The Electromagnetic Drive: Cyclotron motion applied to spaceflight

Alberto Caballero[1]

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 maximum constant acceleration that a crew could withstand during long periods of time. The acceleration phase would last 2.9 months, time in which the crew would be hibernating immersed in water tanks with liquid ventilation. 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 at geostationary altitude.

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,

[1] * alberto.caballero@uvigo.es

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

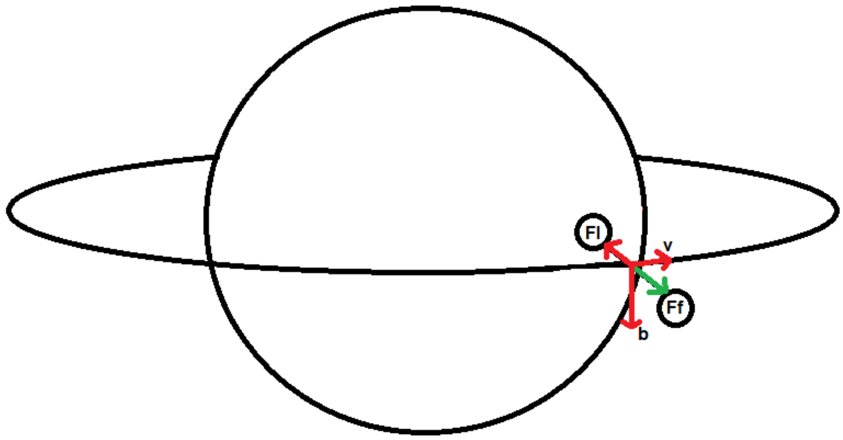

Figure 1: Balance between the Lorentz force (Fl) and the centrifugal force (Ff)

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

Current flux would need to be adjusted once the speed of 42,5 km (first cosmic velocity of Jupiter) is reached, in order to balance the forces and produce a constant acceleration. At this point, if we have a spacecraft with a mass of 1,000 tons, the acceleration produced by the centrifugal force would be the following:

$$F = m \cdot v^2 / r$$

$$F = 1{,}000{,}000 \cdot 42{,}500^2 / 226{,}721{,}837$$

$$F = 7{,}966{,}811$$

$$a = 0.8124 \text{ g}$$

Now, 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, we obtain the following field strength:

$$B = M / r^3$$

$$B = 1.55e20 / 226{,}721{,}837^3$$

$$B = 1.33e{-5} \text{ Tesla}$$

So, for example, at 0.5c, the centrifugal force would produce an unbearable acceleration of 10 million g's. To cancel this, the electromagnetic system would have to produce an opposite Lorentz force equally strong. However, the Lorentz force has to be higher than the centrifugal force in order to maintain the spacecraft in orbit and produce the constant acceleration desired. Considering that the crew could withstand a maximum of 4 g during a prolonged period of time (Poljak, 2018), the acceleration produced by the Lorentz force would be the following:

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

$$F = 13{,}817{,}959 \cdot 150{,}000{,}000 \cdot 1.33e{-5} \cdot \sin(90)$$

$$F = 99{,}240{,}581{,}557{,}950 \text{ N}$$

$$a = 10{,}119{,}724 \text{ g}$$

Considering an initial speed of 10,000 m/s, the amount of time that the crew would have to spend orbiting Jupiter in order to reach the speed of light is the following:

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

$$\mathrm{t} = 300{,}000{,}000 - 10{,}000/39.2$$

$$\mathrm{t} = 7{,}652{,}806\mathrm{sec} = 2.9\mathrm{months}$$

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 acceleration produced by the Lorentz force would be the following:

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

$$F = 489{,}509 \cdot 150{,}000{,}000 \cdot 1.33e{-5} \cdot \sin(90)$$

$$F = 3{,}515{,}654{,}605{,}050 \text{ N}$$

$$a = 358{,}496 \text{ g}$$

4. Discussion

Using the Sun instead of Jupiter would entail a series of advantages. On the one hand, less power would be required. On the other, the spacecraft would have to withstand lower accelerations.

In principle, Solar wind would not excessively discharge the spacecraft because it neutral overall, consisting of both negative electrons and positive ions. However, using the Sun would imply a higher threat from radiation.

In either case, the crew would have to be hibernating during the 2.9 months of the acceleration of phase. NASA has been working on a cryo-sleep design called TORPOR (Torpor Inducing Transfer Habitat For Human Stasis To Mars) (NASA, 2013), but a modified version of it would be necessary.

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).

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