

Magnetically Preloaded Wheels

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Abstract

Friction drives require preloading and this often results in large loads on shafts and bearings which can increase system cost and reduce efficiency. Using the principle of self-help, a friction drive wheel can be coupled to a surface or the motor output by magnetic attraction: One wheel is made from a sandwich of a steel disk, magnet, and a second steel disk. A second wheel or surface with low permeability is placed in contact with the magnetic wheel, the two are attracted to each other, thereby establishing preload without the need for external preload systems. A first-order analytical solution does well to predict the attraction force, where the primary trade-off is the sensitivity to the gap between the wheels. If a rubber layer is used to increase the coefficient of friction, the magnetic attraction force drops rapidly. A flexure allows one wheel to have a degree of freedom in the radial direction, while being stiff in the tangential direction, thereby allowing a motor shaft to be preloaded to a drive wheel to obtain a transmission effect. An application is for an overhead robotic system, dubbed "Magnebots" that allows small autonomous robots to drive across ceilings and up and down walls, such as for hospital automation.

Introduction

Friction drives have had many applications from controlling paper motion in printers to actuating large precision machine tool axes [1,2,3]. In light load applications, it is not difficult to provide the preload force needed in order to develop the necessary traction forces [4]. However, friction drives required to provide large forces, such as to machine tool axes, the preload forces must typically be an order of magnitude greater than the actuation force, and this creates a need for complex preload and bearing support requirements. Borrowing from linear motor technology [5], where the magnets can be used to preload bearings, magnets can be used to preload friction drive components. If, for example, the drive bar is magnetic, then the drive wheel can be comprised of two round steel plates with a strong round plate magnet between them. As illustrated in Fig. 1, The flux path will thus be from the north pole of the magnet, through one round steel plate, into the steel drive bar, over and up into the other round steel plate and to the south pole. Fig. 2 shows a magnetically preloaded drive wheel.

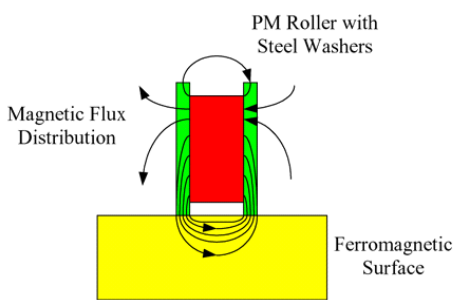


Fig. 1 Magnetic wheel principle



Fig. 2 Magnebot steel wheel plates and magnet core

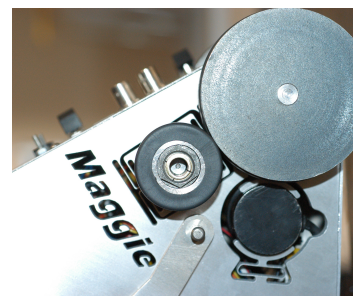


Fig. 3 Drive motor/pinon flexure supports

Since the drive wheel itself now is loaded to the drive surface, there are no preload forces on the bearings that support the drive wheel/motor shaft. However, in order to enable the preload action to occur, the drive wheel support bearings must be allowed to float in a direction perpendicular to the drive surface, while being stiff in the parallel direction. This can be accomplished with flexural bearings as shown in Fig. 3; however, it should be noted that ideally the center of stiffness of the supported wheel would be located at the point of attraction between the two wheels. In order to achieve a reasonable transmission ratio, the drive wheel should be small, yet in order to achieve a high load capacity and a strong magnetic attraction force, the wheel must be large. The interesting compromise is to use the same magnetic design that preloads the drive wheel to the drive bar, to preload a motorized friction-drive pinion to the drive wheel.

Analysis

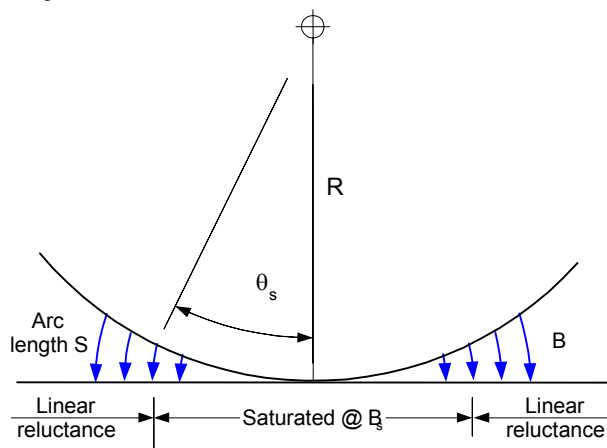


Fig. 4 Magnetic circuit model at wheel/surface interface

There are three design conditions that are analyzed with respect to the magnetic attraction force:

1. Case 1: The magnet wheel is attracted to a thick steel section which does not saturate.
2. Case 2: The magnet wheel is attracted to a roller of diameter d and of comparable width, but the roller is a thin shell to reduce inertia and hence it can also saturate.
3. Case 3: The magnet wheel is attracted to a thin flat metal sheet of essentially infinite area, but it can saturate.
4. Case 4: There is a small gap, e.g., formed by a thin layer of high friction rubber, between the wheel and the surface.

Fig. 4 shows the basic model of Case 3, where the magnetic flux saturates a portion of the air through an angle θ_s of the wheel. Beyond this region, a linear reluctance model is used, based on the arc length S . The details of the analysis

are beyond the scope of this short paper, but assuming that the steel in the surface to which the wheel is attracted does not saturate, the attraction force between the magnetic wheel and the surface will be:

$$\theta_s = \frac{2GT}{\pi R^2} \left[\sqrt{\frac{\mu_o M \pi^2 R W^2}{4GT^2 B_s} + 1} - 1 \right] \quad F = \frac{2R\theta_s B_s^2 T}{\mu_o}$$

Where θ_s is the angle of saturation, W , G , and $\mu_o M$ are the radius, thickness, and strength (1.2 Tesla for neodymium iron boron) respectively of the magnet in the middle of the wheel, R is the wheel radius, T is the wheel thickness, and B_s is the saturation flux density of the material (1.8 Tesla for 410 stainless steel). More in depth models were also created for the other cases, but they are too complex to be presented here.

Application

An important application of this concept is for the *Magnebots* which are under consideration for overhead-based automation in hospitals [6]. The system, shown in Figs. 5 and 6, consists of vehicles with magnetic wheels that move on trackless ferromagnetic walls and ceilings, driven by on-board controllers and commanded by a central computer. Robust mechanical hardware, performance enhancement by controls, and vehicle coordination by wireless communication illustrate a synergistic integration of various precision engineering disciplines. Fig. 5 shows the prototype Magnebot car (patent pending).

For the experimental system, $R=0.0381$ m, $W = 0.0254$ m, $G = 0.0127$ m, $T = 0.0062$ m, $\mu_o M = 1.2$ T, and $B_s = 1.8$ T. For two wheels, the predicted attraction force is 682 N. The measured force was 620 N. When a 0.1 mm effective thickness of rubber was placed between the wheel and a 2 mm steel plate, the measured force dropped to about 310 N. This agrees well for an engineering estimate with the more complex theories that were also developed.

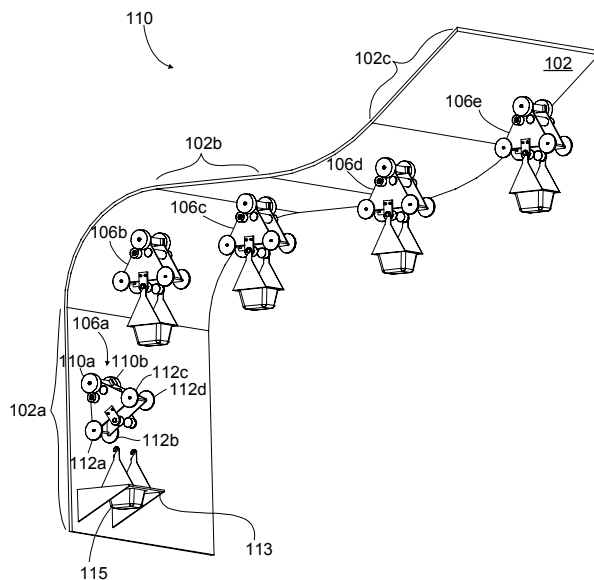


Fig. 5 Magnebot concept

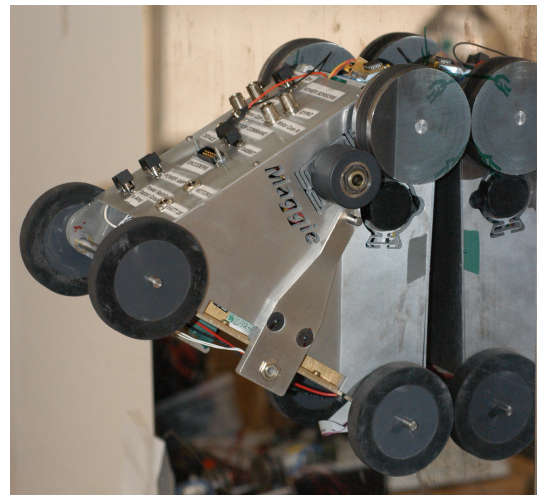


Fig. 6 Magnebot prototype

Conclusions

The Magnetic wheel structure is very effective at preloading a wheel to a surface, and thus eliminates the need for external load application systems for preloading friction drives. The analytical prediction of attraction force, based on a simple magnetic circuit, provides a good engineering estimate to enable a design engineer to initially layout a system. An experimental system can then be built to verify performance, or an FEA simulation could be conducted.

Acknowledgements

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