity. After having attained this velocity, the container is jettisoned into the cyclotron to be prepared for the next launch, while the payload is launched to an orbit.

current in its magnetic field. The payload may be accelerated or in a linear accelerator, or in a giant cyclotron that employs the effect of electromagnetic induction acceleration [8, 13]. Figure 1 displays the layout of such an accelerator. Owing to the conditions on the lunar surface, the cost of the device decreases significantly, since an air-tight vacuum tube or various fast operating gateways for passing the accelerated payload are not needed.

1. ESTIMATED REQUIRED ENERGY

We now estimate the energy needed to launch a payload to three various orbital positions. The first position is a low-lunar orbit where the payload may be intercepted by a lunar tug and further transported to the required orbit. The second position is the acceleration of the payload to the Moon's escape velocity and sending it to space. The third position is the launch of a payload to the libration point L_1 of the Earth–Moon system.

We consider a system similar to that explored in [12, 14–16]. These studies examined the design of a railgun to launch a payload from Earth to a low-Earth orbit. The total mass of the vehicle accelerated in the railgun is, for example, 1250 kg and the payload mass is 300 kg. The railgun exit velocity is 7500 m/s. The energy of the vehicle at the railgun exit is 35 GJ, while the total energy supplied to the accelerating system is 44 GJ.

Thus, the total energy needed to launch a spacecraft to a low orbit is 44 GJ per 300 kg. Most of this energy is used to overcome the resistance of the atmosphere, launch the payload to the jettison height, etc. In other words, the energy cost of the launch of a kilogram of payload is approximately 146.7 MJ. The energy used to launch the payload itself only is 24% of the total energy.

We now calculate the corresponding energy costs for launch from the Moon. In contrast to Earth, there is deep vacuum on the lunar surface; therefore, the launching system does not need have a vacuum tube, the vehicle that delivers payload to space does not need a fairing, etc. The total mass launched from Earth using a railgun consists of the projectile shell (156-kg aerodynamic fairing), a jettisoned container (94 kg), and the vehicle itself, which contains an engine for orbit adjustment and fuel (700 kg), and a payload (300 kg). We calculate the energy needed to only launch the payload (300 kg) and the accelerating container to the three orbital positions described above.

The first position is a low orbit at an altitude of, for example, 50 km above the lunar surface. To deliver a cargo to such an orbit, the vehicle should be accelerated to the first cosmic velocity and additionally gain potential energy due to elevation from the lunar surface $R = 1738.2$ km to the height $R + h = 1788.2$ km. To have a payload with mass $m =$ 400 kg launched to a low near-Moon orbit, the vehicle should be accelerated to the first cosmic velocity for the Moon:

$$v_1 = \sqrt{\frac{GM}{R}} = 1.68\ \text{km/s}. \tag{1}$$

This value corresponds to the following kinetic energy of the vehicle in the accelerating system:

$$E_1 = \frac{mv_1^2}{2} = 564.48\ \text{MJ}. \tag{2}$$

If the vehicle is launched to an altitude of 50 km above the Moon's surface, a potential energy of 32.48 MJ is additionally needed, thus a total energy of 596.96 MJ is required.

The escape velocity under the specified conditions is

$$v_2 = \sqrt{\frac{2GM}{R}} = 2.38\ \text{km/s}. \tag{3}$$

The energy required in this case is 798.15 MJ.

The third position is the L_1 point in the Earth–Moon system. This point is located at a distance of about 61 500 km from the center of the Moon [17]. To reach this point, the initial velocity of the spacecraft should be

$$v_L = \sqrt{\frac{2GM}{R}\left(1 - \frac{R}{R_L}\right)} = 2.35\ \text{km/s}. \quad (4)$$

Here, R_L is the distance between the Moon's center and the L_1 point. To reach this point, an energy of 778.15 MJ is needed. If the spacecraft has this energy at the start, it will arrive to the L_1 point with a zero velocity.

It is very advantageous that the velocity at this point is zero or close to zero, since the motion of the spacecraft may be controlled significantly more easily. The payload may be intercepted and directed to the required trajectory.

THE THROUGHPUT CAPACITY OF THE RAILGUN

We now estimate the throughput capacity of this method to launch a payload to a low lunar orbit. The throughput capacity heavily depends on the power source. A battery of condensers was considered in [7] as a power source for the railgun. This setup may be used in principle for the accelerating railgun. Solar batteries, a nuclear reactor, an isotope source, or even a thermonuclear reactor (in the future) may be used as a power source external with respect to the battery of condensers. We consider radioisotope power sources, which have been used many times in spacecraft. For example, a 7-kW radioisotope power source was installed on the Voyager spacecraft; it operated for at least 50 years. To accumulate the 566 MJ of energy required to launch a payload with the mass $m = 300$ kg, A time of $T \simeq 22$ h is needed. We obtain, hence, that the throughput capacity of such an accelerator is approximately 330 kg per Earth day.

Expression for the throughput capacity may be written as

$$\frac{dm}{dt} \approx 330\ \text{kg/day}. \quad (5)$$

It should be noted that the throughput capacity does not depend on the mass of the payload launched in one discharge. However, the number of launches that the railgun can make depends on the payload mass. Indeed, a less mass requires less energy and, consequently, shorter energy accumulation time.

Another important estimate of the Moon-based launch system is the dimensions of the railgun.

It is assumed that the UTSTAR system [16, 18] will be used on Earth. The main parameters of the system required for our estimates are: the accelerator length is 1600 m, the acceleration time is 0.43 s, and the average acceleration is 17 600 m/s^2. Given that the mass of the vehicle accelerated in UTSTAR is 4 times the mass of the cargo accelerated by the lunar railgun, the average acceleration may be 4 times larger, or the supplied power 4 times smaller.

In making our estimates we assume that the acceleration time is 0.5 s, and the average acceleration is the same as in the UTSTAR project: $a =$17 600 m/s^2. Given these parameters, the length of the accelerator designed to launch the payload to the L_1 point is 157 m. Owing to this, the system is less expensive; the cyclotron is no longer needed; and the linear acceleration segment alone may be retained.

CONCLUSIONS

The energy needed to launch a payload from the Moon's surface to a low lunar orbit or even to the libration point L_1 is significantly smaller than that needed to launch the same payload from the Earth's surface to a low orbit. The total energy required to launch a 300-kg payload to a low Earth orbit is 44 GJ, while the energy needed to launch the same payload to a low lunar orbit is 78 times smaller, that is, only 564.48 MJ. The most important issue in the application of this technique is that the equipment can be delivered from the Earth only once.

Electric power may be generated by solar batteries located on the Moon's surface or by a nuclear power source that may also be delivered from Earth. It should be noted that nuclear power sources have already been utilized in space exploration.

The estimates we made show that this technique to launch various payloads from the lunar surface is rather promising (see review [19] and publications quoted there). In the future, when thermonuclear power will be available, a fusion-based power source may also be used. It may utilize the isotope ^{3}He as a fuel, which is present on the lunar surface.

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REFERENCES

1. T. M. Eubanks and C. F. Radley, Space Policy **37**, 97 (2016).
https://doi.org/10.1016/j.spacepol.2016.08.005
2. https://ru.wikipedia.org/wiki/Kosmicheskii_lift.
https://en.wikipedia.org/wiki/Space_elevator.

3. A. A. Bagrov, A. V. Bagrov, and V. A. Leonov, "Transport system Earth - Moon," RF Patent No. 121233 (2012).
4. A. V. Bagrov, V. A. Leonov, and K. E. Tsiolkovskii, in *Proceedings of the Tsiolkovskii 52nd Scientific Readings on Problems and the Future of Russian Science and Technology* (2017), p. 305.
5. K. I. Golovko, RF Patent No. 2665107 C2 (2018).
6. Yu. A. Sadov and A. B. Nuralieva, KIAM Preprint No. 39 (Keldysh Inst. Appl. Math., Moscow, 2011).
7. L. A. Artsimovich, S. Iu. Luk'ianov, I. M. Podgornyi, and S. A. Chuvatin, Sov. Phys. JETP **6**, 1 (1958).
8. V. Korotkov, V. Amoskov, M. Zenkevich, et al.., Radioelektron. Tekhnol., No. 3, 90 (2018).
9. D. A. Wetz, F. Stefani, J. V. Parker, and I. R. McNab, IEEE Trans. Magn. **45**, 495 (2009).
10. I. R. McNab, in *Proceedings of the IEEE 21st International Conference On Pulsed Power PPC, 2017*.
11. I. R. McNab, IEEE Trans. Plasma Sci. **46**, 3628 (2018).
12. V. Yu. Klyushnikov, I. I. Kuznetsov, A. S. Osadchenko, and Yu. N. Smagin, Vestn. NPO im. S.A. Lavochkina, No. 2, 58 (2020).
13. S. A. Poniaev, R. O. Kurakin, B. I. Reznikov, et al., Acta Astronaut. **135**, 63 (2017).
14. I. R. McNab, IEEE Trans. Plasma Sci. **48**, 4014 (2020).
15. Y. Zhou, P. Yan, W. Q. Yuan, et al., in *Proceedings of the IEEE Pulsed Power Conference* (2009), Vols. 1, 2, p. 1287.
16. I. R. McNab, IEEE Trans. Magn. **39**, 295 (2003).
17. V. K. Abalakin, E. P. Aksenov, E. A. Grebenikov, et al., *Manual on Celestial Mechanics and Astrodynamics,* 2nd ed. (Nauka, Moscow, 1976) [in Russian].
18. I. R. McNab, IEEE Trans. Magn. **35**, 432 (1999).
19. A. V. Bagrov, Vozd.-Kosm. Sfera, No. 1 (102), 90 (2020).