A railgun concept for space launches and return travel from the Moon.

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Abstract- This paper is one of a series of papers that will be published that will present the concept of a space launcher that is able to launch a vehicle from the Moon. In this paper we start addressing the electromagnetic characteristic of a railgun supposed to be located on the Moon. We present the geometry of the system proposed. The propulsion system is based on a synchronous motor and the system is provided with a levitation concept in order to limit friction problems. We estimate the energy needed to launch a realistic vehicle from the moon. A comparison between a superconducting linear synchronous motor and a permanent magnet synchronous motor is performed and it is shown how on the moon it is conceivable to use a propulsion not based on superconducting magnets. Finally, the computed estimations are summarized in order to set some design parameters.

1 Introduction

A new era of space launches is ahead of us. The return of mankind to the moon will shortly happen. Research for a manned mission to Mars is in an advanced phase. A key critical point of these journeys is that any vehicle that is supposed to do a return mission from Mars or the Moon must have all the needed fuel from the journey's beginning. This limits strongly the payload that can be carried and increase the cost of the mission. However, in the near space, the energy from the light of the sun is plenty available. Sunlight can be simply transformed into electrical energy by photovoltaic systems and, as a result, an electromagnetic launcher located on the Moon could provide a viable approach to the return travel providing the necessary energy for the flight back by using a PV installation. The idea of electromagnetic space launch has been already proposed [1]. However, to the knowledge of the authors, the launcher proposed has been thought to be located on the earth and this approach has several limitations (length of the runaway track, over heating of the vehicle because of the air friction etc.). Here, we propose a launcher to be located on the Moon designed to guarantee the flight back journey of a vehicle landed on the Moon and this solution promises to solve several issues.

This paper is one of a series of papers that will be published that will present the concept of a space launcher that is able to launch a vehicle from the Moon. The following papers will address the power electronics, the thermal features, the mechanical features, the PV systems, and the electromagnetic device needed to accomplish such a task.

In this paper, the main goal of this paper is to discuss whether the existing technologies related to linear motors, magnetic levitation and Photovoltaic systems could be integrated in order to assemble an electromagnetic launcher. In this paper we start addressing the general electromagnetic characteristics of a railgun supposed to be located on the Moon. We present the geometry of the system adopted.

The proposed propulsion system is based on a synchronous motor and the system is provided with a levitation concept in order to limit friction problems. A comparison between a superconducting linear synchronous motor and a permanent magnet synchronous motor is performed.

Finally, we will compute the energy needed to launch a realistic vehicle from the moon. These results will be the input to design the power electronics system and the PV installation needed to achieve this goal.

2 ENERGETIC CONSIDERATION

One of the main technological issue of space vehicles is the energy and one of the main constraints related to a constant presence of mankind on the moon is definitely the availability of a reliable and stable source of energy. If on one hand, the energy needs of a base on the moon can be guaranteed by using photovoltaic technologies, on the other hand at this moment the energy needed for the return travel of any moon-ship must be carried from the earth. This fact strongly increases the cost of any moon mission and strongly reduces the pay load, as a result the development of any electromagnetic launcher that has the capability to use the electrical energy produced by a PV installation and to have a vehicle reach the moon's escape speed could be an important technological advance.

One of the main issue on a space launch is related to the friction of the planetary atmosphere, the presence of the atmosphere is on one side a limit of the maximum speed that can be reached inside the atmosphere and on the other hand can be useful in the re-entry phase.

The moon does not have an atmosphere and, as a result this issue strongly eases the problem related to the reach of the escape speed on the moon.

Another feature that potentially eases an electromagnetic launch on the moon, is the reduced gravity of the moon. The gravity acceleration on the moon is:

$g_{moon} = 1.6 m/_{s^2}$ [1]

therefore this fact greatly eases the possibility to use magnetic levitation as a part of the launching system.

The moon's escape speed is:

$$v_{fmoon} = 2.2 \cdot 10^3 \ m/s \qquad [1]$$

This speed is roughly one order of magnitude higher than the speed already reached by the Japanese maglev system which has reached a maximum speed of 200 m/s. However, the speed of maglev system is limited on one hand by the friction with air (which increases the power required to reach higher speed as a quadratic function) and on the other hand by several constructive issues related to the fact the terrestrial gravity is as high as 9.81 m/s^2.

In order to estimate the energy needed to reach the escape moon speed, we assume to deal with a vehicle of 1000 kg.

As a result in order to reach the escape moon speed the launching system must transfer to the vehicle the following kinetic energy:

$$K = \frac{1}{2} m\, v_{fmoon}{}^2 = \frac{1}{2} 1 \cdot 10^3 \cdot (2.2 \cdot 10^3)^2 = 2.42 \cdot 10^9 J \quad [2]$$

If we assume to transfer this energy by limiting the vehicle's acceleration to a maximum of 4 g in the case of a manned mission, the acceleration runaway must have a length expressed by the following:

$$L = \frac{v_{fmoon}^2}{2a} = \frac{(2.2 \cdot 10^3)^2}{80} = 60.5 \cdot 10^3 m \quad [3]$$

This length can be reduced in the case of unmanned missions by increasing the acceleration.

The time needed to reach this speed can be calculated as follows:

$$t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{60.5 \cdot 10^3}{80}} = 38.9\ s \quad [4]$$

and the average power of the launching system can be estimated as follows:

$$P = \frac{K}{t} = \frac{2.42 \cdot 10^9}{38.9} = 62.3\ MW \quad [5]$$

Such a power and energy should be provided by a linear synchronous motor powers by a power electronics system.

The figures above are comparable with the typical steel and wheel traditional high speed train. For such a train the disclosed rated power is in the order of 10 MW and for a Maglev Japanese train the required power has not been disclosed but it should be in the order of 30 MW, so they are not very far from what is required for an electromagnetic launching system placed on the moon.

3 Geometry proposed

The principle of operation of a MAGLEV system can be described as in fig. 1 and 2.

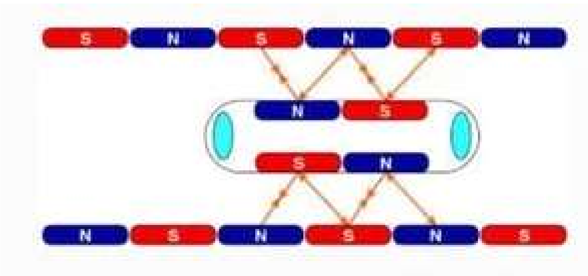

Fig. 1 Propulsion. Principle of operation in a Maglev system. The excitation magnets placed aboard interacts with the traveling wave generated by the propulsion coils placed on side of the track.

Fig. 1 shows how works the linear synchronous motor. Some magnets are placed aboard and the interact with a travelling magnetic wave generated by the armature installed on the side wall. The speed of the vehicle is controlled by adjusting the speed of the travelling wave (i.e. the frequency of the current flowing in the power coils).

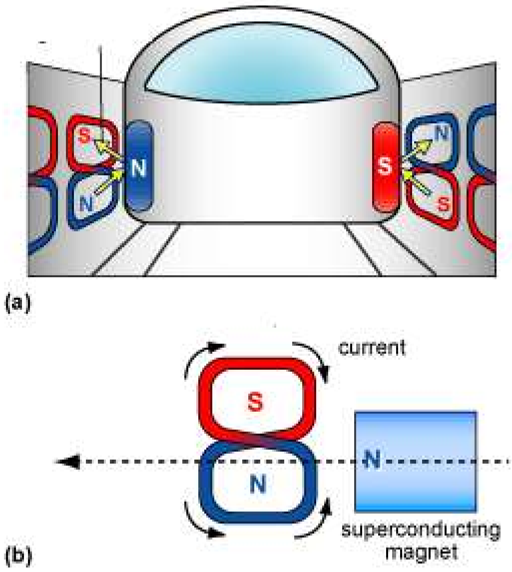

Fig.2 Principle of operation of the magnetic levitation in the Japanese Maglev System

Fig. 2 shows the principle of operation of the maglev suspension. The movement of excitation magnets generate a current on the suspension 8 shaped coil placed on the side of the track and the interaction between this current and the magnetic field of the excitation magnets generate a levitation force that stabilize the vehicle at a height that minimizes the current induced on the levitation coil. This position usually place the magnetic axis of the excitation coil slightly below the axis of the magnetic axis of the 8 shaped coils.

The proposed geometry is the same of that adopted in Japanese Maglev System that already has reached a speed as high as 200 m/s that is one order of magnitude lower than the Moons escape speed and it is shown in fig. 3. It is important to point out, that the structure shown in fig. 3 is an idealized section, the actual shape of the vehicle should be optimized considering all the dynamic aspects related to the space travel.

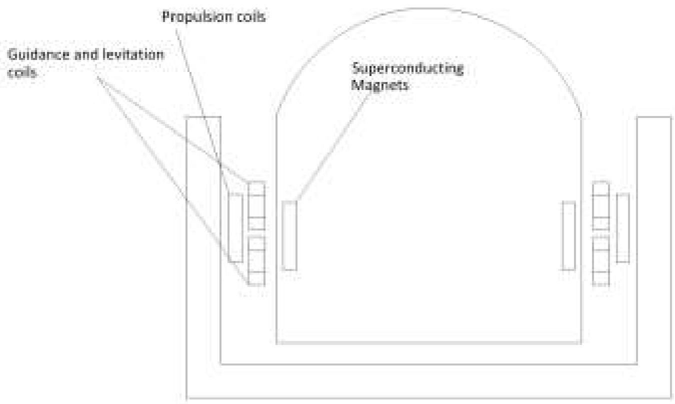

Fig.3 Cross section of the concept of electromagnetic launcher

4 ANAYTICAL MODE, THRUST AND LEVITATION CALCULATION

Referring to Fig.3, in [2] the authors present a circuit model of the system, that for the sake of brevity we are not presenting again. In [2] the authors show that the propulsion force can be expressed as follows:

$$F_p = \frac{P}{v} = \frac{3}{\sqrt{2}} \frac{n_m}{n_b} \frac{M_{s1}+M_{s2}+M_{s3}+M_{s4}}{L+M_{12}-M_{ab}} \frac{V_{ph} I_s}{v} \cdot sin\delta \qquad [6]$$

where F_p is the propulsion force, v the speed of the vehicle, n_m and n_b the number of magnets and coils, M_{xx} the mutual inductance between the coils placed aboard and on the side wall, L the self inductance, V_{ph} the phase voltage and I_s the superconducting current propulsion coil. It can be seen how the propulsion phorce depends on some geometric coupling parameters and on the superconducting current and the phase voltage. As a result one strategy to reduce the needs of superconducting magnets it could be possible to increase the phase voltage. This approach is difficult on the earth because air is not a good insulator causing difficulties inside electrical motors, but these difficulties are strongly reduced when adopting linear geometries in a vacuum space. As a matter of fact linear motors have much constrains than rotating machines to allocate conductors and the absence of air allows to have higher phase voltage. A phase voltage of 100 kV could be easily reached and that allows to reduce supeconducting currents of a factor 3 in comparison with the Japanese system where the voltage used is equal to 33 kW. The reduction of the superconducting current of a factor 3 implies that the flux density generated by the excitation coils is in order of 2 T allowing to avoid to use superconducting coil substituting them with more traditional and sturdy magnets.

In [**2**] the authors show that the levitation force can be expressed as follows:

$$F_L = 3n_m I_s Re\left\{\sum_1^4 I_i \frac{\partial M_{si}}{\partial z}\right\} = F_{LL} + F_{LP} + F_{LG} \qquad [7]$$

Therefore the levitation force consists of three terms: F_{LL} is the force generated by the vertical displacement, F_{LP} is the force generated from the applied voltage, F_{LG} is the force generated by the lateral displacement. It can be shown [**2**] that the dominant term is F_{LL}, that can be expressed as follows.

$$F_{LL} = \frac{3}{2\sqrt{2}} f(v^2) n_m I_s^2 \left[\frac{(M_{S2}-M_{S1})}{L_e} \left(\frac{\partial M_{S1}}{\partial z} - \frac{\partial M_{S2}}{\partial z} \right) + \frac{(M_{S4}-M_{S3})}{L_e} \left(\frac{\partial M_{S3}}{\partial z} - \frac{\partial M_{S4}}{\partial z} \right) \right]$$
[8]

Where the meaning of the symbols is the same as in eq. 6 and $f(v^2)$ is a function of the squared speed

In this case the levitation force depends on the square of the superconducting current, and therefore a reduction of a factor 3 of the current and consequently of the generated flux density implies a reduction of a factor 9 of the levitation force. However, this is not a big issue because the gravity acceleration of the moon is 1/6 of the terrestrial gravity acceleration and the speed of the vehicle is higher than the Japanese system allowing a higher levitation force.

This fact implies that also in this case it is conceivable to guarantee the excitation of the linear synchronous motor by using traditional magnets.

5 Conclusion

The calculation above shows clearly that the performance that the railgun should guarantee to be able to launch a vehicle for a return travel from the moon is equal or near to the performance already obtained on the earth. These results assure that the electromagnetic approach can be an approach to be considered in order to develop a vehicle that guarantees a space flight more economic than the techniques now used.

The maglev system that has been taken as a reference is the Japanese one. With reference to this system in this paper it has been shown that several changes can be adopted:

-the possible use of a higher supply voltage can avoid the use of superconducting magnets:

-the number of turns of the supply coil can be reduced;

-for un-manned journeys a much higher acceleration can be used, therefore reducing the length of the runaway track (few kilometers in comparison of the above calculated 60 kms).

However, probably, the most challenging aspect of this approach is to build such a large infrastructure on the moon, so that the initial cost to establish such an approach could be really huge.

7 Refrences

[1] Ian R. McNab, "Launch to Space With an Electromagnetic Railgun", IEEE TRANSACTIONS ON MAGNETICS, VOL. 39, NO. 1, JANUARY 2003

[2] J.L. He, D.M. Rote, and H.T. Coffey, “Study of Japanese Electrodynamic- Suspension Maglev Systems”, Center for Transportation Research, Energy Systems Division, 1994.