

P2_2 Iron Boots

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Abstract

In Nintendo's computer game "*The Legend of Zelda: Twilight Princess*" the protagonist is able to traverse walls and ceilings by walking along magnetic surfaces embedded in the environment whilst wearing 'Iron Boots'. Upon investigation as to the real world viability it was found that it would be possible with; a 60kg human, iron plates of dimensions $0.15 \times 0.3 \times 0.005m$ and an electromagnet plate with a field strength of at least 0.22T.

Introduction

In the video game "*The Legend of Zelda: Twilight Princess*", boots made of iron can be equipped which enable the hero to walk along magnetised walls and ceilings and to be lifted using electromagnets. The subject of this paper is to ascertain whether it would be physically possible to walk on magnetised walls and the possible nature of the magnetism of the walls. The magnetised areas of the game appear to be natural deposits and there has been a significant amount of study of naturally occurring magnetic minerals such as Lodestone. Lodestone is a rare mineral magnetite (Fe_3O_4) that can act as a permanent magnet with varying field strength [1] commonly used throughout history in the making and operating of compasses [2].

Analysis

In the game the "Iron Boots" (shown in Figure 1) are made entirely of iron and when worn they are heavy enough to allow the character to sink to the bottom of large bodies of water. For the purpose of this paper the components of the boots have been simplified.



Figure 1: a picture of the iron boots in "*The Legend of Zelda: Twilight Princess*" [3].

Firstly, the boots have been assumed to consist of a single plate of Iron strapped to the underside of a pair of boots. Each plate has the dimensions $0.15 \times 0.3 \times 0.005m$ and based on an iron density of $7.9 \times 10^3 kgm^{-3}$ [4] would weigh approximately 2kg each. The weight of the person wearing the boots is estimated at 60kg.

It is assumed that the human would already be oriented such that the plates were touching a planar surface of either a magnetite mineral or electromagnet with a uniform magnetic field as shown in figure 2.

Note that it is only the surface which is perpendicular to the field lines that is relevant to the forces generated through induction. As with the Helmholtz coil, any movement within the field is resisted due to induced drift currents within the conductor (the iron plate) generating a field of equal and opposite magnitude to the external driving field. This is also generated by the presence of a weight (the human) constantly trying to pull the iron plates away from the magnetic field source. As such, provided at least one of the plates remains in contact with the magnetite mineral or electromagnet, the human would remain attached to the ceiling and be able to walk across it. For the purposes of simplicity in this scenario, the prospect of skin depth and diffusion of field lines throughout the conductor has been ignored.

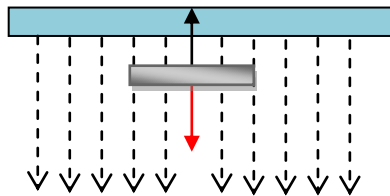


Figure 2: a diagram of an iron plate (grey rectangle) in the magnetic field of a plate source (blue rectangle), where the red arrow is the force exerted by the human and plate on the magnetic field due to gravitational acceleration, the black arrow is the force exerted by the magnetic field on the iron plate and the dashed arrows are the uniform magnetic field lines (which link back to the source as a plate dipole)

The force shown in figure 2 arises from the equation

$$F = \frac{B^2 \times A}{2\mu_0} \quad (1)$$

where F is the force exerted on the iron plates by the magnetic field acting opposite to the direction of the field (measured in Newtons), B is the field strength (Tesla), A is the area surface area exposed to flux from the magnetic field (measured in m^2) and μ_0 is the relative permeability of free space ($4\pi \times 10^{-7}$).

It demonstrates that there must be a minimum value of the field strength for the magnetic field given the weight of the human and iron plates. In other words, in order to keep the human attached to the ceiling in an environment where the acceleration due to gravity is approximately $9.81ms^{-2}$ the field must be strong enough to counteract a force of $640N$ (the total weight of both the human and the plates) plus a reasonable margin of tolerance to ensure that the human would be able to walk whilst still remaining attached to the ceiling; this was estimated to be about $200N$.

Using the aforementioned numbers it is calculated that to maintain a total force of $840N$ the field strength would need to be approximately $0.22 T$. Referring back to the prospect of using lodestone as a magnetic material it is known from research [5] that lodestone ranges from 6.5 to $11.6 emu cm^{-3}$ - converting to Tesla - that is at most approximately equivalent to $0.015T$. In contrast, electromagnets such as those used

in scrapyards have average field strengths of $2.00T$ [6].

Conclusion

Given the low field strength of lodestone and the dimensions of the iron plates it would be impossible to walk on walls or ceilings made of lodestone even with large quantities. Revisiting equation 1 it can also be seen that in order for this to work, the iron plates would have to have a surface area (perpendicular to the field) of approximately $9.2m^2$ which would be onerously impractical.

It is however entirely possible to do this with an electromagnet. Thus it is concluded that given a relatively large electromagnet plate with sufficient uniform field strength, it would be possible to for a human to use "iron boots" to walk upside down on a ceiling.

References

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