The Electromagnetic Drive: Cyclotron motion applied to spaceflight

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Abstract: In this research note it is proposed how the equilibrium between the Lorentz force and the centrifugal force in a crewed spacecraft acting as a tidally stabilised skyhook could prevent the spacecraft form deorbiting and reaching unbearable accelerations. A pair of superconducting electromagnetics would produce a constantly-increasing Lorentz Force, which would cancel the centrifugal force while producing the necessary acceleration. To avoid the effects of the centrifugal force, the crew would have to be immersed in water tanks. The proposed drive forms part of the Solar One project, a program intended to design the first crewed interstellar spacecraft.

Key-words: Lorentz force, centrifugal force, electromagnetic propulsion, skyhook, space tether, cyclotron motion.

1. Introduction

Space tethers are long cables which can be used for propulsion, momentum exchange, stabilization and attitude control, as well as maintaining the relative positions of the components of a large dispersed satellite or spacecraft sensor system.

One type of space tether is the skyhook. Specifically, a non-rotating skyhook is a vertical gravity-gradient stabilized tether.

Here I wish to discuss how a balance between the Lorentz force (which would act as the centripetal force) and the centrifugal force could provide a high yet bearable acceleration to a crewed skyhook-style spacecraft orbiting Jupiter.

The idea is to attempt applying cyclotron motion for charged particles in a magnetic field to a crewed spacecraft orbiting either the Sun or Jupiter. An spacecraft orbiting at scape velocity would leave the desired orbit, and the Lorentz force would gradually weaken.

A possible balance between forces could be achieved with the proper configuration of a system formed by a pair of superconducting electromagnets,

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one on each side of the spacecraft. These elements would provide the Lorentz force to the spacecraft while cancelling the centrifugal force.

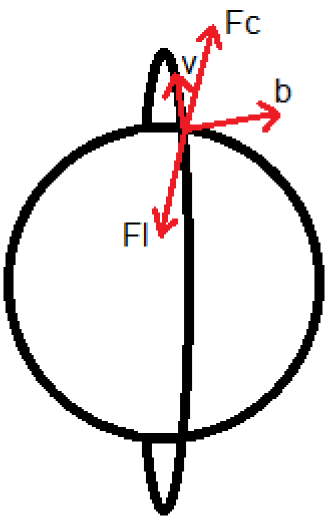

Figure 1: Balance between the Lorentz force (Fl) and the centrifugal force (Fc)

The electromagnetic system would constantly increase the Lorentz force in order to both prevent the spacecraft from deorbiting while it is being accelerated, and from producing an unbearable G-force to the crew. In theory, if the spacecraft is kept under a controlled constant acceleration, relativistic speeds could fall within the realm of plausibility.

2. Cyclotron motion around Jupiter

To calculate the Lorentz force needed to keep the spacecraft in orbit and produce the accelerate desired, we first need to determine the field strength at the geostationary orbit. Considering that Jupiter's Magnetic Dipole Moment is 1.55e+20 T.m^3, and that Juno's first flyby orbit was 4,200 Km, we obtain the following field strength:

$$B = M / r^3$$

$$B = 1.55e20 / 4{,}200{,}000\ ^3$$

$$B = 2.092 \text{ Tesla}$$

So, for example, at 1c, the centrifugal force would produce an unbearable acceleration of 57 million g. Water immersion increases tolerance to acceleration as the acceleration forces are equally distributed over the surface of the submerged body (Wood, 1991). Moreover, animal studies with mice have shown that mice immersed in water can withstand 3800 g for more than 15 minutes without any physical impairment (Rossini, 2007). If the crew is immersed in a water tank large enough during one minute (an amount of time that the crew could withstand without air in their lungs to avoid their damage), the following acceleration would be needed to reach 1c:

$$\boldsymbol{a} = \frac{v_1 - v_0}{t}$$

$$a = 300{,}000{,}000 - 10{,}000 / 60$$

$$a = 509{,}488\ g$$

To cancel the centrifugal force of 21.428e15 Newton, the electromagnetic system would have to produce an opposite Lorentz force equally strong. However, the Lorentz force has to be 5e11 Newton higher than the centrifugal force in order to maintain the spacecraft in orbit and produce the acceleration desired. In order to reach 1c, the Lorentz force would have to be the following:

$$F = q \cdot v \cdot B \cdot \sin(\alpha)$$

$$F = 8{,}928{,}784 \cdot 300{,}000{,}000 \cdot 2.092 \cdot \sin(90)$$

$$F = 21.429e15\ N$$

3. Cyclotron motion around the Sun

Finally, instead of using Jupiter to accelerate the spacecraft, it could be possible to use the Sun for the same purpose. The magnetic dipole moment of the Sun is 3.5e+24 T·m^3. Some NASA scientists have discussed the possibility of sending a crew as close to 6.4 million kilometres from the Sun (Mancini, 2018). The charge necessary to produce the same force obtained in the case of the spacecraft orbiting Jupiter would be the following:

$$F = q \cdot v \cdot B \cdot \sin(\alpha)$$

$$q = F / v \cdot B \cdot \sin(\alpha)$$

$$F = 563{,}988{,}532{,}840{,}410 / 300{,}000{,}000 \cdot 1.33e\text{-}5 \cdot \sin(90)$$

$$q = 141{,}350{,}509{,}484\ C = 39{,}264{,}030\ Ah$$

4. Discussion

Using the Jupiter instead of the Sun would entail a series of advantages. On the one hand, less power would be required. A charge of around 2,480 Ah would be needed to power the spacecraft orbiting Jupiter, whereas 39 million Ah would be needed if the spacecraft orbits the Sun. This difference lies in the fact that it would be easier to protect the spacecraft from Jupiter radiation than from Solar radiation.

The crew would need to immersed in a physiological water solution within a non-expandable rigid container, and using perfluorocarbon for liquid ventilation of the lungs. The Advanced Concepts Team of the European Space Agency has concluded that this set-up could presumably allow the crew to withstand accelerations higher than hundreds of G (ESA, 2007).

The g-force that the crew would have to withstand is 509,488 g. If we consider that the volume of a human is about 0.0664 cubic meters, and the maximum bearable acceleration of 10 g for one minute of duration, the water tank in which the crew is immersed would have a size of 15 meters.

For the case of Jupiter, the spacecraft would approach the planet from either the south or north pole in order to avoid the strongest radiation belts, as with the spacecraft Juno. More specifically, the crewed spacecraft would be sent to the orbit between Jupiter and its inner radiation belt.

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