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HOW TO SPIN A PLANET

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The rotation periods of planets like Venus may render them less suitable for terraforming. This paper describe how to spin a planet to obtain a 24-hour day. Dynamic compression members, formed from high-velocity mass-streams, thrust along the planet's equator, producing the required torque. Energy is obtained from a light-sail windmill in solar orbit. This procedure is more efficient and less costly than earlier concepts; a rotation rate of one revolution per day could be achieved within ~ 30 years.

1. INTRODUCTION

Although Venus has long been thought of as Earth's sister planet, it spins very slowly - only one retrograde revolution in 243 days. It has been suggested [1,2] that the rotation could be increased by bombarding the planet with ice-moons or asteroids off-centre. However, rotation periods as short as 24 hours are not easily obtained. Moreover, the procedure is a costly one, using up far too many valuable asteroid and far more water-ice than is actually required for the creation of planetary oceans. Serious loss of atmosphere to space may also result.

Spinning a planet with antimatter or fusion rocket engines has been considered by a number of authors [1,3,4,5] but the level of power required and the difficulty of operating through an atmosphere, seem to make this technique slow and costly at best.

An interesting proposal [5,6] after Dyson [7] is to turn the planet into a kind of electric motor. The system as described seems unnecessarily complex. A simpler option may utilise a homopolar motor [8], with a dipole field along the rotation axis and an electric current flowing radially outwards from the equator and back down at the poles. In either case, removal of angular momentum at an adequate rate may present difficulties (employing solar tidal forces demands orbital masses 10^{19} kg). Spin-up times of a few thousand years have been claimed.

A rapid-terraforming proposal [9] by the present author abandoned the "brute-force" method of spinning the planet bodily for the cheap and immediate technique of deploying a large soletta mirror in a 24-hour orbit, to provide the desired diurnal cycle. However, some degree of continued maintenance would be required; and there is a school of thought which claims that terraforming ought to leave planets in a stable state, persisting over geological time, without further manipulation.

This paper presents a concept for spinning up planets in a reasonable time - say 30 years - at a modest cost. It should be read in conjunction with Refs. 9-14, where the basic techniques and assumptions are more fully described. This concept is the best of a variety of spin-up ideas utilising orbital rings and momentum transfer that have been examined. Earlier attempts were considered inadequate, because of inefficient energy use, long timescales, or the enormous masses required for rapid spin-up.

For definiteness, we shall stick with the problem of spinning up Venus to a rotation period of 24 hours but it will be apparent that the same technique could be used for other planets, other spin rates and other purposes, such as the centrifugal disruption of gas-giants [6,7].

2. SPINNING UP VENUS

Figure 1 shows how to spin a planet by means of dynamic compression members [14], transferring momentum and energy *via* high-velocity mass-streams to a band about the planet's equator.

Spinning up the planet demands an access of kinetic energy. This may be generated by a light-sail windmill close to the Sun, a particularly cost-effective approach [13].

The kinetic energy of the windmill can then be transferred to a high-velocity mass-stream (v >>300 kms^{-1}), coupled though a co-circular electromagnetic travelling wave accelerator. This accelerator, capable of driving pellets to relativistic speeds, is a "spin-off" of a technique for relativistic interstellar travel which it is hoped to address in future papers.

The accelerated mass-stream, having looped around the Sun on the accelerator's circular track, is projected on a course for the equatorial limb of Venus. There it is caught and slipped onto a track girdling the equator. Once on the track, the mass-stream can enter a reversing loop, shown schematically in the diagram, prior to being launched back towards the Sun.

Because the reversal is essentially lossless and the mass-streams have a very high velocity, they are slowed only slightly - by twice the planet's circumferential velocity ~500 ms^{-1} - on each pass. This small change can be made up by the pellet accelerator as the stream swings back around the Sun.

The reversal loops and equatorial tracks are fixed relative to the planet's surface, and thus share its rotation, but the mass-stream pick-ups have to circle the planet backwards at the circumferential velocity, on the fixed tracks, in order to maintain their position on the terminator.

Spin-up parameters for Venus are obtained as follows. Given that $M_{Venus} = 4.9 \times 10^{24}$ kg and $R_{Venus} = 6056$ km, the moment if inertia, $I_{Venus} \approx 0.33 M_{Venus} R_{Venus}^2$ 6.0×10^{37} kg^{m2}, a little less than for a uniform sphere. The present rotational energy is negligible, so for a rotation period of 24 hours the kinetic energy

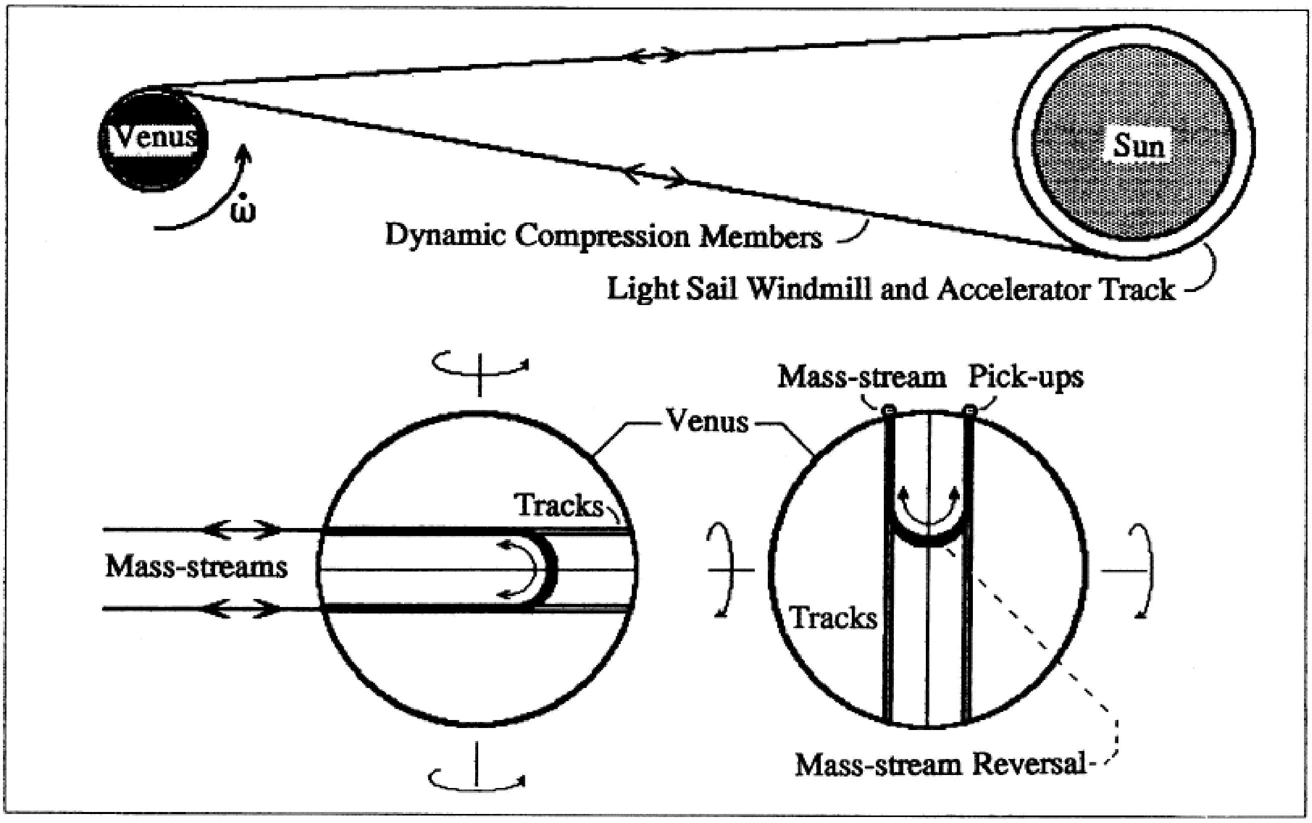

Fig. 1 Spinning Venus with dynamic compression members.

required is ½ $I_{Venus}\,\omega^2 \approx 1.6 \times 10^{29}$J.

If light-sail windmills provide energy at ~5×10^{-17}£J^{-1} for sails of areal density ~3×10^{-4} kgm^{-2} [9,10] the rotational energy required will cost ~8T£.

The net tangential impulse to be applied at the equator is $Ft = I_{Venus}\,\omega / R_{Venus} \approx 7.2 \times 10^{29}$ Ns. For a spin-up time of 10^9s ≈ 30 yr the force required is therefore $F \approx 7.2 \times 10^{17}$N. Throughout spin-up, the net weight of Venus in the Sun's gravitational field is reduced by this amount, about one part in 10^5, and the planet's orbit is temporarily slightly enlarged.

At the Sun, this force can be taken up by a stationary counterweight of ~5×10^{15} kg (costing ~5T£), distributed along a track close to the Sun in a gravitational field ~240 ms^{-2}. The mass-stream track may be permitted to drop below the windmill track if the light-sail material cannot stand the heat that close. Alternatively, a more massive counterweight can be used further out.

At Venus, the 7.2×10^{17} N can be applied to the rock of the planet through an area ~ 3×10^8 m^2, the mass-stream being reversed within a radius ~10^7 m. This corresponds to an acceleration ~ 10^{10} ms$^{-2}\beta^2$, where β is the stream velocity as a fraction of the speed of light. The thickness of fused rock capable of withstanding this acceleration without collapse is ~0.25 mm/β^2, suggesting the suitability of mass-streams with $\beta \leq 0.25$.

The mass of the dynamic compression members [14] is ~9×10^{11} kg/β^2. Provided that $\beta \geq 0.02$, this is much less than the counterweight mass. Thus, choosing β~0.1, the cost of the stream should be only a small fraction of the total cost.

The energy stored in the dynamic compression members [14] is $E \approx ½\ FD \approx 3.9 \times 10^{28}$ J, where $D = 1.08 \times 10^{11}$ m is the distance from Venus to the Sun. At a quarter of the total amount of rotational energy that must be provided, this is not negligible; if we reduced the spin-up time below about ten years it would begin to dominate. For relativistic mass-streams the stored energy is doubled, so it is advisable to keep the stream velocity below the relativistic domain.

Although either continuous or discrete mass-streams could be employed, in view of the long passage though open space, where accidents may easily happen, a pellet stream is probably preferable. The loss of a few pellets would not be significant.

Thus, a mechanism has been outlined whereby the rotation of Venus can be accelerated over some thirty years to the rate of one revolution per day, at a cost ~13T£. This could fit into the terraforming scenario of Ref. 9 before the colonisation of the cooled surface, between epochs 2100 and 2130 AD, where the additional expenditure could be funded out of income.

However since the Venus sunshade would still be necessary in order to attenuate the excessive solar flux, it is debatable whether physically spinning the planet is after all advantageous. One argument in its favour is the generation of natural weather through the Coriolis effect, which is dependent on the planet's physical rotation.

This technique could also be employed to *de-spin* rapidly rotating planets, with a net production of useful energy. For example, if a supramundane planet is to be built around Uranus [10], its rotation - once every 10¾ hours at an inclination of 98° to its orbit - is best eliminated first, by a force ~ 1.1×10^{20} N over 30 yr. This might cost ~750T£ (~ ½% of the cost of Supra-uranus) and release ~ 2.1×10^{32}J of rotational energy at ~4×10^{-18} £J^{-1}.

Changing the spin of the Sun is less simple. For an equatorial speed of 365 km/s (when $I_{Sun} \approx 0.2\,M_{Sun}R_{eq}^2$, $R_{eq} \approx 1.43\,R_{Sun}$ and centrifugal disruption begins) the full solar output would be required to supply the necessary 2.7×10^{40} J in 2 Myr.

Although utilisation of the Sun's internal heat [10] could reduce that period to ~2000 years (at 1000 L_{Sun}), it would appear that spin-up and centrifugal disruption is not the most attractive approach to stellar mining.

Moreover, even complete reversal of the planets' orbits would fail to supply the requisite angular momentum (by a factor of

2.3); whilst coupling the equatorial force of ~2.2 x 10^{24} N (at 1000 L_{Sun}) to the non-rigid Sun through its magnetic field would require that field to be increased many-fold to ~1T.

However, despinning the Sun (thrusting outwards on the planets at one end and against the Sun's limb at the other) could provide a useful 10^{36} J at low cost.

It is evident that dynamic compression members could also be used in changing planetary orbits, albeit with greater difficulty than in changing their spins. This is the topic of another paper in this issue [15].

3. CONCLUSIONS

We conclude that high-velocity dynamic compression members can apply large torques efficiently, allowing planets to be spun and despun on convenient engineering timescales ~30 years; that the cost of such operations is not excessive in conjunction with terraforming or artificial-planet-building projects; that energy can be converted to and from energy of rotation with little loss; and that the technique may also apply to the modification of planetary orbits.

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