Magnetic Propulsion Along an Orbiting Grain Stream

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If a stream of grains is in orbit about a central body such as the sun, a vehicle could accelerate along the stream using magnetic propulsion. After reaching a high velocity, i.e., a significant fraction of the speed of light, the vehicle could reach the end of the stream and enter free space. Although such a system would require investments in space beyond present levels, it could be realized without major technological advances. One of the requirements of a propulsion system using an orbiting grain stream would be maintenance of the grain-stream shape. Vehicles traveling along the stream with low relative velocities could be used. Some of the problems of maintaining the stream are discussed, as well as maintenance-vehicle requirements.

Nomenclature

a = acceleration
B = field intensity, T
D,D' = torus diameter before and after swelling, respectively
M = vehicle mass
P,P' = mechanical and magnetic pressures, respectively
q,q' = constants
r = distance to the sun
V,v = orbital and relative speeds, respectively
W,w = mass of grains per meter and mean grain mass, respectively
x = specific susceptibility of substance

Introduction

CONSIDER a stream of paramagnetic grains with a circular cross section and a uniform distribution in orbit around a central body such as the sun (Fig. 1). The stream should not form a complete loop around the orbital path, but it could be complete except for a gap.

Consider also a flight vehicle with a solenoid around a hole in the vehicle (Fig. 1). If the vehicle is placed such that the stream passes through the hole, the solenoid can create a magnetic field such that the vehicle accelerates along the stream. When the vehicle reaches the end of the stream at the gap in the loop, it would fly off into free space. The velocity could be a significant fraction of the speed of light.

A third system requirement is as follows. Because the stream shape and orbit would change, a maintenance vehicle would be needed. The maintenance vehicle would also have a solenoid around a hole that would be placed around the stream. The maintenance vehicle would circulate around the entire stream orbit at a low relative velocity. The magnetic field of the maintenance vehicle would be adjusted to give the stream the desired circular shape when leaving the hole of the maintenance vehicle. The maintenance vehicle would also adjust the orbit of the stream as required to correct for any unwanted changes, such as those caused by the accelerating flight vehicle. More than one vehicle would be required. The spacing between maintenance vehicles is discussed below.

Typical Application

Although many missions could be flown using the flight vehicle, an example is presented herein to better understand the size of the system. A stream of $NiSO_4$ grains with a stream length mass of 35 kg/m and 10^5 grains/m of stream length is placed in circular orbit around the sun at a distance on the order of Earth orbit. A 1000-ton vehicle could reach $\simeq 5000$ km/s with a field of 1.6 T and an acceleration of $\simeq 50$ m/s^2 along a stream length of $\simeq 0.25$ of the circumference of the orbit. If the stream diameter is 1 m before the flight vehicle arrives, it will swell $\simeq 3$ cm when the vehicle passes at maximum speed.

Stream Flattening

One of the changes in stream shape that might need to be corrected by a maintenance vehicle is the tendency of the stream to flatten into rings (Fig. 1). Each grain is in a slightly different orbit, and all of the orbits tend toward a line one-quarter of the circumference away from an initial point where the stream has a circular cross section. This phenomenon has been discussed in Refs. 1 and 2. Maintenance vehicles would have to pass a section of stream before a significant flattening occurs, or before a significant fraction of one-quarter of the circumference. Since a stream at a distance from the sun near that of the Earth would take a year to orbit the sun, maintenance vehicles would have to pass on the order of weeks.

Vehicle Following Stream

In this section it will be shown that a vehicle accelerating along a stream will follow the stream. The stream is assumed to have a circular cross section provided by sufficient passes of maintenance vehicles.

If the flight vehicle is moving as the stream ($v=0$) when a first nonmagnetic start impulse is exerted, the vehicle tends to reach the perihelion or aphelion of a new trajectory according to the direction of the impulse. With no grains within, the axis of the vehicle initially aligned with the stream axis would rotate. However, if the vehicle moves along the stream, mechanical pressure on the stream is

$$P = Mg^2/2, \quad \text{with} \quad g = v(2V \pm v)/r, \quad \text{and} \quad v = at \qquad (1)$$

Actually, the grains inside the winding will resist any coil axis torque by an opposite magnetic pressure. If this pressure balances P, the vehicle will continue along the stream with its new speed up to the end of the stream. Acceleration will cause a relative motion, and it is known that a single grain moving in a solenoid's field is subjected to a magnetic centering pressure, acquiring a moment and behaving like a magnet—N and S poles aligned with the field lines (Fig. 1). This grain acquires a certain amount of energy when moving from a region where $B=0$ to the middle of the solenoid, and an equal amount when moving out. The total energy contributes to magnetic pressure.[3]

With a stream of grains, interactions between grains will resist axis deformation by stream swelling, with the grains developing mutual repulsion since alternate N and S poles are aligned in all of the planes along the orbital path (Fig. 1).

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Longitudinal accelerations are opposed in the two halves of the coil, and attraction between consecutive grains cancel one another, swelling remaining only radial. Through the field, weight exerts radial convergent forces all around the torus, balanced by divergent repulsive forces (exploding effects).

Concentrated along the axis, the mass of grains strengthens the local field so that the radial gradient is directed outward, and expansion occurs because the grains are confined within a volume smaller than the solenoid. The grains act as spokes-springs radially compressed around a wheel axis and pushing away an elastic rim when released; each grain acting like a growing "magnetic bubble" to occupy a volume proportional to its own force potential. These swelling forces will dissociate grains and restore radial spacing as the stream flows, and on moving out, the grains become neutral again. If grain debit and field B are adequate, the stream thus sustains the vehicle through swelling around an axis at a constant altitude, with v remaining constant. As magnetic pressure is

$$P' = vB^2/2q^2, \quad \text{with} \quad q = (\mu^0/2Wx)^{1/2} \tag{2}$$

$$B = qg(M/v)^{1/2}, \quad \text{with} \quad P' = P \tag{3}$$

When $P' \neq P$, swelling occurs around an axis deviated upward or downward (Fig. 2). Due to eccentric penetration, a component of the swelling force then increases or reduces v until $P' = P$, but the vehicle and the coming stream remain on rendezvous trajectories tangent at a point rotating at a speed of $V \pm v$ relative to inertial space, the angle of attack reducing as $P - P$. Eccentric penetration could also be due to an uneven stream path. Both causes of eccentric penetration would have resulting effects.

Thus, vehicle and stream are linked like "needle and thread," balance being reached only when penetration is normal with $P' = P$. As P varies more rapidly than P', P ultimately will balance P', and in the meantime, the stream is deviated upward or downward (Fig. 2). The coil acts as a pressure vessel moved upstream when losing pressure downstream, and v remains constant ($P' = P$), increases ($P' > P$), or decreases ($P' < P$) until $P' = P$. Thus, a definite value of B attains the following velocity:

$$v' = (Br/q)^{2/3}(1/M)^{1/3}, \quad \text{with} \quad g = v^2/r \tag{4}$$

After a nonmagnetic start, the flight vehicle will therefore accelerate through its own field until the above speed is reached (Fig. 2).

If $P' \neq P$, $(P' - P)$ is the potential acting for propulsion. If B remains constant, $(P' - P)$ is reduced as v increases until $P' = P$ (Fig. 2). Acceleration will be reduced accordingly, v' reached in a long run along the stream. $(P' - P)$ also can be kept at an adequate level to reduce the runway length and keep a constant if B varies as a function of v.

Setting $P' - P = kP$, then $a = kg$, and

$$B' = q(Mg/v)^{1/2}(g+a)^{1/2} \tag{5}$$

If B' is constant, a decreases until v' is reached for that field. As

$$v' - v = at/2, \quad t = 2(v' - v)/a \tag{6}$$

where t is the time to reach balance, and a and v are initial values.

Stream Shaping

Magnetic acceleration of flight vehicles will change the orbit of the stream. But deviations will remain moderate if acceleration is not too high, and over a long period, circulation in both directions will tend to maintain a mean stream path near the initial orbit. Maintenance vehicles could also correct unwanted deviations through combined force and field actions. The stream should be forced to swell before total flattening is reached to restore a uniform distribution of grains. Entering the magnetic field of any vehicle with a definite mean diameter, the grain stream will swell and leave it with a larger one. Force being the energy gradient, the mean spacing increase is $M(g+a)w/vW$ [from Eqs. (2) and (5)], and

$$D' = [q'M(g+a)/v + D^{2/3}]^{3/2} \quad \text{with} \quad q' = (w/W)^{2/3}(4/\pi)^{1/3} \tag{7}$$

Thus, magnetic propulsion cannot be used at the start or until v has reached a significant level.

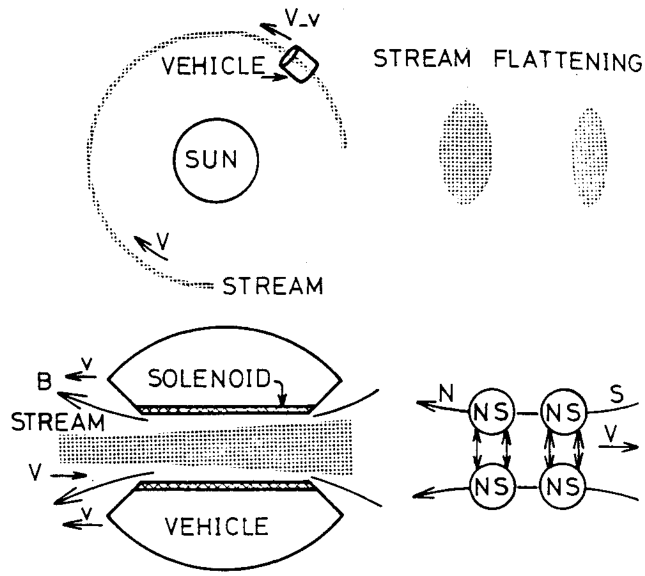

Fig. 1 Relative positions of vehicle and stream.

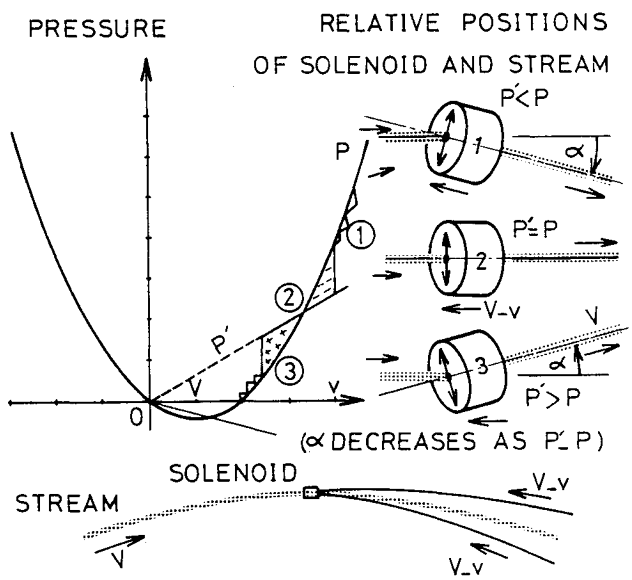

Fig. 2 Balance dynamics between vehicle and stream.

Maintenance Vehicle Spacing

The stream of grains will not remain perfectly parallel after leaving each vehicle. The most deviant grain will leave the stream at some rate. The next maintenance vehicle must arrive at that part of the stream before the most deviant grain moves so far from the stream that it will not enter the hole of the maintenance vehicle. This leads to a rather high accuracy requirement on the parallelism of the stream or frequent vehicle passes. Actually, the stream should tend to maintain parallel flow, and the maintenance vehicle should require only small corrections. Highly accurate stream aiming should be possible under such circumstances.

Concluding Remarks

A space transportation system using a stream of grains in orbit and a flight vehicle with magnetic acceleration along the grain stream has been discussed. Maintenance vehicles would be needed to keep the stream shaped and in the desired orbit. Although such a system would require a large investment in space transportation, it could be realized without major technology advances.

References

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