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P2_04 Making a Day Longer

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Abstract

The rotational speed of the Earth is very gradually slowing. This paper aims to investigate the possibility of artificially increasing the length of a day by accelerating the rate at which the Earth's spin is slowing down. It is found that no noticeable affect could be made in a reasonable time frame using current technology.

Introduction

It is well understood that the rotation of the Earth is slowing down. The momentum gathered in its initial formation is very gradually being lost to tidal friction caused by the Moon, it's estimated that the length of a day is increasing by 2.3×10^{-3} seconds per century [1]. The Earth's angular momentum is transferred to the Moon, the orbit of which is constantly increasing in size. While it is difficult to make an exact estimate of how the speed has changed throughout history, and the rate at which it will change in the future (changing temperatures, the polar caps and variations in the Earth's core all play a part) [1], we can be fairly certain that originally the length of a day was significantly shorter, and it will continue to get longer.

As most people are acutely aware there is rarely enough time in the day to get everything they would like to do done. However if it were possible to slow down the speed of the Earth's spin, the length of a day could be increased. To do this a force would need to oppose the direction of the spin, and although almost retired the current largest controlled and directed force comes from the thrust of a Space Shuttle. This paper assumes the possibility of using a stiff tether to connect the Space Shuttle to the Earth, perpendicular to the equator. The thrust could be applied on the ground, but it would generate less torque.

Model

The Earth has a dense core, a thick layer of mantle and a relatively thin crust, however if it modelled as a uniform sphere, then its rotational inertia is given by

$$I = \frac{2}{5} M_E R_E^{\ 2}, \qquad (1)$$

where M_E is the mass of the Earth (5.9742×10^{24} kilograms)[2] and R_E is the equatorial radius of the Earth (6378.135km) [3]. This gives the inertia as 9.721×10^{37}kgm^2. The angular velocity of the rotation Earth is calculated using

$$\omega = \frac{2\pi}{T}, \qquad (2)$$

where T is the period of the rotation of the Earth (86400 seconds). This gives the Earth's angular velocity as 7.27×10^{-5}s^{-1} (in radians). The Earth's angular momentum is given by

$$L = I\omega, \qquad (3)$$

which gives a value of 7.607×10^{33} Nms.

The Space Shuttle would have to apply a torque (or moment) against the momentum to slow down its spin. Using all of its engines (two solid rocket boosters, the external tank and 2 orbital manoeuvring engines) the Space Shuttle can provide a combined total thrust of 30.308×10^6N [4]. The torque is determined using

$$\tau = F \times R, \quad (4)$$

where F is the thrust of shuttle and R is the distance from the centre of the Earth that the shuttle was orbiting. The highest orbit the Space Shuttle has ever been in was during STS-82, which reached a peak distance of 618.568 km above the Earth [5] so this will be used, as it will provide the greatest torque. The maximum torque is then $1.933\text{x}10^{14}$Nm. To stop the rotation of the Earth entirely this would require the shuttle to maintain this thrust at that orbit for $3.656\text{x}10^{19}$ seconds (dividing the angular momentum by the torque) or 1158 billion years.

Discussion and implications

This is clearly an unfeasible period of time as the Sun will have expanded into a Red Giant, consuming Earth's remains long before this happens; and based on the estimates of the current natural slowing of the Earth's spin, it may have already stopped entirely. So to decrease the period necessary a greater thrust or a greater radius will be needed.

The Saturn V rockets had a total theoretical thrust of 40.2MN, but due to the separation sequence preventing all engines from being able to fire at once they had a peak thrust of 34MN [6]. The N1 (the Russian equivalent of the Saturn V) had a thrust of 43.0MN, but it never achieved orbit [7]. The maximum torque the N1 could have generated in same orbit is $3.00\text{x}10^{14}$ Nm, which would equate to 816 billion years to stop the Earth's spin entirely. To merely increase the length of a day by 1 second it would still take 94.4 million years ($816\text{x}10^{9}/86400$). If the radius is increased to the distance to the moon (384403km) and all 13 Saturn V rockets were used (a thrust of 442MN) it would still take 15000 years to add one second. A significant decrease, but still far too long to be practical. To reduce the time period to something sensible, a thrust on 1TN would need to be applied at a distance of 1AU. By doing this it would only take just over 1 year to increase the length of a day by 1 minute.

The problem then becomes supplying enough fuel. Each Saturn V rocket used around $2.15\text{x}10^{6}$kg of fuel during stage 1 (peak thrust) which gave a burn time of 150 seconds [8]. Scaling it up, this example would need around $4.5\text{x}10^{11}$kg of propellant, although this isn't necessarily impossible if it could be somehow sourced from a large asteroid.

Conclusion

In conclusion the Earth's angular momentum is far too great for current technology to make any noticeable difference to the length of a day. The force needed to slow the Earth in a reasonable time period is significantly more than anything we are capable of generating in a controlled thrust. Several other major hurdles would need to be overcome such as supplying the fuel, creating the tether, and the huge costs that would come with such a project.

References

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