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Reports

Magnetic Damping of Rotation of Satellite 1958β2

Abstract. From over 200 observations of the decreasing spin rate of Vanguard I made during the year since its launching, eddy-current induction theory yields 0.115 ± 0.001 gauss as the mean magnetic field normal to the spin axis of the satellite. This measured value agrees with that deduced from Bauer's model of the earth's dipole field.

The theory of the exponential decay of rotation of all celestial bodies due to magnetic induction of electric currents in them may now be demonstrated (*1*) experimentally with artificial satellites. Vanguard I (1958β2) has been tracked for a year by the Minitrack Branch of Project Vanguard, by radio signals from dipole antennas on the satellite. The signals are at maximum intensity for the antenna axis perpendicular to the line of sight. The time rate of this intensity variation, as a means for measuring the spin rate of the satellite, has been regularly deduced from station passage traces and tabulated for over 200 dates during the year since launching. Ten-day means of these spin rates, plotted in Fig. 1 on a logarithmic scale against the date, closely follow a straight line for which the relaxation time (that is, a reduction factor of 1/2.718) is 210 ± 3 days, from four determinations. Since the rotation rate ω was 2.72 rotations per second on Julian Date 2,436,280 (T_0), the empirical equation generally representing it is:

$$\omega = 2.72 e^{-(T-280)/210} \qquad (1)$$

rotations per second for $T = $ (J.D., 2,436,000) days. For the theoretical discussion below, it is convenient to use the equivalent form, with t ($= 86400\ T$) in seconds:

$$\omega = 2.72 e^{-5.51 \times 10^{-8}(t-t_0)} \qquad (1a)$$

rotations per second.

Now the general equation of rotational motion of any body about an axis having moment of inertia I, under a damping couple C, is:

$$\omega = \omega_0 e^{-C(t-t_0)/I\omega} \qquad (2)$$

Since, for Vanguard I, the moment of inertia I about the spin axis was measured before launching as 67,885 g-cm², Eqs. 2 and 1*a* show its observed total damping coefficient to be:

$$C/\omega = 67885 \times 5.51 \times 10^{-8} \text{ g-cm}^2\text{/sec}$$
$$= 0.00374046 \text{ g-cm}^2\text{/sec} \qquad (3)$$

We assume practically all this quantity to be due to magnetic damping couple on the satellite, since, at its range of height, other possible factors, such as aerodynamic drag on the antennas, would be relatively negligible. For Vanguard I, its almost continuous and complete spherical shell, 8.13 cm in radius, of aluminum alloyed with 2.5 percent magnesium and 0.25 percent chromium

0.081 cm thick, would be expected to be a major source of magnetic damping from induced currents. For any thin shell of radius r and thickness Δr, having conductivity σ, the damping couple due to a mean field $\overline{H}_{\perp}$ perpendicular to the spin-axis, and magnetic permeability μ is given by:

$$\frac{C_o}{\omega} = \frac{2\sigma\pi r^4 \Delta r \mu^2 \overline{H}_{\perp}^2}{3} \qquad (4)$$

For all light materials here involved μ is unity to four figures and, for this commercial alloy, the volume resistivity $1/\sigma$ is given as 5200 electromagnetic units (c.g.s. system) at 40°C (no thermal coefficient given; estimated as 0.003 per degree centrigrade) (*2*).

The other sources of magnetic damping in this satellite are several small cylindrical shells: (i) seven battery cans of cold-rolled nickel-plated steel for which $\mu = 100$ and $1/\sigma = 78$ may be estimated (*3*), and three instrument packages of aluminum, all of which rotate about their axes of symmetry, and (ii) six antennas and six antenna cups which may be considered to rotate chiefly about axes having a mean angle $\sin^{-1}(2/\pi)$ to the perpendicular to their axes of symmetry. The couple for the first group is given by:

$$\frac{C_1}{\omega} = 2\sigma\mu^2\overline{H}_{\perp}^2 h^2 r\left[r - \frac{h\pi}{4} + \frac{h^2}{\sqrt{h^2-4r^2}} \times \tan^{-1}\sqrt{\frac{h-2r}{h+2r}}\right]\Delta r \qquad (5)$$

where h is the height of the cylinder. For the battery cans, which are most important because of their magnetism, $r = 0.79$ cm, $h = 4.96$ cm, and $\Delta r = 0.0254$ cm.

For the second group of cylinders:

$$\frac{C_2}{\omega} = \sigma\pi\mu^2\overline{H}_{\perp}^2 r^3\left[\frac{h}{4} + \frac{11r}{24}\right]\Delta r \qquad (6)$$

Using the known dimensions involved in Vanguard I, it may be estimated that the couples given by Eqs. 5 and 6 amount to about that due to the spherical shell, or

$$\frac{C}{\omega} = \frac{2C_o}{\omega} = \frac{4\sigma\pi r^4\Delta r\mu^2\overline{H}_{\perp}^2}{3} = 0.00374046\,\frac{\text{g-cm}^2}{\text{sec}} \qquad (7)$$

where $\overline{H}_{\perp}$ is the only environmental quantity external to the satellite. A convenient quantity to describe the satellite itself would appear from Eqs. 2 and 7 to be:

$$I\omega\mu^2\overline{H}_{\perp}^2/C = K \qquad (8)$$

which might be named the "satellite damping constant." For Vanguard I the above theoretical derivation gives $K =$ 238,200 sec-gauss^2 = 2.757 day-gauss^2, which could be checked experimentally by spinning the satellite in a known magnetic field in the laboratory.

OBSERVED SPIN-RATE VS TIME FOR SATELLITE 1958 BETA 2 (VANGUARD I)
(STRAIGHT LINE REPRESENTS EXPONENTIAL DECAY WITH RELAXATION TIME OF 210 DAYS)

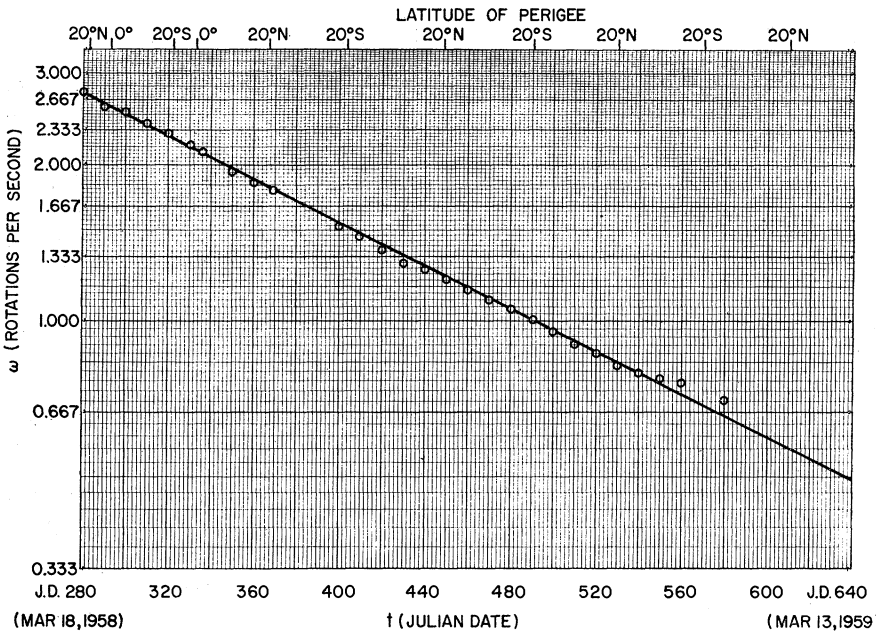

Fig. 1. Observed spin rate versus time for satellite 1958β2 (Vanguard I). The straight line represents exponential decay with a relaxation time of 210 days.

Equation 7 may be solved directly, using $r = 8.13$ cm, $\Delta r = 0.081$ cm, $1/\sigma =$ 5200, and $\mu = 1$, for the mean effective environmental magnetic field of Vanguard I in its orbit:

$$\overline{H}_{\perp} = \sqrt{\overline{(H_v \sin\alpha)^2} + \overline{(H_H \sin\theta)^2}} = 0.115 \pm 0.001 \text{ gauss} \qquad (9)$$

The probable error corresponds only to that of the measured relaxation time, 210 ± 3 days; it would be increased by the probable error of the satellite damping constant. Also,

$$\overline{H} = \sqrt{\overline{H_v^2} + \overline{H_H^2}}$$

is the mean total scalar field, for which the mean vertical and horizontal components, $\overline{H}_v$ and $\overline{H}_H$ bear angles α and θ to the spin-axis such that their mean sines are $\overline{\sin\alpha}$ and $\overline{\sin\theta}$, respectively.

It will be of interest to estimate these components so as to compare the total field with that indicated from geomagnetic ground surveys. For simplification of this discussion it will be assumed that the satellite is in its original orbit of eccentricity 0.19 having a geographical inclination of 34°, where the spin axis is tangent to the orbit in its plane at the perigee point, which is at a geographical latitude of about 22°N.

Obviously, the vertical component of the earth's magnetic field will always be approximately radial in the orbit plane. For the moderate eccentricity the mean value of its effective projection will differ little from that for a circle, i.e., $\overline{\sin\alpha} = 2/\pi = 0.637$.

The effective projection of the horizontal component is more complicated. We have for θ, the angle between the satellite axis and the meridian at any point of the orbit:

$$\cos\theta = \cos M \cos A \qquad (10)$$

where M is the mean anomaly at the point and A the azimuth of the orbital tangent. By spherical trigonometric relations A may be expressed in terms of M and the orbital inclination i, giving the exact relation:

$$\cos\theta = \frac{\cos M}{\sqrt{1 + \cot^2 i \sec^2(40° - M)}} \qquad (11)$$

The mean of this function may be estimated by numerical integration as $\overline{\cos\theta} = 0.338$, for which $\overline{\sin\theta} = 0.941$.

The magnetic dipole field of the earth is represented by the equations (*4*):

$$H_H = H_o \cos\phi_m \qquad (12a)$$

$$H_v = 2H_o \sin\phi_m \qquad (12b)$$

where ϕ_m is the magnetic latitude for a dipole inclined 11.5° to the geographic axis, and H_o has a mean value at the earth's surface given by Bauer (*5*) as

$$H_o = 0.3109 - 0.0002(t - 1922) \text{ gauss} \qquad (13)$$

For the Vanguard I orbit the range in magnetic latitude would be to about

45°, so the mean *ground* components and total field for $t = 1958$ would be:

$$\overline{H}_H = 0.304(4/\pi)\int_0^{\frac{\pi}{4}} \cos \phi_m d\phi_m = 0.274 \text{ gauss}$$

$$\overline{H}_V = 0.304(8/\pi)\int_0^{\frac{\pi}{4}} \sin \phi_m d\phi_m = 0.227 \text{ gauss} \quad (14)$$

$$\overline{H}_o = \sqrt{\overline{H}_H{}^2 + \overline{H}_V{}^2} = 0.356 \text{ gauss}$$

The mean field $\overline{H}$ varies as the inverse cube of geocentric distance, which, for the present satellite, ranges between 1.10 and 1.62 earth radii. Using as first approximation to its orbit

$$r = a(1 - e \cos M)$$

where $a = 1.36$ earth radii, $e = 0.19$, and M is the mean anomaly of the satellite, the time mean field, according to Bauer's theory, surrounding Vanguard I is:

$$\overline{H} = (0.356/2.52\pi)\int_0^{\pi} \frac{dM}{(1 - 0.19 \cos M)^3} = 0.142 \text{ gauss} \quad (15)$$

evaluated by numerical integration.

Now, to obtain for comparison the total mean field implied by the measured effective field of Eq. 9, we assume the mean ratio (invariant with radius in a dipole field):

$$\overline{H}_V/\overline{H}_H = 227/274 = 0.8286 \quad (16)$$

given by Bauer's theory. Solving Eq. 9 approximately for the mean total field gives:

$$\overline{H} = \overline{H}_{\perp}\sqrt{\frac{1 + (0.8286)^2}{(0.8286)^2\,\overline{\sin^2 \alpha} + \overline{\sin^2 \theta}}} \quad (17)$$

where, inserting the values found above, $\overline{\sin \alpha} = 0.637$, $\overline{\sin \theta} = 0.941$, and $\overline{H}_{\perp} = 0.115 \pm 0.001$ gauss, we find:

$$\overline{H} = 0.138 \pm 0.001 \text{ gauss} \quad (18)$$

as the mean total field implied by rotational damping. The agreement with the theoretical value given by Eq. 15 is satisfactory.

Perturbations in the mean effective couple on Vanguard I are to be expected to result from the regression of orbital nodes (3.019° per day), the advance of perigee (4.408° per day), the space-wandering of the spin axis, and the temperature variation of satellite resistivity. There seems to be perceptible evidence of such perturbations in the slightly wavy track of the radio-observed points in Fig. 1, but a precise study of such small effects would seem to await (i) frequent optical observation of reflections from some more efficiently designed satellite shape, such as a specular polyhedron (*6*), (ii) axis-orientation data, and (iii), experimental determination of satellite electrical and magnetic properties. The optical spin rate for Vanguard I on 10 January 1959 of 0.673 rotations per second, obtained from a Smithsonian Astrophysical Observatory photograph (*7*), which fits closely to the empirical curve of Fig. 1, would seem to be a first step toward more precise rotational studies.

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6 July 1959

Simplified Way to Cultivate Chick Kidney Cells and Maintain the Culture without Serum

Abstract. Chick kidney fragments were easily dispersed after incubation in trypsin solution for 1 hour at room temperature. The centrifuged cells were resuspended in Melnick's growth medium, diluted to 100 ml for each pair of kidneys, and seeded at 1 ml per tube. The cultures were maintained for 7 days or longer in the medium modified by replacing the serum with tryptose.

The methods of preparing cell suspensions by means of treating minced tissue with 0.25-percent trypsin solution reported by Youngner (*1*) and Bodian (*2*) required the use of a magnetic stirrer and took considerable time. In the course of a study of propagating avian viruses in chick kidney cell culture, a simplified technique for the preparation of the culture was sought (*3*). It was felt that, in order to avoid virus inhibitors or specific antibodies in animal serum in the culture system, development of a nonserum-containing maintenance medium which would maintain the culture for a period of a week would be desirable.

The cell culture was prepared from the kidneys of 1-week-old chicks. Kidney fragments were incubated at room temperature for 1 hour in 0.25-percent trypsin solution, prewarmed to room temperature, 10 ml being used for each pair of kidneys. The mixture was shaken vigorously by hand for 3 to 5 minutes until the pink tissue fragments disappeared. After the cell suspension had been centrifuged at 800 rev/min for 10 minutes, the sediment was resuspended in growth medium and filtered through four layers of gauze. The filtrate was further diluted with medium to a total volume of 100 ml for each pair of kidneys used. One milliliter of the cell suspension was seeded into each tube. A dense, full, cell sheet developed in 5 days. Melnick's growth medium was used; it contained 0.5 percent lactalbumin hydrolyzate (*4*), 10 percent calf serum, and 100 units of penicillin, 100 μg of streptomycin, and 100 units of mycostatin, respectively, per milliliter, in Hanks' (*5*) salt solution.

The culture was changed to maintenance medium as soon as a full cell sheet formed. The maintenance medium contained 0.5 percent lactalbumin hydrolyzate, 0.5 percent tryptose (Difco), and antibiotics, in Hanks' salt solution with 0.07 percent sodium bicarbonate. The culture remained in good condition for 7 days or longer. This maintenance medium has been used with satisfactory results for avian encephalomyelitis virus titration and neutralization tests which usually require 5 to 7 days' incubation.

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5 June 1959

A Nomenclature for Conformations of Pyranoid Sugars and Derivatives

Abstract. A system is presented for designating, with symbols, all chair and boat conformations of all pyranoid sugars and derivatives. For chairs, these symbols are *CA* and *CE*: for boats: B_1A, B_1E, B_2A, B_2E, B_3A, and B_3E. Symbols *A* and *E* describe an axial or equatorial "glycosidic" group of the α-anomers (D and L series).

A recent note by Guthrie (*1*) on a system of nomenclature for sugar conformers prompts us to describe one that we have devised. The two systems are much alike, but ours appears to be more concise. Features common to the two are: (i) use of carbon atom 1 as the point of