INDUCTION MOTORS WITH MULTIPLE AXES OF ROTATION

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ABSTRACT

Despite the continuing huge technological leaps in computing and other technologies, the basic idea of a motor has not changed for roughly a century (Tesla). Motors have become stronger, faster, and more efficient, but they still only either move objects in a circle, or in a line. One of the primary uses of motors is powering wheels; an interesting development has occurred last fifteen years, omni-wheels. Omni-wheels are wheels that have wheels on them, allowing the rotation of the motor to also move the object in a direction that is at least partially parallel to the axis of rotation of the motor. This is advantageous because it means that more operations can be performed, but it seems like there should be a better way given our technology today since omni-wheels require multiple motors in order to control. What if one could take a spherical ball style caster, and make it powered so the wheel was also a motor? The metal ball could be replaced with a plastic ball that had conducting copper paths on the surface and the whole caster could be turned into an induction motor.

To test the viability of this idea I wrote a computational simulation. It used a numerical fourth order differential equation solver with simplified calculations for flux and magnetic force. The results showed that it is possible to place a torque on the rotor (the plastic sphere). However, a uniform torque cannot be applied by the magnetic field if the rotor has finite conduction paths. This means that while the simulation does act as a validation of the basic idea, it also shows complications of such a design. A potential solution to the problem of non-uniform torque would be to have a more complex geometry of the rotor conductors or a continuous conductor on the surface of the rotor. This type of omnidirectional motor would be capable of moving objects in any direction along the plane that they were placed on. There are some limitations in that casters already can't support larger weights, but this design should work for moving smaller objects such as small robots.

I. BACKGROUND

Three phase induction motors operate on the principle of symmetrically positioned electromagnets in the non-rotating casing (stator). These electromagnets then create a rotating magnetic field that induces a current in the rotor. The magnetic field produced by the current in the rotor interacts with the exterior magnetic field, producing a force on the rotor without any electrical conduction between the rotor and the stator. The rotor always rotates at a speed that is less than the speed of the rotating magnetic field which is called the slip speed. Induction motors offer advantages of high efficiency and reliability. Both of these advantages are largely due to the lack of moving electrical contacts (Garce).

This multiple axes motor should use induction instead of brushes because the spherical geometry allows for neither good winding configurations nor good contact points. Windings can be as simple as a single straight wire or, more commonly, multiple loops of wire through which current can flow to create a magnetic field to apply a force between the stator and the rotor. The spherical geometry would allow for nearly infinite axes of rotation which enables the motor to function in more than one mode. The purpose of this simulation was to show the viability of building a motor that has multiple possible axes of rotation. The basic model was validated by comparing it to a three-phase induction motor that rotates around a single axis.

This project is significant because it is an introduction to alternate types of electromechanical interfaces. In general, these interfaces only translate linearly or rotate in a single plane. By experimenting with designs that move beyond these spheres of thinking, it is possible to add to the types of electromechanical interfaces and make greater use of available technology. Applications include versatile movement in small spaces such as robotics joints or manufacturing processes that require complex motion.

II. Simulation

The model was simplified in order to minimize computation time and to avoid complications in interpreting the results. The simulation was written using a fourth order ordinary differential equation (ODE) solver. There were a total of ten inputs to the solver, two for positions in the directions of phi and theta, two for velocity in phi and theta, and six for the various currents that flow around the rotor. The current values for each of these were handed to different functions to calculate the change in current, force on the conduction paths, and friction. These values where then handed back to the main function that the ODE was being applied to. The ODE solver was then handed back change in position, velocity, and current for each of two directions and six loops, respectively.

It was assumed that the rotor and surrounding material were composed of polycarbonate plastic for calculating permeability. Other assumptions include having a uniform magnetic field that is capable of rotating with two degrees of freedom. The assumption of a uniform magnetic field reduced the complexity of the simulation and made verification of the simulation easier.

The torque was calculated for each conducting loop, and then summed to find the total torque on the sphere. The torque on each loop was described by the following equations:

$$\phi = \pi \frac{R^2}{2} cos\theta cos\varphi B$$

Where is the magnetic flux through the surface bound by the edge of the loop and θ and φ are the relative angle between the magnetic field and the area vector of the loop. R is the radius of the sphere and is used to calculate the area of the loop.

$$I = \frac{\frac{-d\phi}{dt}}{Resistance}$$

The change in flux in order to find the electromotor force was calculated numerically using the known position and velocity to calculate the future position and velocity for some time, dt, away. The ODE solver used a fixed time step in order to make this possible. Ohms Law was then used to calculate the current traveling around that loop. The current in each loop also stayed in that loop for a small amount of time because it was essentially an RL circuit. Thus the change in the current for each loop with respect to time had to be fed back into the ODE solver. This change in current had to take into account both the new current that was induced in the loop and the rate of decay of the current. The value of a current in any RL circuit is given by:

$$I = I_o e^{\frac{-tL}{R}}$$

L is the self-inductance of the loop of wire which was calculated using:

$$L = \mu_o \mu_m \frac{R^2}{2}\left(\ln\left(\frac{4R^2}{a}\right) - 2\right)$$

This equation also took into account the radius of the wire, *a* , that surrounded the loop. The ODE solver then returned a new value for the current based on the decay of current and the induced electromotor force, which was used to calculate the torque on each loop.

$$\tau = I\pi \frac{R^2}{2} sin\theta sin\varphi B$$

I could then sum all of the torques including the torque due to friction, taking into account that the torque wasn't being applied at the center of the sphere, and find the angular acceleration to return to the ODE solver.

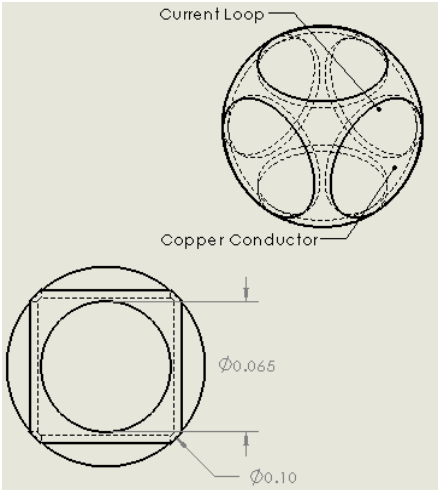

FIG 1: Shown above is the rotor that was used for the simulation where the interior of the sphere was made out of polycarbonate plastic and the conducting paths were made out of copper.

As shown in figure 1, the rotor was assumed to be a sphere of polycarbonate plastic with embedded copper that acted as the conductor. For the purposes of this simulation the sphere was assumed to be 5 cm in radius. The purpose of this larger size was to make the answers easier to rationalize from a qualitative perspective. A simple form of linear friction was applied with a coefficient of friction of 0.008. This value was chosen to improve speed of the ODE solver despite the fact that this is less than the listed coefficient of friction of copper or polycarbonate (Haynes). With larger values the ODE solver had difficulty with the discontinuity as the velocity of the rotor passed through zero.

III. Results

The results validate the principle but reveal problems in its application. The velocity of the rotor, shown in the figure on the right, is highly irregular. The figure to the right has a magnetic field that is rotating at 7 radians per second in the theta direction and 10 radians per second in the phi direction. There are certain positions at which the magnetic field exerts little torque which causes the rotor to slow down due to friction. The easiest way to conceptualize these stall points is to think of the rotor as a cube. This is reasonable for conceptual purposes since the rotor has six faces, similar to a cube, and the area of each of those faces is flat, simplifying the calculations for the flux. If the cube was oriented such that it was resting on a single edge and you were looking at one of the faces that were vertical, then a magnetic field that was pointing downward and rotating in the plane that goes away from you and through the cube would apply relatively little torque. This makes sense because the magnetic flux through the non-vertical surfaces would be less. Also, less force would be applied to the current carrying wires since they wouldn't be as perpendicular to the magnetic field.

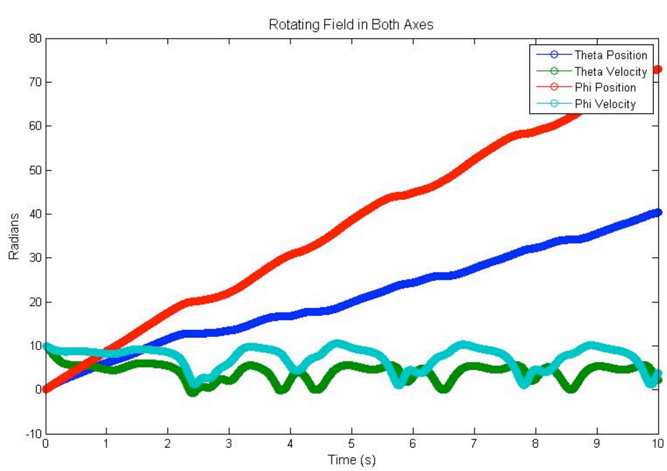

FIG 2: The figure above shows the position and velocity of the rotor in both directions. The position is measured in radians from the starting position and the velocity is measured in radians per second.

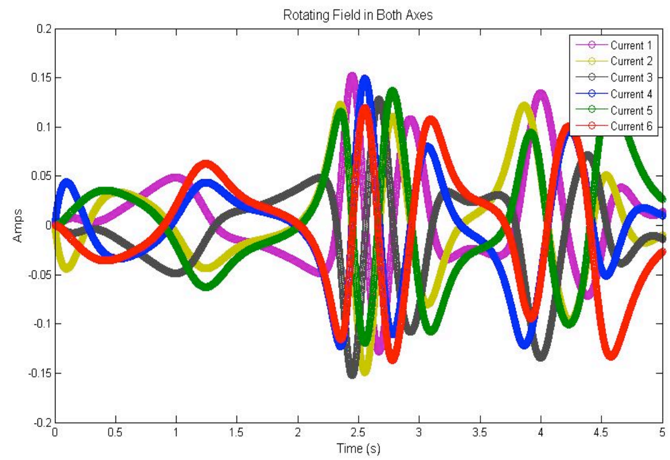

FIG 3: Each line represents the current passing through one of the six conducting loops in the rotor from the simulation in the previous figure.

Some of the validation for this model is that it acts as a normal single axis induction motor when operating in any individual direction. Also the current in each of the directions is in holding with what would be expected from a conducting loop moving in that way inside of a magnetic field. As seen in figure 3, the velocity and position of the rotor due to the magnetic field rotating in the theta direction are identical to those of the rotor rotating around only the phi direction except with the velocity and position being in phi instead of theta.

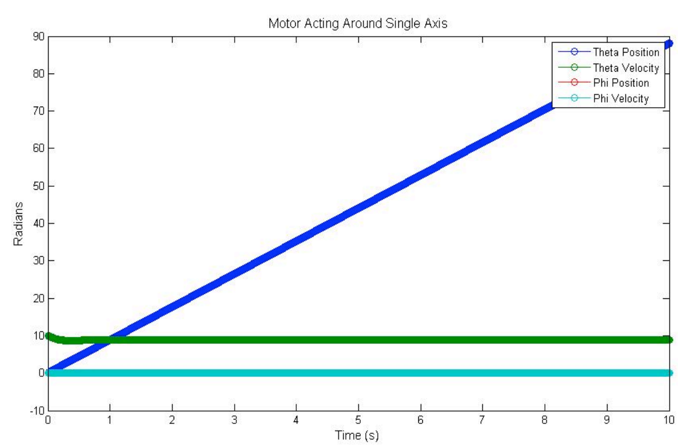

FIG 4: The magnetic field is rotating in only one direction in the simulation, thus there is no change in magnetic flux through two of the conducting loops. The position in blue is measured in radians from the starting position and the velocity is measured in radians per second.

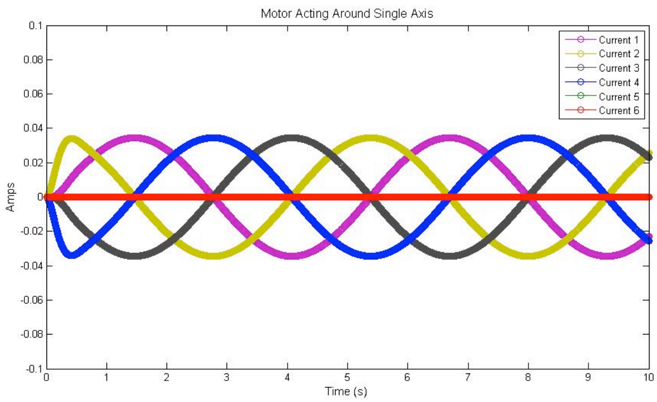

FIG 5: Each line represents the current around one of the current carrying loops from the same simulation as the previous figure.

While the results of this simulation indicate some problems with this type of motor, the possibility is still worth pursuing. If the rotor had a more complex geometry then the stall positions wouldn't have as low of a torque. Another possibility is to design the rotor as a conducting shell, similar to the continuous conducting rotors used in some single axis induction motors. This would mean no stall position. Some disadvantages of this design are possible instabilities when changing direction or magnetic field rotation quickly and possibly less efficient conversion of electrical energy to mechanical energy. Further research into this area is warranted since the results of this simulation support the basic idea but not any particular design.

IV. References

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