A laboratory scale Foucault pendulum for the measurement of frame-dragging

Matthew P. Cartmell* and Edmondo A. Minisci*

Department of Mechanical and Aerospace Engineering, University of Strathclyde, Glasgow, G1 1XJ, Scotland, UK

Abstract. A Foucault pendulum is generally considered to swing in a fixed orientation relative to the inertial frame of the fixed stars. However according to general relativity there is a small but finite precession over time of the pendulum swing plane relative to the fixed stars due entirely to the frame-dragging effect predicted by general relativity. This form of frame-dragging is represented physically by the Lense-Thirring precession of a gyroscopic test mass due to the proximity and the rotation of a massive body to the test mass. This precession may be calculated for various astrodynamic scenarios, but can also be modelled and calculated for a small test mass in the vicinity of the rotating planetary mass of the Earth. This manifestation of frame-dragging has already been measured in LEO by the GP-B and LAGEOS missions, but has not, to the authors' knowledge, been measured terrestrially as yet. The work described in this paper is one attempt to make this measurement, using a short, instrumented, Foucault pendulum in the northerly latitude of Glasgow in Scotland. The paper will summarise the work done to date to model the frame-dragging effect using the analogy of gravitoelectromagnetism, and then will focus on the modelling, the design and build of the Foucault pendulum which will be used to attempt the measurement, and will end with a brief summary of the requirements of the measurement itself.

Introduction

An inertial frame is considered not to accelerate in the usual detectable sense. General relativity shows that inertial frames are 'influenced and dragged by the distribution and flow of mass–energy in the universe' [1]. This frame-dragging influences the flow of time around a spinning body. An object on a prograde orbit will take longer to get back to the starting point than a similar object which is travelling retrograde on the same orbit. Twins travelling on exactly the same equatorial orbit but in opposite directions will age differently on meeting up at the starting point by around 10^{-16} s. This is the well-known twins paradox, and a consequence of frame-dragging. Frame-dragging was modelled by Lense and Thirring in 1918 such that inertial frames are dragged around a central rotating mass due to the effect of its gravity on the surrounding spacetime [2]. Rotation of the central mass twists the local spacetime and perturbs the orbits of other masses nearby. This is Lense-Thirring (LT) precession. The Earth's gravitational field is capable of generating frame dragging. We note that LT precession is based on both the presence and the rotation of a massive body in the proximity of a test mass. It is important to note that today, to the authors' knowledge, no terrestrial measurement has been made of LT precession. This is principally because of the extremely high level of accuracy required to discriminate the very small LT precession from other effects and noise, and the fact that this problem is compounded at non-polar locations.

Results and discussion

It is the aim of the research reported here to continue to move a little closer to making a reliable terrestrial measurement. Previous analysis of terrestrial LT measurement [3] obtained a prediction of 219.5 mas/year at the North Pole and 162.6 mas/year in Glasgow, Scotland. The polar value differs by 0.227% from the value of 220 mas/year calculated by Pippard [4] for that location. The work in this paper summarises the measurement of LT from the theoretical perspective of gravitoelectromagnetism, and goes on to propose a measurement algorithm for measurement of the LT precession of the laboratory Foucault pendulum with reference to the azimuth of a guide star. The main features of the Foucault pendulum are described and some of the initialisation tests are stated, specifically that an electromagnetically excited laboratory Foucault pendulum has been installed at the University of Strathclyde in a converted laboratory space and is currently being commissioned. It is 4190 mm in length terminating in a cylindrical copper bob of mass 2.54 kg. The pendulum is suspended from a pivot system designed for accurate and repeatable swing and precession. Bob motion is detected by an optical system, and an algorithm to detect the orientation of the pendulum swing-plane with reference to the azimuthal position of a guide star, and then the LT precession is to be accrued over time.

References

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