Proposal for laboratory generated gravitomagnetic field measurement

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We describe how to create a measurable unbalanced gravitational acceleration using a gravitomagnetic field surrounding a superconducting toroid. Such a gravitomagnetic toroid has been experimentally quite impractical. However recent advances in nanorod superconducting wire technology has enabled a new class of SMES devices operating at current densities and magnetic field strengths sufficient to develop measurable gravitomagnetic fields, while still maintaining mechanical integrity. In the present paper an experimental SMES toroid configuration is proposed that uses an absolute quantum gravimeter to measure acceleration fields along the axis of symmetry of a toroidal coil, thus providing experimental confirmation of the additive nature of the gravitomagnetic fields, as well as the production of a linear component of the overall acceleration field.

Keywords: Gravitational, Gravitomagnetic, Lense-Thirring, Superconducting Magnetic Energy Storage, SMES, nanorods, nanowires.

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1. Introduction

When Forward[1] first proposed a gravitomagnetic toroid for unbalanced gravitational force production in 1962, any experimental realization was quite impractical. However recent advances in high-temperature superconducting (HTSC) nanorod wire (nanowire) technology[2] has enabled a new class of superconducting magnetic energy storage (SMES) devices operating at current densities and magnetic-field strengths sufficient to develop measurable gravitomagnetic fields, while still maintaining mechanical integrity. In the present study, an experimental SMES toroid configuration is proposed that uses a quantum gravitometer to measure acceleration fields along the axis of symmetry of a toroidal coil, thus providing experimental confirmation of the additive nature of the gravitomagnetic fields, as well as the production of a linear component of the overall acceleration field. See Fig. 1 for details.

In Forward's gravitational generation coil described in this paper, superconducting electron flow provides the change in mass current in the toroid.

2. Background

We summarize enabling developments in high-current-density nanorod conductors and the overall design and use of SMES devices, which are emerging as an alternate approach to energy storage that does not require chemical energy technologies.

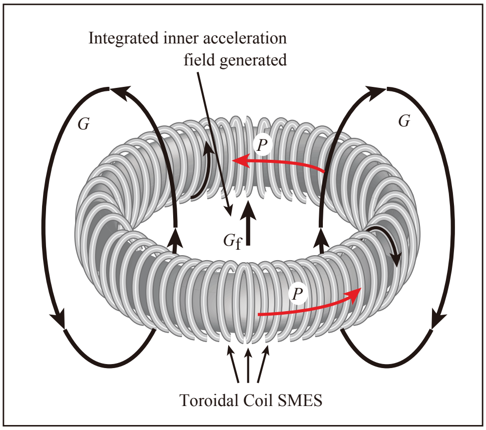

Figure 1. Gravitational force generation coil from Forward 1962[1] with an inspiraling mass current, with a vector potential P, creating gravitomagnetic field G, which is additive in the center.

2.1. *Superconducting Nanorods*

New developments in superconductor nanomaterial processing[3] led to nanotubular superconductors[2] with a T_c at 92 K. A uniqueness of the nanotubular and other geometric structures of HTSC makes for a practical wire form without using the melt texturing techniques which make for brittle thin films that are also difficult to shape into wire. Another aspect of these new HTSC materials is negation of post oxygenation at high temperatures. The elimination of this requirement makes room temperature forming and application of HTSC materials practical. The process has been demonstrated to be a low-cost and mass production method of superconductors which is scalable and without vacuum or cleanroom requirements.[2] These developments have led to the commercialization by True 2 Materials PTE, LTD (T2M) in Singapore, of a new HTSC wire using standard wire-making practices.

Although the critical temperature of the wire is 92 K, operation at 77 K in liquid nitrogen is more reasonable due to safety issues with gases and nitrogen's inertness, nonexplosive and nonflammable, as a cryogenic liquid. Currently T2M prototype wire is in the millimeter range and approaching the micron range. However, development of an HTSC wire, or filament at nanometer scale is on the roadmap[3] of T2M. The estimated diameter of the wire used in this study, currently theoretical, is 200 nm O.D. including insulation and a 30 nm O.D. HTSC core, with the total weight of the wire at approximately $0.001\,\frac{\mathrm{g}}{\mathrm{m}}$.

Individual wires make up a 19-nanofilament cable of 1 μm diameter as shown in Fig. 2, illustrating the compactness of the nanocable design. This allows the scaling up of the critical current limit, quenching aside, without adding significant weight to the toroidal coil. The individual nanofilament as described in Fig. 3 consists of a core (A), core sleeve (B), a highly insulated sleeve (C) with good heat-transport properties, and a high-strength gigapascal (GPa) outside sleeve (D), which also possesses

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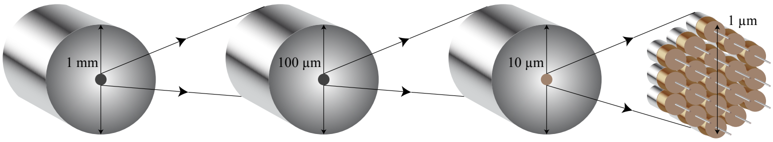

Figure 2. Representation of multiple filaments in a cable where each 1 μm yields 19 nanofilaments.

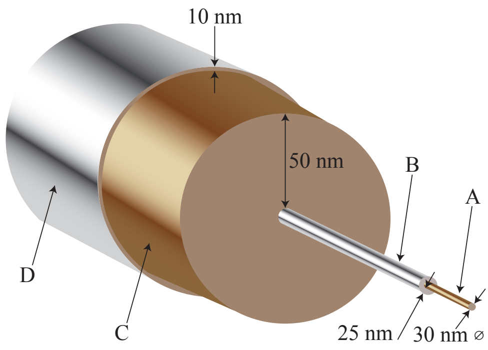

Figure 3. Detailed illustration of a nanowire filament.

good heat-transport properties at low temperatures. The main consideration for a candidate of the materials used in this study would be of carbon composition.

2.2. *Superconducting Magnetic Energy Storage*

SMES devices are an emerging battery replacement technology.[4] A typical application is shown in Fig. 4. The device is fed by a DC current, developing a magnetic field, typically in a toroidal geometry coil. When the need for emergency power is detected, an output switch is activated that provides DC current out, which may be converted to AC power by a power inverter.

Given the recent advances in nanowire technology, these devices are poised for remarkable improvements in capability in the very near term. With these coming improvements in this technology, and the similarity in geometry with the Forward design of Fig. 1, the present paper will study this technology at its limits for possible reapplication as a generator of an unbalanced DC gravitational force.

3. SMES Mass Current

The linear force, G_{f}, developed by gravitomagnetic force in the mass flow toroid of Fig. 1 is given by Eq. (1):[1]

$$G_{\mathrm{f}} = \frac{\eta}{4\pi} \cdot \frac{N\dot{T}r^2}{R^2}, \tag{1}$$

where G_{f} = gravitomagnetic force, η is gravitomagnetic permeability, $\eta = \eta_{\mathrm{o}}\eta_{\mathrm{r}}$, η_{o} = absolute gravitomagnetic permeability, η_{r} = relative gravitomagnetic permeability,

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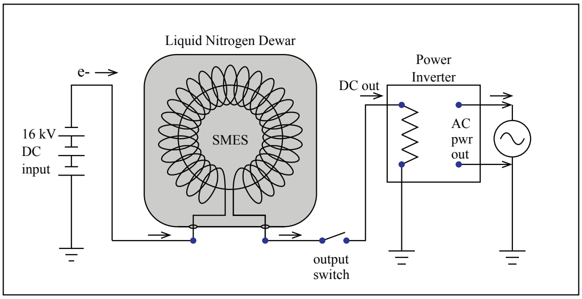

Figure 4. SMES in an energy-storage application.

N = number of turns in the coil of the torus, $\dot{T}$ = change in mass flow, r = the cross-sectional radius of the torus, and R = the centerline radius of the torus.

Change in mass flow for a single electron flow is given by

$$\dot{T}_{\rm e} = \dot{p}_{\rm e} = a \times m_{\rm e} = (\Omega \times v) m_{\rm e}. \tag{2}$$

This is equivalent to a centripetal force of

$$\dot{T}_{\rm e} = F_{\rm e} = m_{\rm e}\frac{v^2}{r} = m_{\rm e} a_{\rm e} = m_{\rm e}(\omega^2 r), \tag{3}$$

We now attempt to estimate the possible mass currents enabled by emerging nanowire SMES technology as it relates to the core geometry constraints described by a torus geometry. We start with the assumptions needed to calculate the number of turns, N.

For the purposes of describing an idealized case with a realistic geometry, we develop a description of a device bounded by a 10 m toroid centerline diameter and with a cross-sectional core diameter of 1 m. We further assume a conductor winding depth of 0.5 m wound about the core. Assuming each nanowire conductor has a diameter $d_{\rm c} = 100\,\mu$m, then the cross-sectional area of each conductor will be given by $A_{\rm c} = \pi r^2 = 7.854 \times 10^{-9}\,{\rm m}^2$. For packing the conductors described above to the winding depth described, it can be shown[5] that the total number of windings for the entire toroid can be as high as $N = 1.256 \times 10^9$.

What is $\dot{T}$ with the forgoing assumptions? In this idealized case electrons circulate about a coil of circumference c_r, or slightly larger, as described by $c_r = 2\pi r = 3.14$ m. Assume further a supply voltage of 16 kV, resulting in 16 keV of kinetic energy for each electron, which corresponds with the upper limit of a nonrelativistic case where, for idealized electron mobility, $v = 0.25c$, so that $\gamma = 1.06 \approx 1.0$. Then, from Eq. (3) for nonrelativistic circular motion, the vector change in DC current flow is

$$\dot{T}_{\rm e} = \frac{m_{\rm e} v^2}{r}, \tag{4}$$

which, for a single electron, has the following values: $m_{\rm e}$ = mass of the electron $= 9.11 \times 10^{-31}$ kg, v = velocity of the electron $= 0.25c = 0.75 \times 10^8\,\frac{\rm m}{\rm s}$, $r = 0.5$ m

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for the assumed geometry. The angular acceleration of the electron is

$$a_{\mathrm{e}} = \frac{v^2}{r} = 1.125 \times 10^{16}\,\frac{\mathrm{m}}{\mathrm{s}^2} \tag{5}$$

Thus, change in mass flow represents centripetal acceleration in the case of circular motion:

$$\dot{T}_{\mathrm{e}} = m_{\mathrm{e}} \times a_{\mathrm{e}} = 10.25 \times 10^{-15}\,\mathrm{N}. \tag{6}$$

Equation (6) corresponds to the change in mass flow for one electron in one loop of coil. Total mass-flow change is, therefore, the mass-flow change per electron times the number of electrons:

$$\dot{T} = \dot{T}_{\mathrm{e}} \times N_{\mathrm{e}}. \tag{7}$$

N_{e} in one loop can be described by the current I times the period of a single-loop circulation Δt:

$$N_{\mathrm{e}} = I \times \Delta t, \tag{8}$$

where, for idealized mobility, the period of an orbit in a loop can be described by

$$\Delta t = \frac{c_r}{v} = 2\pi\frac{r}{v} = 41.89\,\mathrm{ns}. \tag{9}$$

What is the possible current inside the idealized device for the case where the entire winding is in series? We make the assumption about max current to stay below critical current density of 250 $\frac{\mathrm{MA}}{\mathrm{m}^2}$. Current is limited by the maximum permissible current density and the cross section of the conductor t:

$$I = J \times A_{\mathrm{c}} \tag{10}$$

where J is material dependent. For the nanowire assumed in Ref. 2, $J = 250\,\frac{\mathrm{MA}}{\mathrm{m}^2}$. The assumed cross-sectional area $Ac = 7.85 \times 10^{-9}\,\mathrm{m}^2$ yields a maximum current of $I = 1.96\,\mathrm{A}$.

Expanding on Eq. (8), the number of electrons N_{e} in circulation in one loop may be calculated by noting that there are 6.24×10^{18} electrons per Coulomb.

$$N_{\mathrm{e}} = \left(\frac{\text{electrons}}{\mathrm{C}}\right) I \left(\frac{\mathrm{C}}{\mathrm{s}}\right) \times t = 5.12 \times 10^{11}\,\text{electrons} \tag{11}$$

4. SMES Forces

Expressing Eq. (7) as force per electron times the number of electrons in motion in one loop:

$$\dot{T} = \dot{T}_{\mathrm{e}}\left(\frac{\mathrm{N}}{\text{electrons}}\right) \times N_{\mathrm{e}}(\text{electrons}) = 5.248\,\mathrm{mN}. \tag{12}$$

Thus, each loop experiences about 5 mN of integrated centripetal force ($\dot{T}$) due to the electrons in circulation within.

We now describe the scale factor to couple the centripetal force to the gravitomagnetic effect. Revisiting Eq. (1), which describes the overall linear force developed at the center of the toroidal coil, total gravitomagnetically developed force will be

$$G_{\mathrm{f}} = \eta_{\mathrm{o}}\eta_{\mathrm{r}} \cdot \frac{N\dot{T}r^2}{4\pi R^2} = \eta_{\mathrm{o}}\eta_{\mathrm{r}} \cdot 5{,}248\,\mathrm{N}. \tag{13}$$

grouping known variables on the right and unknown variables on the left. This raises the question, What are the correct values for η_{o} and η_{r}? If η_{o} goes as $\frac{G}{c}$, as does gravitomagnetic potential (Ref. 6, Eq. (1.5)), then

$$\eta_{\mathrm{o}} = -\frac{G}{2c} = 1.11 \times 10^{-19}. \tag{14}$$

In this case $G_{\mathrm{f}} = 5.8 \times 10^{-16}\eta_{\mathrm{r}}$. Values of η_{r} are experimentally unknown at this time. However, if values of η_{r} track values of μ_{r}, then values as high as $\eta_{\mathrm{r}} = 10^6$ may be possible, yielding $G_{\mathrm{f}} = 5.8 \times 10^{-10}\,\mathrm{N} = 0.58\,\mathrm{nN}$.

Even with very sensitive quantum gravitometer, this would be a very difficult measurement. However, with additional current or winding count, a device scaled up from the idealized case considered in this paper may someday achieve a measurable DC gravitational field, even in the nonrelativistic case considered here.

5. Conclusion

An argument is made for using SMES to gravitomagnetically create an unbalanced force, possibly of measurable amplitude. Further research would be required to determine to what extent SMES devices could be operated into relativistic regimes to enhance relative mass flow change in the rest frame thus improving effect detectability.[5]

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