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Statement of The Design Problem

Customer needs for attitude control systems may differ because not all spacecraft missions are the same. Different missions require different maneuverability capabilities, some may require passive attitude keeping for stationary missions and others may need a more controllable and active system. Regardless of the different quantitative needs, the qualitative need of all attitude control system actuators is the same and that is to provide a torque about an axis to allow for orientation changes.

One main attribute that consumers desire in attitude control systems is reliability and most systems in use are prone to mechanical failures and ineffectiveness. The ferrofluid system is virtually non-mechanical and isn’t prone to mechanical issues, the ferrofluid is simply enclosed in a container and spun by a magnetic field. Because failure is less prevalent, the need of multiple systems is negated.

Another attribute that is sought after in attitude control is the need of large torques within a small space because spacecrafts must be as compact as possible for optimal rocket launches. This is actually two attributes that’s needed, space and torque, but they go hand-and-hand. Ferrofluid solves this with two ways, initially it being of high density and it can also be used to control multiple axis of rotation within a single system. Due to ferrofluid’s high density, large torques can be attained without occupying a large space, and since the ferrofluid system can be spun in any direction, the need of multiple components for each axis is not needed. And as previously stated, since the ferrofluid system is less prevalent to failures, space can also be saved due to the unneeded use of redundant backups.

Scalability and flexibility are also important with spacecrafts. Spacecrafts often need their attitude control systems re-engineered or redesigned to meet requirements, and this occurs for nearly every new spacecraft mission. Having an attitude control system as a basis that can be scaled up or down to fit spacecraft needs is demanding. The ferrofluid system is quit flexible in this sense, for larger spacecraft using a larger magnetically induced field with a larger amount of ferrofluid should meet the torque ratio needed. Similarly, for smaller spacecraft, the ferrofluid system can utilize smaller parts and smaller induced magnetic fields with a smaller quantity of ferrofluid.

Lastly this brings us to complexity. Since the ferrofluid system is essentially an electromagnetic motor, this field of research has been thoroughly studied and applied. The ferrofluid can simply replace the use of magnets and the existing induced magnetic field should be able to operate a similar system to that of an electromagnetic motor, which are widely used today, without an issue.

Requirement Specifications

Cost requirement is estimated to be around $1,000 for complete construction. As a functional requirement the ferrofluid system must be able to demonstrate that the fluid can be go into rotation. To demonstrate the rotation, the container that holds the fluid must either be clear to show that the fluid is moving or the container must be put on a rotating platform or bearing to demonstrate that some kind of rotation is induced. Since only a small quantity of fluid can be afforded, the system should be small enough and will most likely fit in a one cubic foot space.

The most optimal container to hold the ferrofluid is most likely going to be a toroid shape because it can keep the mass on the edge of the rotating center and maximize the amount of ferrofluid that can be activated. Since the system is most likely going to be enclosed in a small space, portability shouldn't be an issue and the system should be able to be transported easily.

Summary of Physical characteristics

Style:	Toroidal or spherical shape
Size:	12"x 12" x 12" space
Demonstration:	Either a clear container or a rotating platform to demonstrate rotation
Structure Materials:	PLA or ABS for container, enameled coil wire (20-30 gauge) wrapped to induce a magnetic field, ferrofluid (5-10 oz)
Circuit analysis:	Either a multi-phase AC power supply, or a DC circuit that consists of multiple IC's: Timers, CMOS Counter/Divider, and a High-Current Darlington Transistor Array.

These are the possible Circuits that could be used:

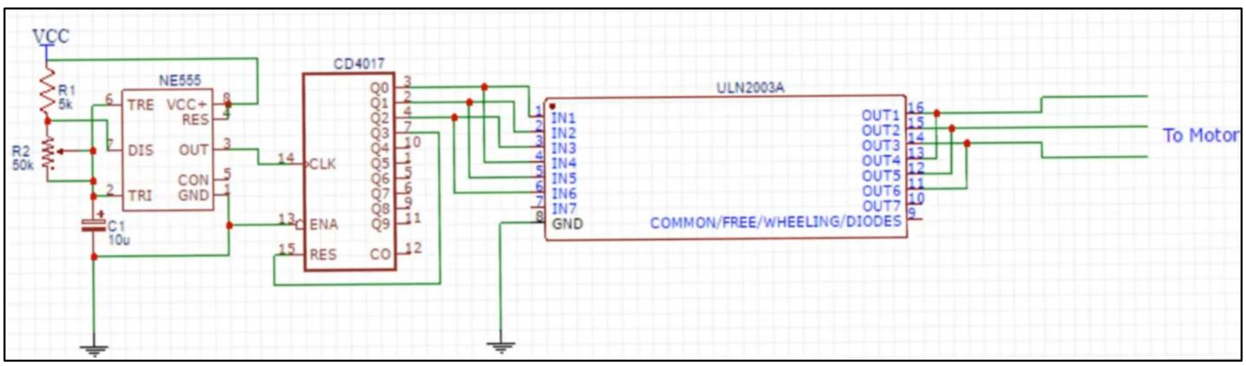

Figure 1. DC circuit design (lines going to the motor are going to the individual coil packs, possibly in pairs)

The NE555 timer and the CD4017 divider in Figure 1. can be taken out and an Arduino can take their place and perform the same function. This circuit simply turns on and off the coils sequentially.

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If an integrated circuit design is not used a possible direct link to a multi-phase AC will work the same as described in Figure 2. and 3. below. At different positions within the period shown, the magnetic field should rotate as the angle changes respectively. A 3-phase can be used for a stronger and more continuous magnetic field.

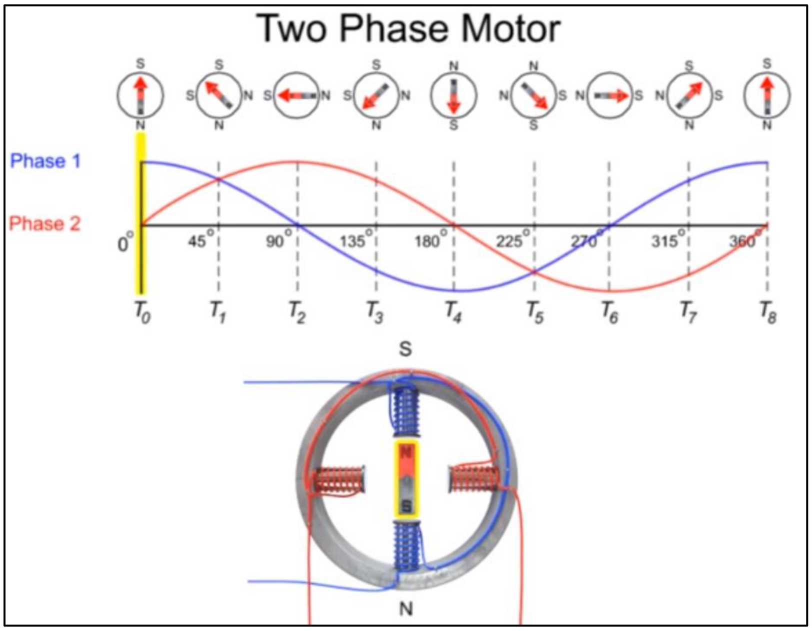

Figure 2. Possible 2 phase motor utilizing AC

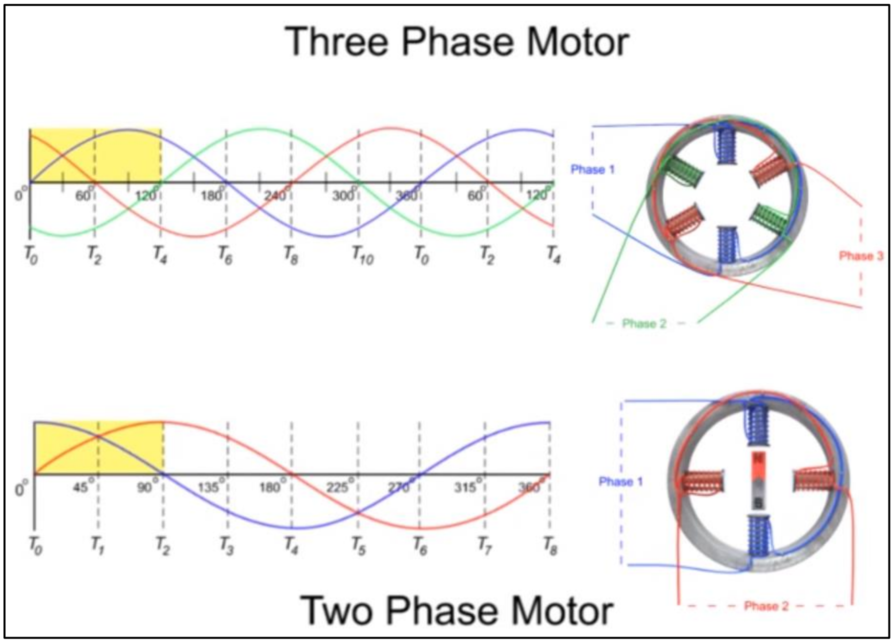

Figure 3. Difference between 2 and 3 phase AC motors. Both are feasible.

After defining the input and going with a selected choice of circuit, these physical design sketches are a possibility of what the system might look like:

The first design possibility can be similar the one shown in figure 4. 5. & 6. Where a cylinder surrounded internally by copper wire-wounds is placed around a sphere filled with ferrofluid that is supported on a bearing allowing for rotation.

Figure 4. Cylinder structure with coils on the inside.

Figure 5. Sphere of ferrofluid supported on a stand with a bearing underneath for possible rotation.

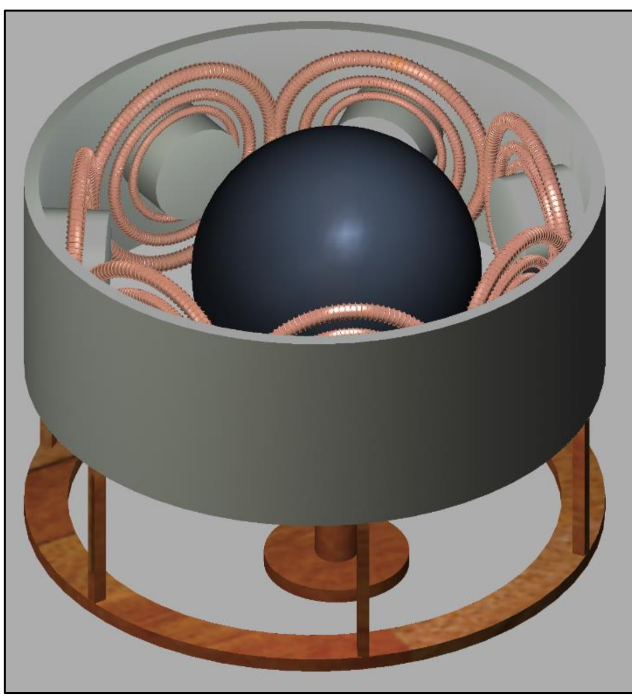

Figure 6. First theoretical design construction.

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The second design possibility can consist of a torus or donut shape filled with ferrofluid that is accelerated by surrounding copper wounds as seen below.

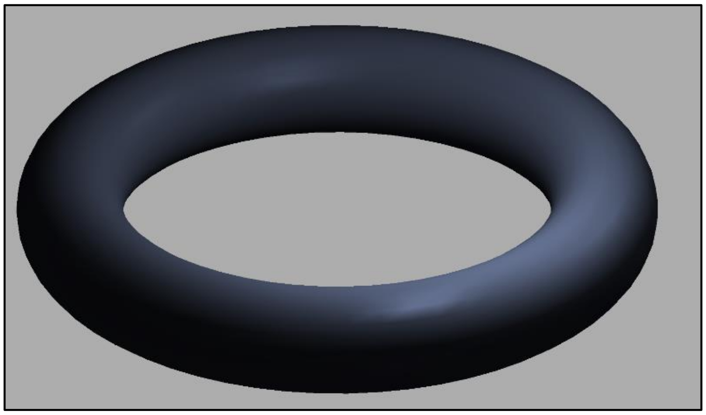

Figure 9. Torus filled with ferrofluid.

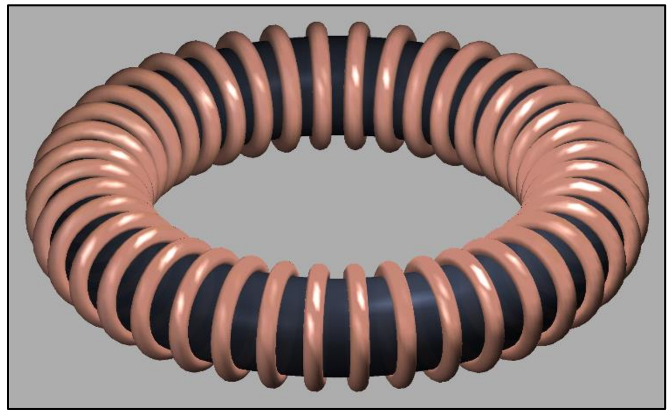

Figure 8. Torus surrounded by insulated copper wire.

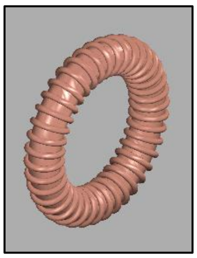

Figure 11. Possible additive coils for additional magnetic field force.

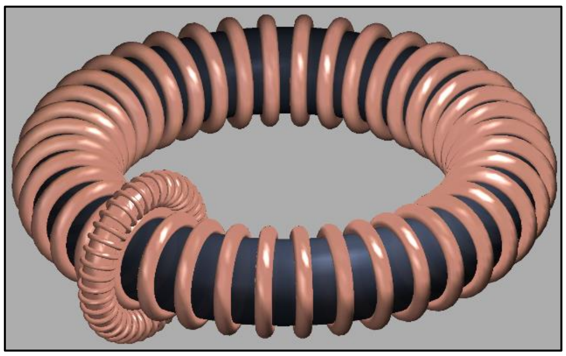

Figure 10. Additive coil added on.

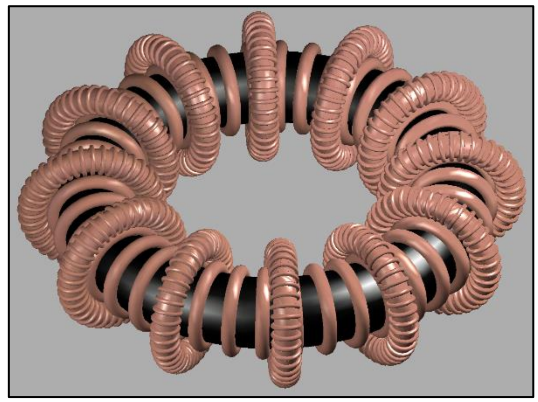

Figure 7. Torus surrounded by many additive coils.

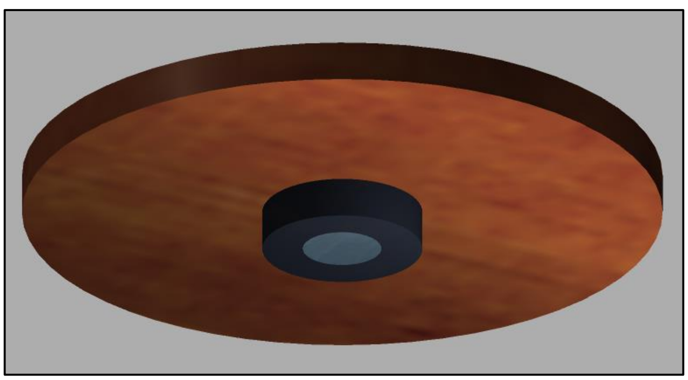

Figure 12. Platform for the torus design to allow for rotation with a bearing underneath.

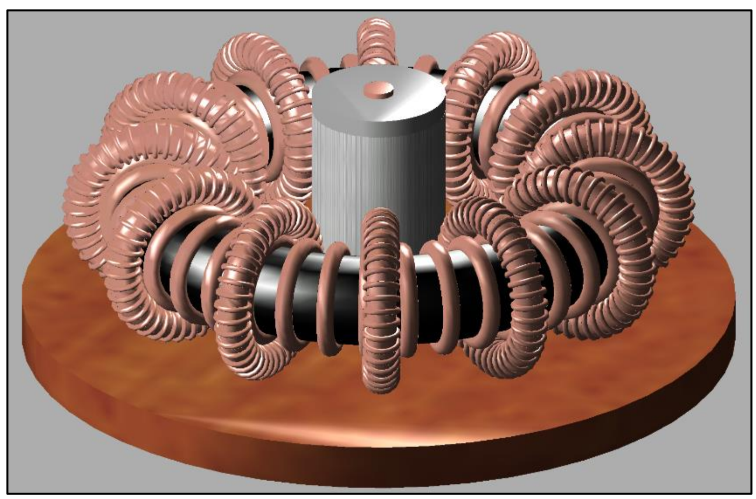

Figure 13. Theoretical completed design of a torus system with a battery pack supplied at the center.

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Assumptions, Constraints, and Dependencies

The system as shown, will have electrical power as its input and it will output a torque. User requirements should allow for frequency control and power control to achieve wanted rotational speed.

Possible environmental concerns include: magnetic field disruptions to nearby instruments, ensuring ferrofluid leakage is accounted, and ensuring circuit and structure is water proof or resistant incase of possible contamination. Magnetic field disruptions can be handled by using magnetic field shields to protect other instruments or at minimum decrease the exposure of the induced magnetic fields. Incase of regulatory conflicts, inductor noise should be kept at a minimum.

If needed, inductors can be replaced, as shown, by copper windings to provide similar magnetic fields. The figure below can be used to ensure that proper magnetic field direction and magnitudes are met. The right-hand applies here too when dealing with current and magnetic fields (same theory).

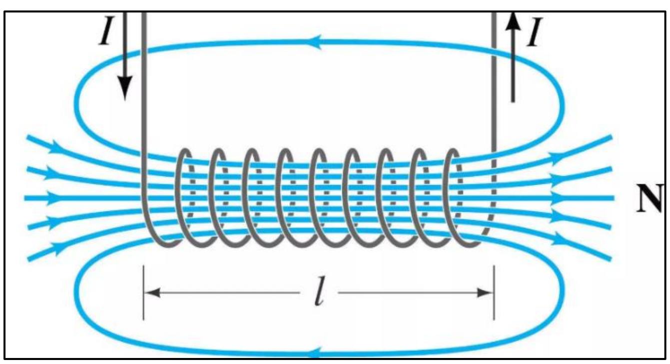

Figure 14. Magnetic field lines shown in blue, with a current running though the wire shown in grey.

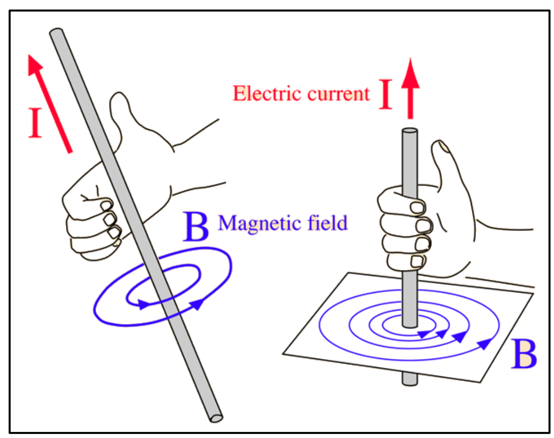

Figure 15. Shows how the right-hand rule can be used to determine current and magnetic field directions.

Some of the software that will be needed includes: STL slicer (used for preparing stl files from cad files for 3d printing), AutoCad (used to create the cad files that will be used in the STL slicer), and CircuitMaker (used for circuit analysis to ensure that proper inputs and outputs are achieved before constructing the circuit).

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Preliminary Plans & Conclusion

The preliminary test plan is to firstly construct a simulated circuit that will input and output the desired controls in CircuitMaker or any other circuit analysis program. Once the simulation is complete and successful then a physical circuit must be constructed and tested to verify performance and expected values as seen in the simulations.

Once the circuit portion is finished, the structural design must be created using AutoCad software and exported into a STL slicer for 3D printing format support. Once the structure is printed and structural tests are performed to ensure no ferrofluid leakage is present and rotation is possible if the torques are strong enough, the inductors or coil windings will be introduced.

The circuit designed will connect to our coil windings or inductors and a magnetic field test with metallic material or magnets ensure that we have a strong enough induced magnetic field that is able to provide a spin.

Lastly the ferrofluid will be introduced to the system and frequency and power tweaking will be necessary to ensure that ferrofluid manipulation is achieved. At minimum, the ferrofluid should be able to rotate at least one rotation. Optimally, the ferrofluid should display some constant rotational spinning. The best result that can be achieved would be having the ferrofluid rotate the bearings it’s on to display that a strong enough torque can be achieved and can be utilized in attitude control systems.

In conclusion, I believe the minimum expectation is achievable and an optimal result is most likely expected. If the induced magnetic field can be tuned for a strong enough force and our structure is light and frictionless enough, it can most definitely display rotational momentum about the bearing platform its planted on.