

Techniques for a High-Precision Frame-Dragging Measurement Using an Unsupported Gyroscope in a Drag-Free Satellite

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Abstract: A satellite experiment designed to measure the frame-dragging drift of an unsupported relativity gyroscope to an accuracy of about one part in 10^6 is described. High accuracy is achieved at ambient temperatures by using a pure unsupported gyroscope with a low noise autocollimator readout and by designing an experiment dedicated to frame dragging.

The Relativity-Gyroscope experiment consists of measuring the relativity drift of a gyro spin axis with respect to a reference star. There are two effects, the geodetic drift which has been discussed elsewhere [1] and frame dragging. Depending on the altitude, the frame-dragging drift is approximately 3×10^4 microarcseconds (μas)/yr; and an accuracy of 10^{-6} requires that the drift be measured to $0.03 \mu\text{as}/\text{yr}$. Such a small drift may be measured in an experiment designed especially for frame dragging. Besides the methods discussed in [1] which are applied to the measurement of the geodetic drift such as a low-noise autocollimator readout of the gyro, spinning the satellite with its attitude controlled to the gyro, using a bright reference star, reducing the telescope linear range and calibrating its scale factors with the aberration of starlight, etc.; there are several techniques which only apply to the frame-dragging case. These include having experiment runs that last 5 to 10 years, eliminating the star's proper motion by subtracting the result of two simultaneous frame-dragging measurements at very different altitudes, fine tuning the orbit to eliminate the geodetic-relativity and the gravity-gradient drifts, and repeating the measurement several times at different altitudes and averaging the results. The ideal frame-dragging experiment would use a polar orbit with the gyro spin axis perpendicular to the orbit plane and with a bright reference star exactly on the equator. This orientation is necessary to eliminate the geodetic drift which can be as much as 160 times as large as frame-dragging making it a major error source. In the real case no star is exactly on the equator; and it can be shown that because of orbital precession, the star must satisfy the declination-time condition, $t_e \delta < 8r_s^2 / 3J_2 R_e^2 n$ where t_e is the experiment duration, δ is the star's declination, r_s is the radius of the orbit, and n is the mean orbit rate. If the reference star satisfies this condition, it is possible to keep the average orbit plane perpendicular to the gyro so that the geodetic and gravity-gradient drift angles return to zero at the end of an experiment run. At 700 km this condition requires that $t_e \delta$ be less than about 300 arcmin-years.

Because of presumably known physics and prior experimental results, a frame-dragging drift measurement first becomes interesting when its accuracy exceeds about one part in 10^5 . Under the assumption that the Eddington parameter, γ , had already been measured to an accuracy of 10^{-8} or better, the experiment described here would be able to improve the bound on the Will-Nordtvedt PPN parameter, α_1 , to about 10^{-5} ; or if γ were large enough, it could provide a concordant measurement of γ . In order to determine the experiment errors and allow a unique interpretation of the results, it is important that the measurements be repeated several times at different altitudes giving the altitude signature of the effect. Repeating the measurements also greatly increases confidence in the results.

[1] B. Lange, *Phys. Rev. Lett.* **74**, 1904-1907, (13 Mar 1995).