Homopolar Artificial Gravity Generator based on Frame-Dragging

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Abstract

Space exploration is linked in many ways to the generation and challenges of artificial gravity. Space stations and drag-free satellite platforms are used to provide microgravity environments for scientific experiments. On the other hand, microgravity or reduced gravity environments such as on Moon and Mars are known to put limits for long-term human presence. Large centrifuges in space may provide Earth-like gravity environments during long-term travels, however, such technology certainly has its limits to provide similar environments for human outposts on other moons and planets. One can imagine a different technology using a prediction out of Einstein's general relativity theory which is called frame-dragging. In principle, frame-dragging might be used to generate artificial gravitational fields similar to electric fields generated by time-varying or moving magnetic fields. We will show that it is also possible to generate constant artificial gravitational fields that could provide microgravity or artificial gravity environments. Although such technology is possible in principle, the field strengths calculated from Einstein's theory are too small to be useful so far. However, recently detected anomalies around low-temperature spinning matter as well as fly-by anomalies point to possible enhancement mechanisms that might make an artificial gravity generator based on frame-dragging a reality in the future.

Key words:
Microgravity, Artificial Gravity Generator, Frame Dragging, General Relativity

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1. Introduction

Space exploration is linked in many ways to the generation and challenges of artificial gravity [1]. Microgravity environments are presently generated using drop towers, parabolic flights, sounding rockets, balloons or space stations and satellites. While Earth-based access is limited to around half a minute, space provides microgravity for periods from months to years until the space station needs to be re-boosted to maintain its orbit or until satellites have consumed their fuel. Therefore, long-term microgravity is linked to high costs and limited access.

Microgravity or reduced gravity on Moon or Mars poses challenges for long term human presence due to degeneration of muscles and bones, blood circulation etc. [2]. Besides in-flight countermeasures based on extensive training exercises, large rotating space-stations or space-ships are thought to be the only tool to generate Earth-like gravity in space [1]. Although this is a good possibility for long-term spaceflight, it is hardly an option for human outposts on Moons or planets as the generated force will be always at right angle to the planet's own gravitational field if the centrifuge is mounted on the surface. The only known technology to simulate gravitational fields on the surface of a planet is diamagnetic levitation using very large magnetic fields and objects with a magnetic susceptability less than zero. Since water is diamagnetic, it is possible to levitate living organisms including humans as demonstrated by Berry et al [3] with a frog inside the bore of a magnet with a field strength of 16 T. Although nowadays technology only enables such large magnetic fields over small volumes, it might be possible one day to extend this region to larger volumes. However, this technique only works for diamagnetic objects and the magnetic field must be finetuned just for one object. Ferromagnetic materials used in computers, tools, etc. would be obviously strictly forbidden inside such a chamber.

All of these technologies are simply based on Newton's mechanics using reactive forces (i.e. the centrifugal force from the orbiting space station exactly counterbalances the Earth's gravitational pull) or electromagnetism (diamagnetic levitation). However, one can imagine a different technology using a prediction out of Einstein's general relativity theory which is called frame-dragging that could indeed simulate a "perfect" artificial gravitational field.

Since Einstein's general relativity theory from 1915, we know that gravity is not only responsible for the attraction between masses but that it is also linked to a number of other effects such as bending of light or slowing down of clocks in the vicinity of large masses. One particularly interesting aspect of gravity is the so-called Thirring-Lense or Frame-Dragging effect: A rotating mass should drag space-time around it, affecting for example the orbit of satellites around the Earth. However, the effect is so small that it required the analysis of 11 years of satellite orbit data to confirm Einstein's prediction within 10% using the LAGEOS laser-ranging satellites [4]. The effect can be simply described as a magnetic-type component of gravity generated by moving masses [5]. Therefore, frame-dragging is also often called gravitomagnetism. In fact, to a first approximation, general relativity can be expressed by the Einstein-Maxwell equations which resembles ordinary electromagnetism but applied to gravity including a gravitational induction law based on time-varying gravitomagnetic (or frame-dragging) fields [5]. These equations allow one to compute the gravitational counterparts to classical electromagnetic effects. Many of such gravitational analogues can be found in the literature (e.g. [5], [6], [7], [8]).

This close analogy between gravity and electromagnetism allows us, in principle, to use frame-dragging fields to generate constant force fields using similar principles that we use to make constant electric fields (i.e. homopolar generators). Such force fields may be orientated against or towards Earth's gravitational field to simulate either microgravity or even hypergravity environments on Earth as well as Earth-like gravitational fields on other planets.

The advantages of such a technology would be enormous:

- Earth-based artificial gravity generators could provide similar long-term microgravity environments like space-stations but with easy access and much less costs to simulate the space environment,
- Space-based artificial gravity generators could be used to generate artificial gravitational environments for long-term spaceflights and to provide Earth-like gravitational environments for human outposts to enable long-term human presence in outer-space.

A first artificial gravity generator concept based on frame-dragging was described by Forward in the 1960s [5], that allowed one to provide time-varying artificial gravitational fields only by pumping matter through a coil wound up along a torous. However, since frame-dragging of even the entire Earth is so small, Einstein's equations require mass densities equivalent to the ones found in the core of a neutron star to produce frame-dragging fields that allow the generation of force-fields powerful enough to counterbalance the Earth's gravitational field. So at first sight, frame-dragging force-fields look more like a mathematical exercise rather than a real technology concept to generate artificial gravity. Recently detected anomalies around low-temperature spinning matter [9], [10], [11], [12], [13] as well as fly-by anomalies [14] point to possible enhancement mechanisms that might make an artificial gravity generator based on frame-dragging a reality in the future.

2. Design of a Homopolar Artificial Gravity Generator

Many examples of homopolar generators have been developed especially at the beginning of the electric age to generate direct current (DC), contrary to the usual alternating current (AC), such as the Faraday disc or the Barlow's wheel. The basis of all designs is the use of the Lorentz-force which acts on a charge that is moving perpendicular to a magnetic field. Similarly, a mass moving perpendicular to a frame-dragging field will produce a constant force which we might use to create an artificial gravity generator in order to extend Forward's time-varying artificial gravity generator concept [15] which was only based on the induction law and not on the Lorentz-force law.

Linearized general relativity closely resembles electromagnetism and we may use this formalism to design a homopolar artificial gravity generator. Two major assumptions are used in the linearization process which are

- objects move much slower than the speed of light so that special relativistic effects can be neglected,
- and gravitational effects are supposed to be weak in order to neglect space curvature effects.

Under these assumptions, general relativity can be described by a gravitoelectric (i.e. Newtonian gravity) and a gravitomagnetic part as well as the usual Lorentz force law. The gravitational version of the Lorentz force law is given by

$$\vec{F}_g = -m(\vec{g}_0 + 2\vec{v} \times \vec{B}_g) \tag{1}$$

where $\vec{g}_0$ is the gravitational acceleration and $\vec{B}_g$ is the frame-dragging or gravitomagnetic field. The major differences compared to electromagnetism

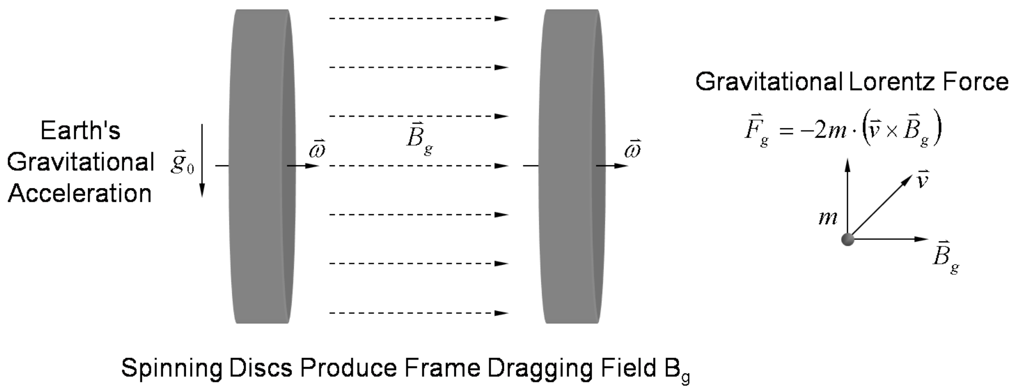

Figure 1: Principle of Generating a Lorentz-Type Acceleration using Frame-Dragging-Like Fields

are the minus sign since masses attract but similar charges repel, as well as the factor of 2 in front of the velocity $\vec{v}$ which originates from the spin-2 character of the graviton. The major challenge is to find a large frame-dragging field source. As magnetic fields are generated by moving charges, frame-dragging is generated by moving matter. For a rotating disc, the field strength at its center is given by

$$\vec{B}_g = \frac{4G}{c^2}\frac{m_0}{r_0} \cdot \vec{\omega} \tag{2}$$

where m_0 is the mass, r_0 the radius and $\vec{\omega}$ the angular velocity of the disc. The pre-factor $\frac{4G}{c^2} \simeq 3\times10^{-27}$ is the reason why classical frame-dragging fields are so small and in general require masses at least on the scale of planets to be detectable. Nevertheless, in principle such fields allow the creation of constant force fields as illustrated in Fig. 1. A pair of rotating discs has been used in this example as they will produce a quite uniform frame-dragging field between them similar to the uniform magnetic field between two Helmholtz coils. Let's assume that the rotation axis is horizontal above the Earth's surface. If now a mass m is moving at right angle to both the disc rotation axis and the Earth's gravitational acceleration, it will experience a constant force that points opposite or towards the Earth's gravitational acceleration $\vec{g}_0$ (depending on the disc rotation axis and mass velocity vector) to simulate either micro- or hypergravity if the rotation axis is oriented parallel to the Earth's surface.

2.1. Linear Generator

One can simply imagine a linear array of such spinning disc pairs and a cabin that moves between them as shown in Fig. 2. At constant ω and cabin velocity v, any observer inside the cabin will experience a constant artificial gravitational field. Assuming a homogenous field across the moving path and field strength close to the one at the center of the disc, we can approximate the absolute artificial acceleration as

$$|a| = v \cdot B_g \tag{3}$$

Let's assume a spinning disc with the highest density of all non-radioactive materials (Osmium), a radius of 3 m and a thickness of 0.5 m rotating with an angular velocity of $\omega = 3000$ rad.s^{-1}. With a cabin velocity of v=10 m.s^{-1} we can simulate an artificial gravitational field for a period of 100 s with an assembly length of 1 km and 166 disc pairs. Using Equs. 1 and 2, we can compute $|a| = 1 \times 10^{-18}$ m.s^{-2}.

So although we used extreme values for both the disc's density and angular velocities (the assumptions $v \ll c$ and weak gravitational effects are still valid), the resulting field strengths are unfortunately still too small to be detectible. However, it is indeed a possibility to simulate a "perfect" artificial gravitational environment that could be used on planet surfaces (Earth and human outposts). Materials in the far future will maybe enable to build generators with higher field strengths such as the one outlined here to generate Earth-like environments for humans on other planets.

Some controversial experiments have already been reported in the literature that may lead to larger-then-classical effects:

- In a series of conference papers, anomalous laser gyroscope signals above spinning matter at low temperature were reported that may be interpreted as largely-amplified frame-dragging fields [11], [12], [13]. Although this interpretation is controversial, the signature of the effect is not totally similar to classical frame-dragging (parity violation) as well as the measurements were not reproduced by other teams so far, it might point to an enhancement possibility for classical frame-dragging fields similar to ferro-magnetic materials that amplify magnetic fields. The anomalous gyro signals are some 18 orders of magnitude above

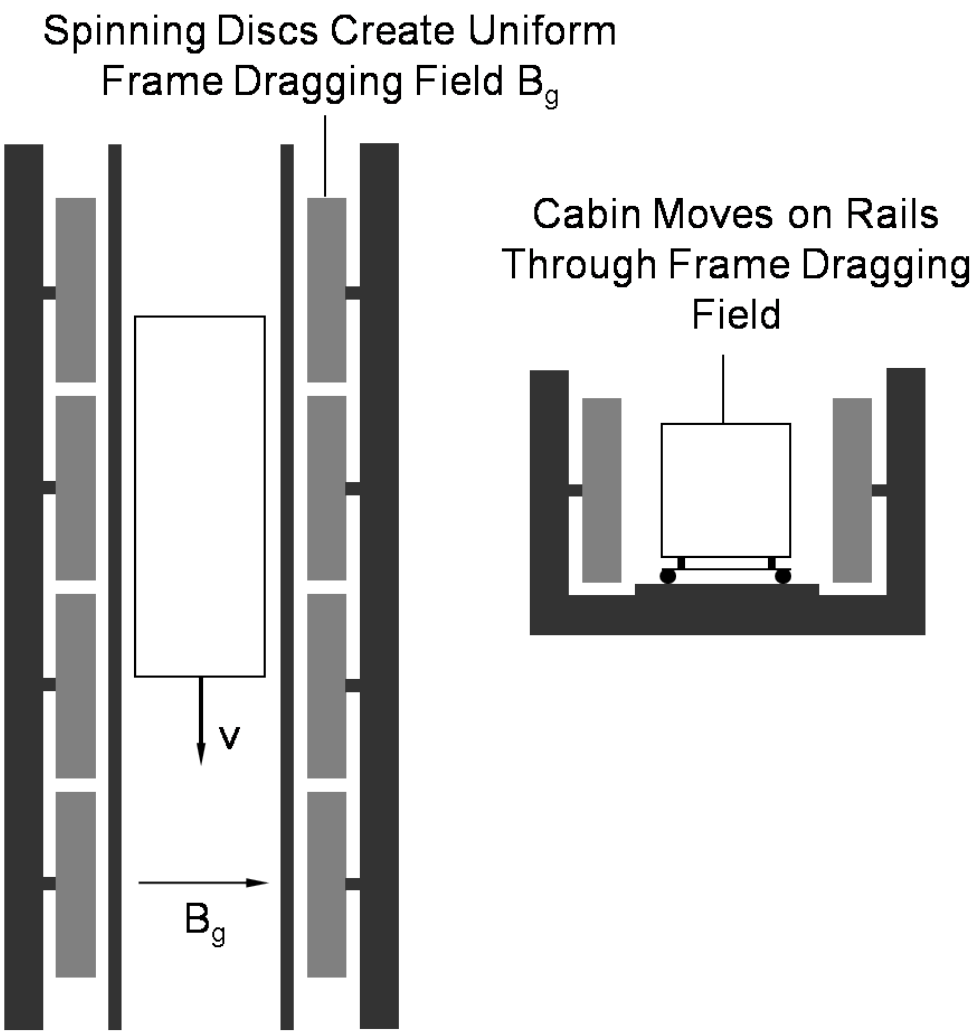

Figure 2: Linear Artificial Gravity Generator using Spinning Discs

classical predictions. By extrapolating these results to our linear assembly in Fig. 2, we find that if we would cool the spinning disc to temperatures below a critical value that triggers this amplification, our linear generator example could create artificial gravity environment in the order of the Earth's acceleration g_0. These numbers indicate that such an artificial gravity generator would appear feasible with present-day technology if the anomalous amplification effects exists and if it can be extrapolated to such designs and field strengths.

- A number of spacecraft trajectories were assessed in detail during their fly-by maneuvers around Earth. It was found that the spacecraft experience an additional force that may be interpreted by an amplified Earth's frame-dragging field [14] about 6 orders of magnitude above classical frame-dragging [16]. Also here, the nature of the effect is still unknown and its interpretation controversial, but it might lead to larger than expected frame-dragging fields.

Of course, it is not clear at this stage if and how such large frame-dragging fields may alter the validity of the gravitational Lorentz force law equation that was derived under the assumption of weak gravitational effects. However, even Earth-like gravitational fields as we are interested in may well be classified as a weak gravitational field since Earth's spacetime influence is still very weak.

2.2. Circular Generator

It would be preferable to generate such environments for much longer time periods than 100 s as with the linear assembly in the example above. That requires transforming the linear arrangement into a rotationally symmetric one as illustrated in Fig. 3 where r_c is the cabin radius and ω_a the assembly angular velocity. In this case, the cabin is maintained at rest and the spinning discs are rotating around the toroidal cabin. This avoids the centrifugal forces that would appear in addition to the artificial gravitational field due to a rotating cabin. We can now approximate the absolute artificial acceleration as

$$|a| = \omega_a r_c \cdot B_g \tag{4}$$

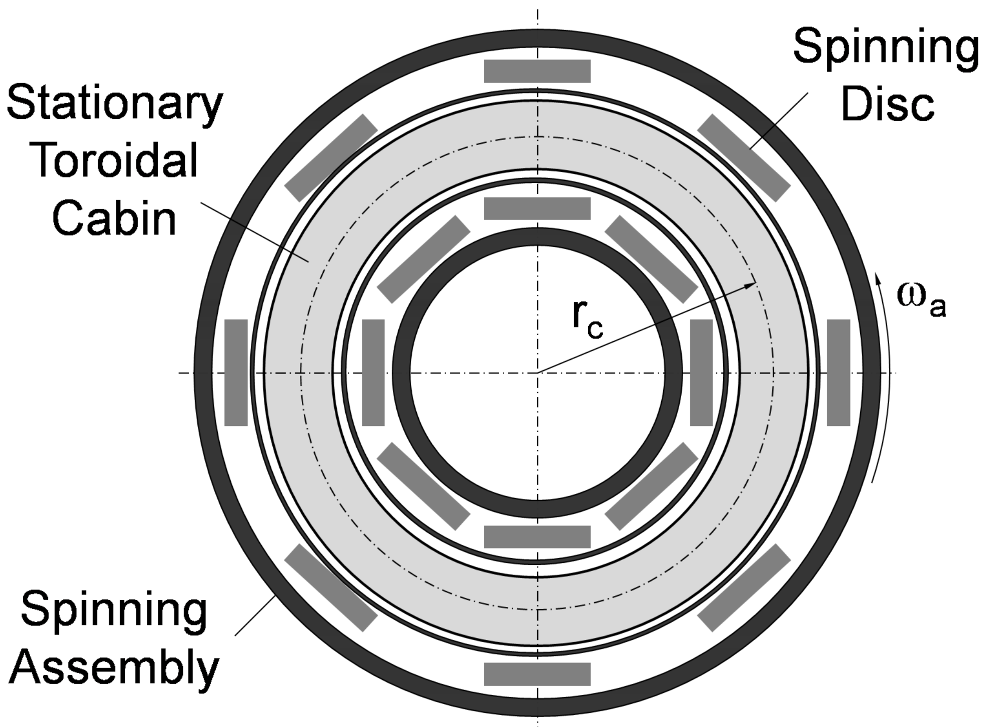

Figure 3: Circular Artificial Gravity Generator using Spinning Discs

In fact, our design now closely resembles a large centrifuge with the difference that the cabin stays at rest and the generator parts (the spinning discs) are rotating. The largest centrifuges built so far have a radius of 7 m [1]. However, there are designs of centrifuges using railways that enable a radius of up to 100 m and more [17].

Taking the same spinning disc pairs as in the linear configuration and cabin radius of r_c=100 m and an angular assembly velocity of ω_a=0.1 rad.s^{-1}, we would get the same artificial acceleration of $|a| = 1 \times 10^{-18}$ inside the cabin using the classical predictions from general relativity. However, in this case, this artificial acceleration is provided for unlimited durations. Such a design could form the nucleus of human outposts that can balance either micro-gravity of hyper-gravity environments to the Earth's standard gravitational acceleration. Of course, one would still need to find ways to enhance this effect as described above.

An artist view of such a facility is shown in Fig. 4.

3. Conclusions

In this paper we present two novel designs that can generate an artificial gravitational field using frame-dragging or gravitomagnetism, a magnetic-type component of gravity. This work extends a previous design from Forward [15] and enables constant force fields for potentially unlimited durations. However, since gravity is so weak, calculations using realistic values for material densities, size and speed yield very small artificial accelerations on the order of $|a| = 1 \times 10^{-18}$. Future amplification mechanisms are required in order to make such artificial gravity generators practical. Some effects reported in the literature may provide first hints towards "ferro-gravitomagnetism" although at a very early stage. In the far future, such designs may form the nucleus or human outposts that can balance either micro-gravity of hyper-gravity environments to the Earth's standard gravitational acceleration.

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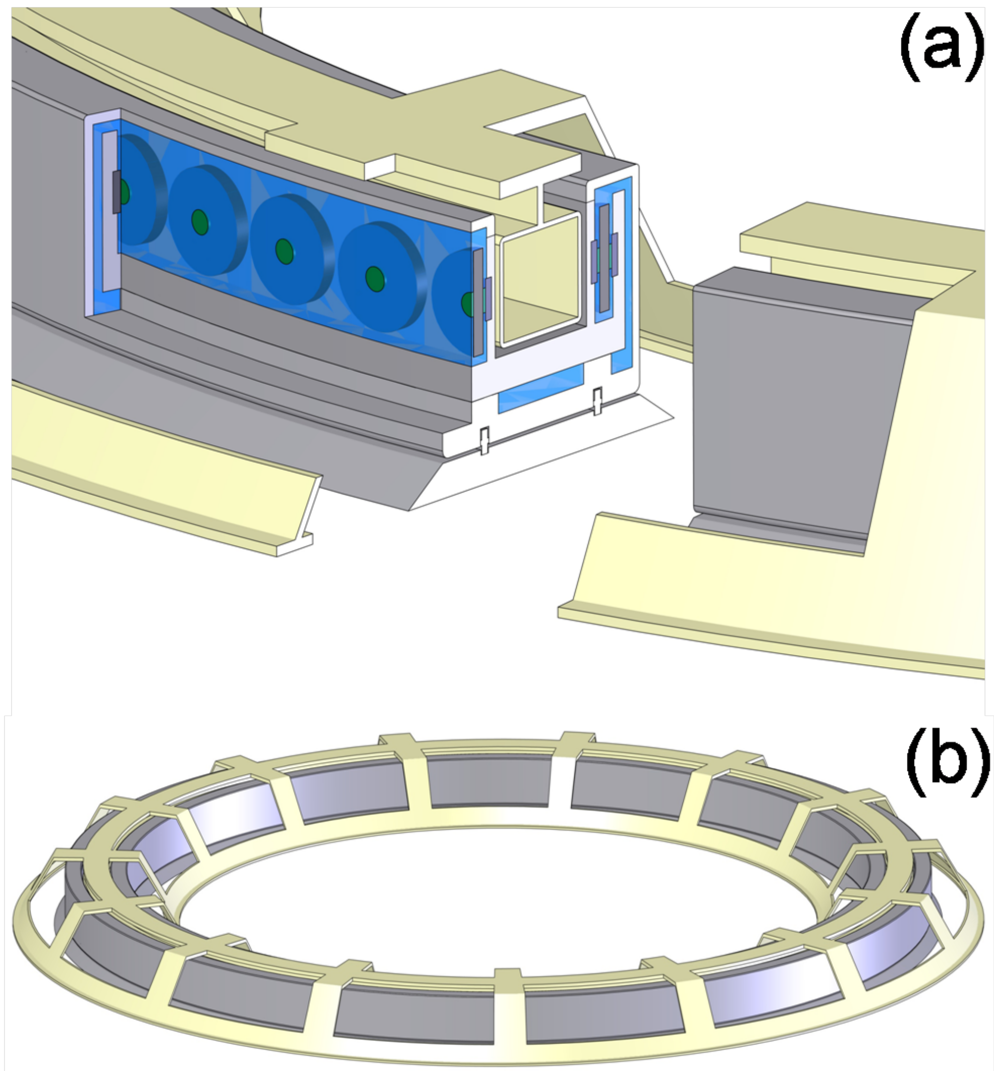

Figure 4: Artist View of Circular Artificial Gravity Generator: (a) Section and (b) Total View

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