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 a special pressure vessel. 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.

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. A 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.

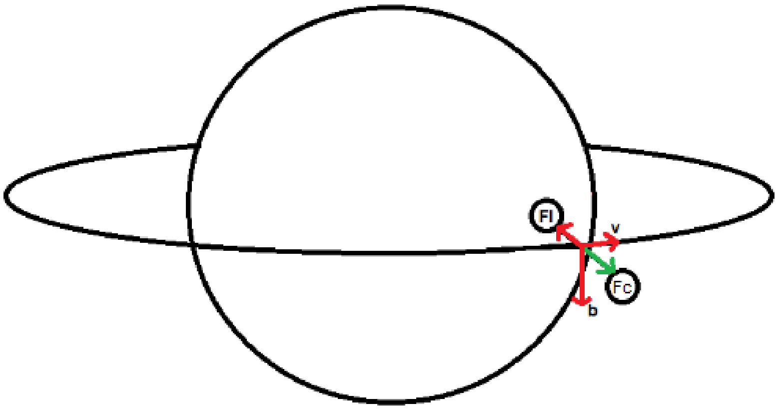

Figure 1: Balance between the Lorentz force (Fl) and the centrifugal force (Fc)

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 the Sun

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 the Sun’s Magnetic Dipole Moment is 3.5e+24 T.m^3, at 1 AU we obtain the following field strength:

$$\begin{aligned} B &= \frac{M}{r^3} \\ &= \frac{3.5e24}{147{,}110{,}000{,}000^3} \\ &= 1.099e-7 \quad Tesla \end{aligned} \tag{1}$$

The constant acceleration would be 4 g. This is because it is the maximum acceleration that the crew could withstand for long periods of time (Poljak, 2019). It would take almost 3 months to reach the speed of light:

$$
\begin{aligned}
a &= \frac{v_1 - v_0}{t} \\
\mathrm{t} &= \frac{v_1 - v_0}{\mathrm{F}} \\
&= \frac{300{,}000{,}000 - 10{,}000}{39.2266} \\
&= 7{,}647{,}617 \text{ sec} = 2.9 \ months
\end{aligned}
\tag{2}
$$

At 1 AU for example, the centrifugal force at the speed of light would be the following:

$$
\begin{aligned}
\mathrm{F} &= \frac{\mathrm{m} \cdot \mathrm{v}^2}{\mathrm{r}} \\
&= \frac{1{,}000{,}000 \cdot 300{,}000{,}000^2}{147{,}110{,}000{,}000} \\
&= 611{,}787{,}098{,}090 \text{ N}
\end{aligned}
\tag{3}
$$

Now we have to calculate the necessary force to produce a continuous acceleration of 4 g for the spacecraft:

$$
\begin{aligned}
F &= m \cdot a \\
&= 1{,}000{,}000 \cdot 39.2266 \\
&= 39{,}226{,}600 \ N
\end{aligned}
\tag{4}
$$

To cancel the centrifugal force of 6.1e11 Newton, the electromagnetic system would have to produce an opposite Lorentz force equally strong. However, the Lorentz force has to be 3.9e7 Newton higher than the centrifugal force in order to produce the acceleration desired. The total necessary charge would be the following:

$$\begin{aligned} \mathrm{F} &= \mathrm{q} \cdot \mathrm{v} \cdot \mathrm{B} \cdot \sin(\alpha) \\ \mathrm{q} &= \frac{\mathrm{F}}{\mathrm{v} \cdot \mathrm{B} \cdot sin(\alpha)} \\ &= \frac{611,826,324,690}{300,000,000 \cdot 1.099\mathrm{e}-7 \cdot \sin(90)} \\ &= 18,557,061,713 \ \mathrm{C} = 5,154,739 \ \mathrm{Ah} \end{aligned} \tag{5}$$

4. Cancelling the centrifugal force

Here I suggest the use of a pressure vessel to cancel the centrifugal force produced during acceleration. The crew would have to withstand a centrifugal force of 521.88e9 Newton. If we consider that the volume of a human is about 0.0664 cubic meters, in a pressure vessel with a size of 93.217 square meters, the axial or longitudinal stress would be the following:

$$\begin{aligned} \sigma\mathrm{L} &= \frac{P \cdot d}{4 \cdot t} \\ &= \frac{2,319,476,620 \cdot 9.6549}{4 \cdot 1} \\ &= 5,598,543,615 \ Pa = 812,000 \ Psi \end{aligned} \tag{6}$$

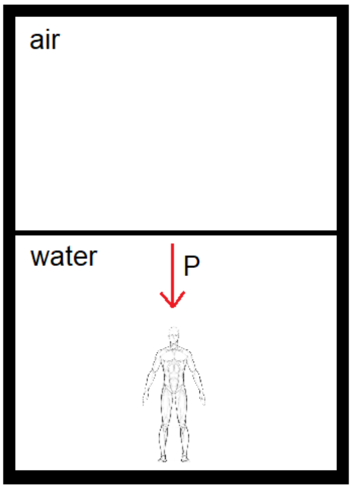

Figure 2: Pressure vessel immersion

5. Discussion

Orbiting Jupiter instead of the Sun to accelerate the spacecraft could be an alternative. The main problem lies in the fact that Jupiter’s magnetic field only extends out to 3 million kilometres. At this distance, the centrifugal force that the crew would experience at the speed of light is over 3 million g for a 1,000 ton-spacecraft. Moreover, at that distance, the field strength would only be 5.74e-9 Tesla. For these two reasons, orbiting the Sun is a better option.

The crew would have to be immersed in a pressure vessel and, therefore, the acceleration phase would be intermittent and last longer than 3 months previously mentioned.

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