

P2_8 “It’s the wrong trousers Gromit!” Part 2

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November 14, 2013

Abstract

Following on from a previous paper by Raymer et al. (2013) this paper considers whether the magnetic field generator in the boots of the ex-NASA “Techno Trousers” would work. It is found that the field generated needs to be 0.37T. A flat, cylindrical electromagnet with an iron core would be able to produce a field of this magnitude and hence the trousers would work.

Introduction

The paper by Raymer et al. (2013) [1] considered whether the vacuum component in the boots of the “Techno Trousers”, which featured in the Wallace and Gromit film *The Wrong Trousers*, would work on Earth’s surface and in space. It found that they would work on Earth with a short operating time, but were unlikely to work in space.

This paper will consider the other mechanism in the boots; the magnetic field generator as shown in figure 1 [2], and will discuss whether the trousers will function in the same two conditions.

Theory

When the trousers are in use on Earth, the magnets need to be able to support the weight of both the trousers and the person wearing them. Newton’s second law will be used to calculate the combined weight,

$$F = mg, \quad (1)$$

where F is the force due to gravity, m is the combined mass of the trousers and wearer, and g is the acceleration due to gravity, 9.81ms^{-2} on Earth.

The pull force exerted by a permanent magnet or an electromagnet is given by the following equation

$$F = \frac{B^2 A}{2\mu_0}, \quad (2)$$

where B is the magnetic induction exerted by the magnet, A is the cross sectional area of

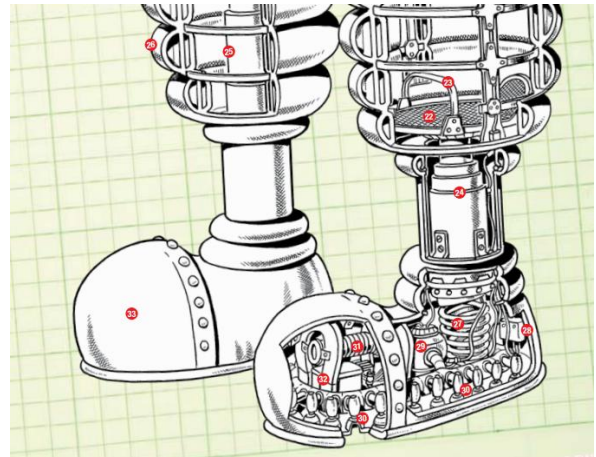


Figure 1 Detailed drawing from the Haynes manual of the boot part of the trousers [2].

the magnet and μ_0 is the permeability of free space [3].

By equating the two forces and rearranging for B , the magnetic flux density can be calculated

$$B = \sqrt{\frac{2\mu_0 mg}{A}}. \quad (3)$$

To walk, the magnets must satisfy two conditions. Firstly each magnet needs to be strong enough to be able to support all of the weight and secondly the magnets need to be able to be switched on and off. Therefore an electromagnet would be most suitable. The electromagnet will only be switched on when the boot(s) are in contact with the wall. In the previous paper it was assumed that there was a slightly raised rubber insulator surrounding the boot. Since the magnets need to be in direct contact with the metallic surface, it will

be assumed that the magnets can be made level with this insulating layer, so that there is no loss in strength of the magnet.

If the electromagnet is given a ferromagnetic core instead of just air, the strength of the magnet will increase significantly depending on what material is used. The magnetic flux density is given by

$$B = k\mu_0 nI \quad (4)$$

where k is the relative permeability of the ferromagnetic core, n is the number of turns per unit length; N/L , and I is the current [4]. This is for an electromagnet with no air gaps which is commonly used as a lifting magnet [5]. By substituting equation 4 into equation 2 it can be seen that a short flux path L and a wide surface area A is needed to maximise the force and hence it will be flat and cylindrical in shape.

If the current is kept constant, increasing the number of turns of a coil, the strength of the magnetic field increases. However, the core has a saturation point, B_{sat} , beyond which increasing the number of coils has no effect.

Discussion and Results

The dimensions of the boot were discussed in the previous paper [1]. If we assume the magnet to have a circular surface area, then its maximum radius will be 0.1m. This will give a surface area A of 0.03m^2 . The combined mass will also be the same as the previous paper and therefore is 170kg. Using these numbers in equation 3 gives a value for B of 0.37T.

Since A can only be as wide as the boots, we have chosen 0.05m for the value of L which will form a flat cylindrical electromagnet. There are many different ferromagnetic materials that can be used for the core, but typically iron is used, so we shall base our calculations on this. An iron core has a relative permeability of 200 and B_{sat} is approximately 2.1T [6]. Since this value is much greater than the field needed for the trousers we will not need to consider the saturation point in our discussion. Using the magnetic field calculated from equation 3, $NI = 73.61$ Ampere-turns. So it will be possible to calculate the number of turns required based on the input amps.

The type of metallic surface that the magnet will be attracted to has not been considered. When considering whether the trousers could operate in space it was found in the previous paper that the vacuum generators would not work [1]. A spacecraft will be in freefall when orbiting Earth and therefore there will be no acceleration relative to it. Hence the magnets will work at this altitude and since spacecraft are generally metallic, this solves the issue of the vacuum generators not being able to work in these conditions.

When the trousers are in use on Earth, such as the applications depicted in the film, it is likely that the surfaces were non-metallic. Therefore the magnetic field generator mode would not be of much use in these conditions.

Conclusion

The field that needs to be produced by the magnet in order to walk on a ceiling is a feasible value. Using an electromagnet with an iron core, along with the dimensions required by the design of the boot, would allow a person to walk upside down on a ceiling. Like the previous paper, issues arise when considering how to power the magnetic field generators and hence it has not been considered.

Therefore, in a real life scenario the “Techno Trousers” will be able to work, so long as they can switch between the two mechanisms.

References

- [1] K. Raymer et al., *P2_6 “It’s the wrong trousers Gromit!” Part 1*, PST **12**, (2013).
- [2] <http://www.haynes.co.uk/wallace/PDFs/H4958spread6.pdf> accessed on 09/11/2013.
- [3] François Cardarelli, *Materials Handbook: A Concise Desktop Reference*, (Springer, 2008), 2nd ed., p. 493.
- [4] <http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/elemag.html#c5> accessed on 09/11/2013.
- [5] John Avison, *The World of Physics*, (Thomas Nelson and Sons Ltd., 1989), 2nd ed., p. 294.
- [6] <http://www.coilgun.info/theorymath/home.htm> accessed on 09/11/2013.