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A2_3 Terraforming Mars: Creating a Magnetic Field

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Abstract

This paper investigates the possibility of generating a magnetic field on Mars by using a single turn coil. It was found that the current needed to create a magnetic field of similar magnitude to that of the Earth's is 9.47×10^8A. In order for a cable of copper to be able to carry this current without melting it was found that it would need a radius of 70.4m. The power that is needed to run this coil was found to be 2.06×10^{13}Js^{-1} which is 121% of the power used on Earth every second.

Introduction

Due to the increasing population of the Earth and the constraints this will cause on the resources available, there has been much talk of moving to other planets. Mars is a prime target for future expansion due to its location in the solar system. However, Mars' magnetosphere is currently too weak to provide protection to an atmosphere from solar radiation. Should any atmosphere be formed on Mars it would be stripped away by solar radiation. This paper works out what size electromagnet would be needed to create a magnetosphere of the same magnitude as Earth's. The electromagnet is modelled as a single turn coil of copper around the equator of Mars.

Discussion

The magnetic field strength of a planetary dipole is given by [1],

$$B = B_{eq}(1 + 3\cos^2\theta)^{\frac{1}{2}}\left(\frac{R_E}{r_r}\right)^3, \quad (1)$$

where; B is the magnetic field strength, B_{eq} is the magnetic field strength at the equator, θ is the colatitude, R_E is the radius of the Earth (6371km), and r is the radial distance. We used a colatitude of 0° (magnetic North Pole), $r_r = R_E$, and B_{eq} on Earth as 31μT[2].

The value of B obtained was 62μT. It was assumed that the magnetic field strength at 0° colatitude on Mars would be the same as that on Earth at this position [2].

The magnetic field strength for a single turn coil is given by [3],

$$B_z = \frac{\mu_0}{4\pi}\frac{2\pi R^2 I}{(z^2 + R^2)^{\frac{3}{2}}}, \quad (2)$$

where; B_z is the magnetic field strength at a point on the z-axis, μ_0 is the permeability of free space, R is the radius of the loop, I is the current, and z is the distance along the z-axis. In this situation the z-axis is the line traversing the poles with its centre in line with the equator.

By rearranging Eqn. 2 and using the values for B_z of 62μT (as worked out earlier), R as the radius of Mars, 3393km [4], and z also as 3393km it was possible to determine what the current needed to create this magnetic field is. This lead to a value for I of 9.47×10^8A.

The next step was to work out what the minimum radius of the wire would have to be to sustain such a current without melting. In order to do this heat loss through radiation [5] was equated with the ohmic heating,

$$I^2 R_\Omega = e\sigma A_e(T - T_0)^4, \quad (3)$$

where; R_Ω is the resistance of the wire, e is the emissivity, σ is the Stefan–Boltzmann constant, T is the temperature of the radiating surface, T_0 is the ambient temperature, and A_e is the emitting surface area. The emitting surface area is calculated using,

$$A_e = 2\pi r_w L = 4\pi^2 r_w R_M, \quad (4)$$

where; r_w is the radius of the wire, L is the length of the wire taken as the circumference of Mars, and R_M is the radius of Mars.

The resistance, R_Ω, was found using,

$$R_\Omega = \frac{\rho L}{A_c}, \tag{5}$$

where; ρ is the resistivity of copper, $1.68 \times 10^{-8} \Omega m$ [6], and A_c is the cross-sectional area of the wire. The cross-sectional area of the wire is given by,

$$A_c = \pi r_w^2. \tag{6}$$

Combining Eqn. 3, Eqn. 4, Eqn. 5 and Eqn. 6 the following relationship is obtained,

$$r_w = \left(\frac{\rho I^2}{2e\sigma\pi^2(T-T_0)^4}\right)^{\frac{1}{3}}. \tag{7}$$

From Eqn. 7 and using values for the emissivity of 0.03 [7], T as the melting point of copper, 1358K [6], T_0 as the maximum surface temperature on Mars, 293K [4], the radius the wire would have to be to sustain the current needed was found to be 70.4m.

The power needed to run such a current can then be calculated by,

$$P = I^2 R_\Omega , \tag{8}$$

where P is the power. Using Eqn. 5 for the resistance along with Eqn. 6 and Eqn. 7, the power required was calculated to be $2.06 \times 10^{13} Js^{-1}$. To put this into real terms, the amount of power that is used on Earth each year is $5.36 \times 10^{20} J$ [8], the equivalent amount of energy would allow the coil to run for 303 days. This means that the coil uses 121% of the power used on Earth every second.

Conclusion

This paper has shown that although it is possible to create a magnetic field with the same intensity of that of Earth's on Mars, it would require an unfeasible amount of energy to do so. It must be noted that this energy is only to create the magnetic field, and that in event that this causes the creation of an ionosphere there will be situations where resulting currents will create magnetic fields opposing the one created, resulting in even more energy required to shield Mars from solar radiation. Being so thick, the wire would unlikely heat homogenously and heat would not be conducted very efficiently to the surface.

Further investigation could take place into whether this magnetic field could in fact sustain an atmosphere and what effect said atmosphere would have on the temperature, and therefore the maximum current that the coil can carry, on Mars.

References

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