

# Application of Ferrofluid in Radial Bearings for Low Friction Systems

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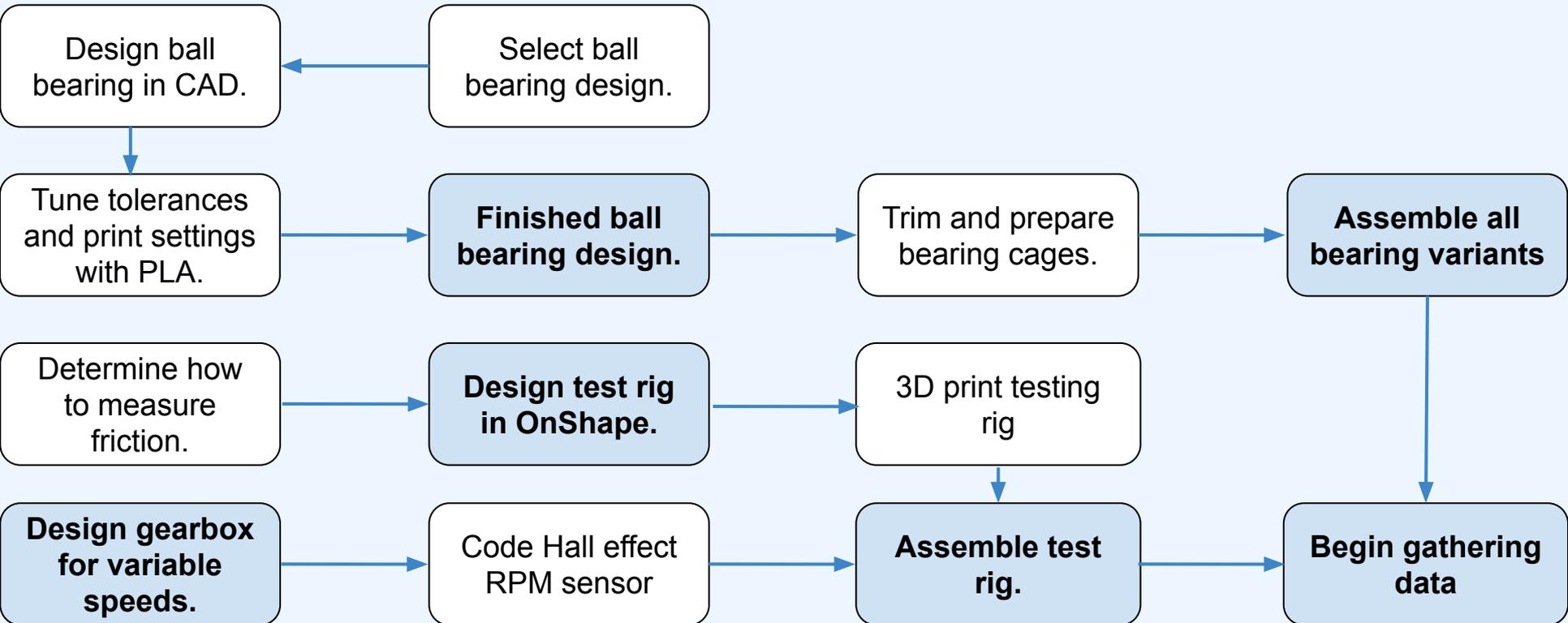
# Introduction

**Question** - How will ferrofluid act as a lubricant in a traditional ball bearing, and is it possible to reduce friction further by introducing magnets?

**Goal** - Create a bearing that is able to outperform a traditional radial ball bearing using ferrofluid and magnets in both friction and lifespan.

- Bearings require consistent greasing in many settings to maintain their lifespan.
  - Depending on their operating conditions, different materials like ceramic or plastic will be used to make the balls, race, and cage.
  - Different lubricants are also used based on operating conditions to increase lifespan.
- Over 20% of humankind's energy consumption is related to overcoming tribological contact (Holmberg and Erdemir, 2017).
- Ferrofluid has shown promise as a lubricant due to its manipulability through magnetic fields.
  - It can help prevent lubricant starvation and is more effective at heat dissipation than traditional greases and lubricants (Xu et al).
  - It is a colloidal suspension of ferromagnetic particles in a light hydrocarbon oil.

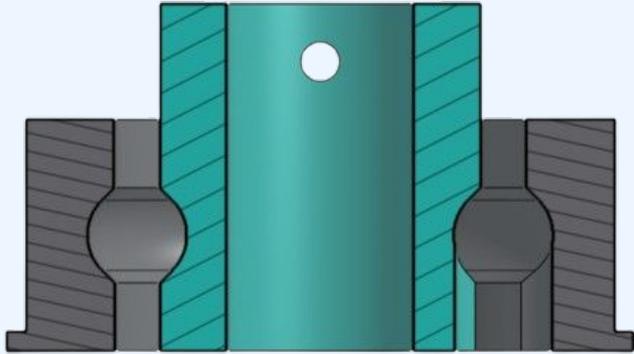
# Engineering Goals



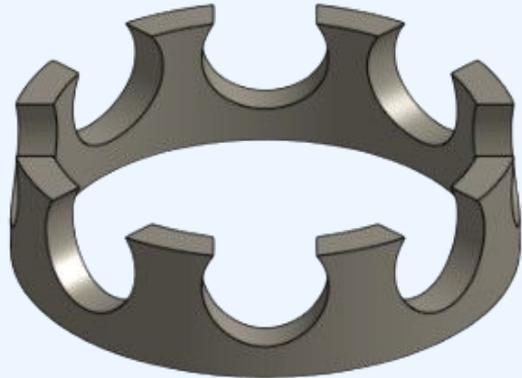
# Procedure

- A. Design of Bearing** - Several bearing designs were created and iterated upon. The final design was an 8-ball caged radial ball bearing that used 5mm steel bearings printed out of PLA. A lot of time was spent fine tuning printer settings to get consistent prints without any major surface roughness.
- B. Testing Rig** - The testing rig had many parts, chiefly the bearing hubs and flywheel. These would hold the bearings in place and the flywheel would allow the system to have higher moment of inertia, leading to longer periods of recorded data. The clutch and gearboxes were designed to be able to get consistent speeds for each trial. Finally, load was applied to the bearing system via a hung weight. The weight was hung on fishing line on top of a bearing, allowing just the radial load to be applied.
- C. Testing** - There were 5 trials of data taken, each with slightly different variations. There were 5 different RPMs with 3 bearing designs, 2 lubricants, and 3 different loads. Each bearing was tested for the same amount of time as well, starting with the initial addition of lubricant to the final test to ensure sameness across trials. Each lubricant method had an individual bearing pair, so 6 total pairs were used.

# Bearing Design



Model created by experimenter in OnShape



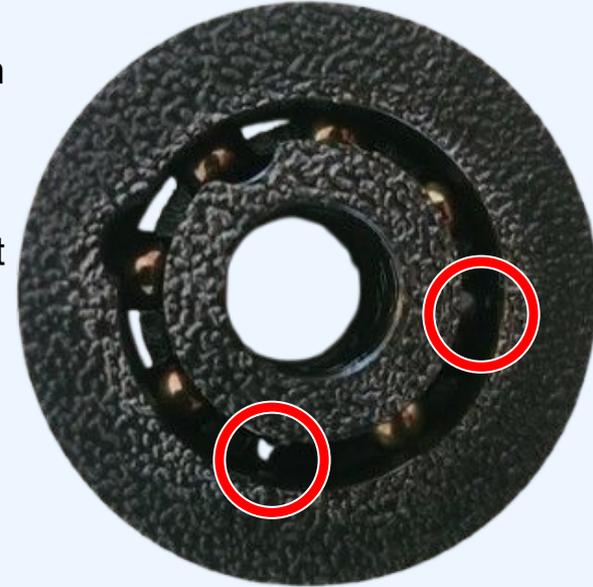
Model created by experimenter in OnShape

Each bearing uses the same design of a single raceway (where balls travel) and having an 8-ball cage.

The two novel designs swapped out one or two of the regular rolling elements with magnetic balls.

The right hand shows the 6:2 ratio design. The magnetic balls are shown circled, being harder to see as they have attracted the ferrofluid around them, making them darker.

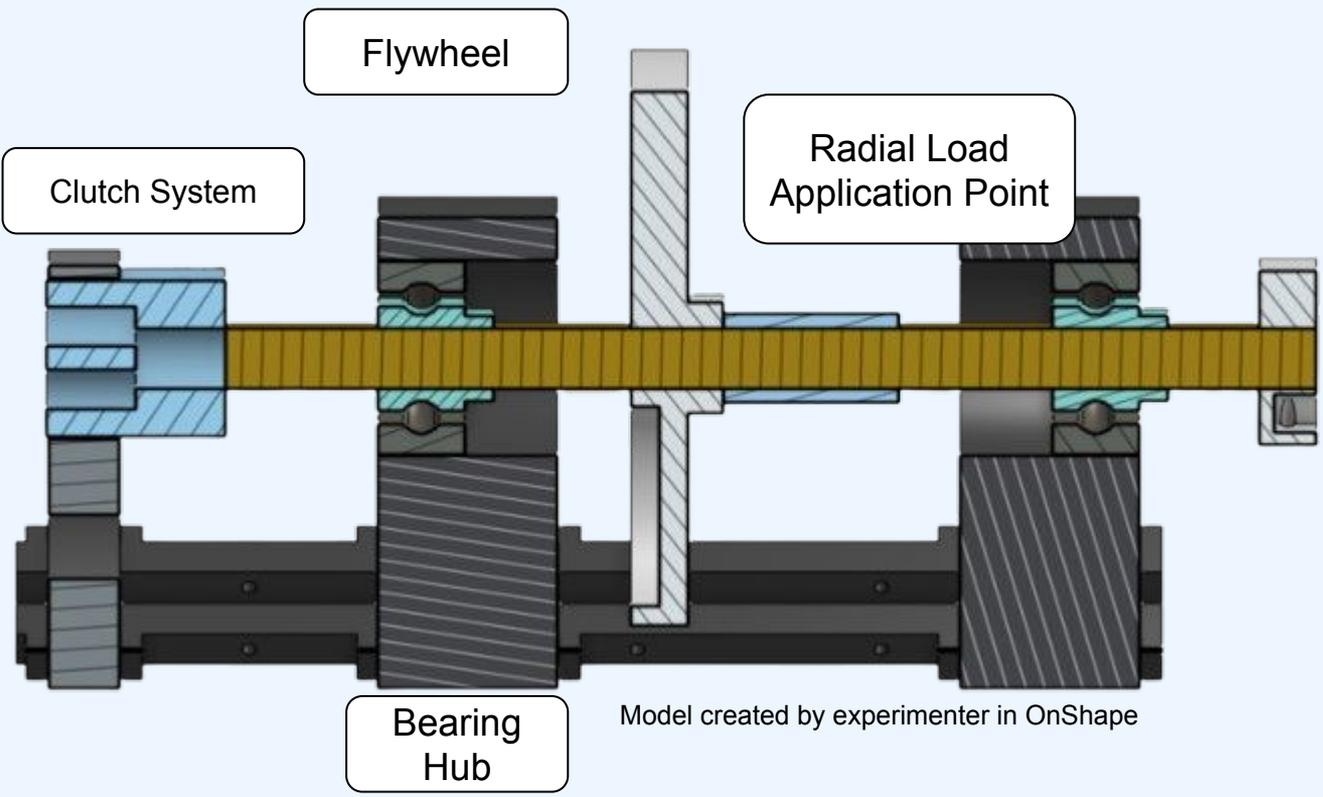
Offsetting the magnets helped reduce the friction that arose as they were attracted to each other.



Picture taken by experimenter.

The other 7:1 design would swap out merely one steel ball for a magnetic ball.

# Test Rig Design



The test rig went through a handful of iterations, mostly due to inconsistencies in design. The clutch system now goes to a lego gearbox that gears a motor that runs at a constant speed, giving more controllable RPM.

The RPM sensor is also at the very far right, as a series of 4 magnets that pass a hall effect sensor, allowing RPM calculations from the time between each pulse.

# Procedure

## Bearing Assembly

Cage Preparations - Using a 7/32" drill bit, drill out holes in cages to loosen them.

Preload - Place 6 steel balls in each bearing.

Basic Assembly - Place cage in and rearrange balls to fit in desired position, adding magnets last into the whole system.

## Test Rig Assembly

RPM Counter - Assemble hall effect circuit and create code to log RPM pulses.

Shaft Prep - Sand and drill holes on the wooden shaft where necessary to attach elements later on.

First Run - Place in bearings and bearing hub on shaft before assembling everything else.

Set Up - Swap out bearings from old ones to new ones.

## Data Collection

Lubrication - Using a dropper, add a drop of lubricant to each bearing and spin to coat.

Preparations - Set up loads and proper gearboxes.

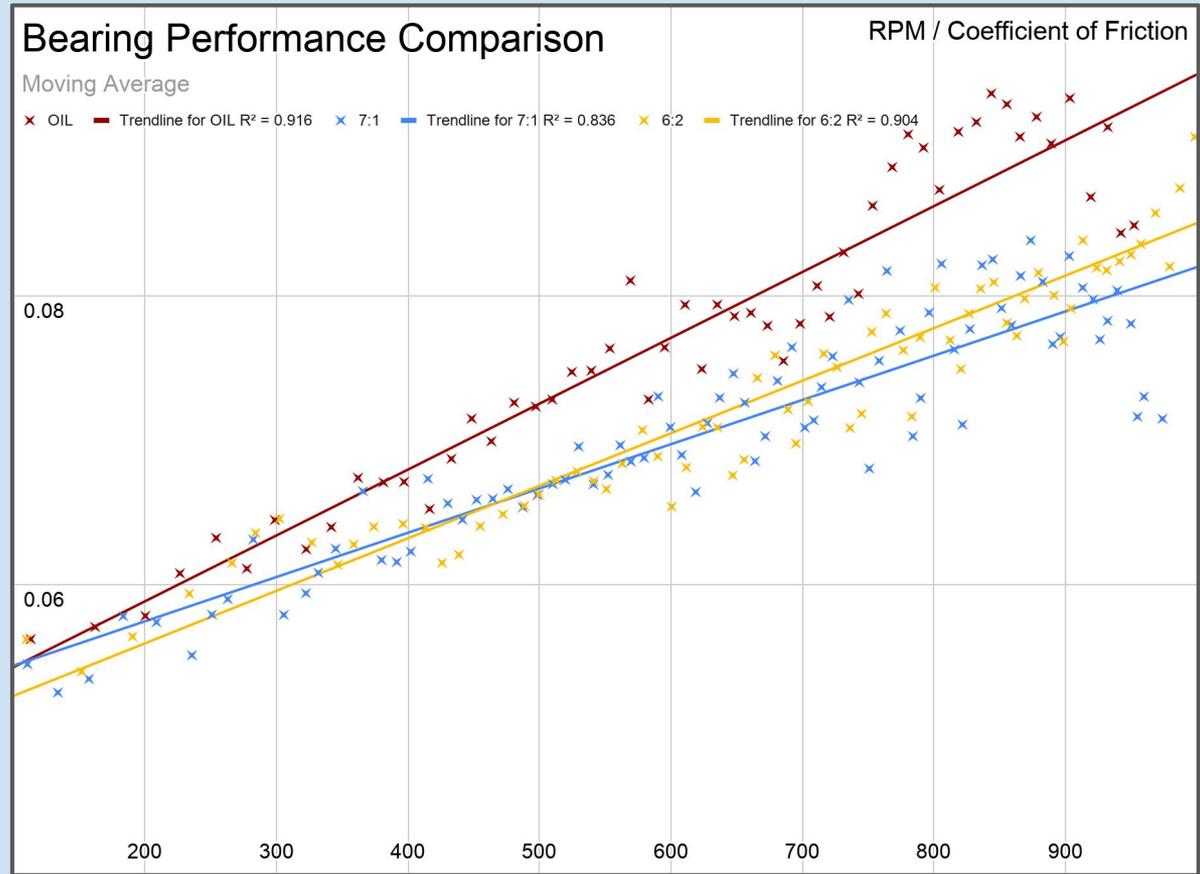
Collection - Run the motor up to speed and disconnect the whole system (gearbox included).

# Results

Ferrofluid demonstrated itself as an effective lubricant in the two new bearing designs, increasing performance by over 20% in the 6:2 ratio bearing and around 10% in the 7:1 bearing. When compared to the traditional bearings, ferrofluid was still more effective, but less so, around 8.6% for 7:1 and 5.1% for 6:2.

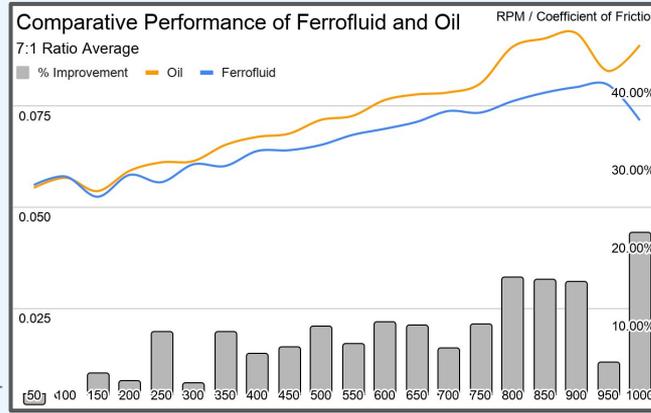
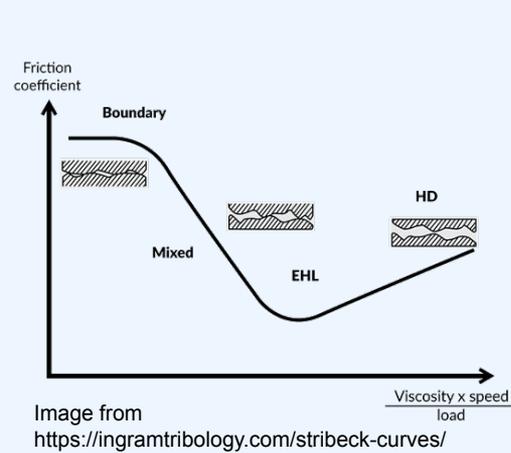
In general, ferrofluid performed better at higher RPMs, having a less pronounced increase in friction as RPM went up.

All data was found to be statistically significant with a p-value < 0.001

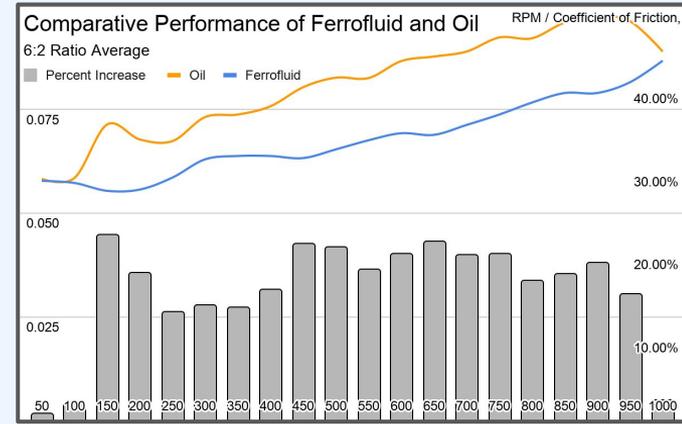


Graph created by experimenter in Sheets

# Analysis



Graph created by experimenter in Sheets



Graph created by experimenter in Sheets

Throughout, ferrofluid was able to outperform the traditional lubricant in various scenarios, as well as outperforming the traditional bearing. By using the Hamrock-Dowson equation the specific film thickness of oil was found to be very low, mainly due to the surface roughness of PLA.

Since ferrofluid behaves as a non-newtonian shear-thinning fluid under a magnetic field, this allowed it not only hold a better film, but also deal with loads more effectively. Both bearings operated in the boundary lubrication region of the Stribeck Curve, as depicted on the top left image.

# Conclusion and Discussion

In conclusion, ferrofluid works well, if not better than traditional oil lubricants in radial ball bearings.

- My results show that it is possible to use magnets inside bearings to hold the ferrofluid in place, creating a more stable lubrication film.
- Because of the behavior of ferrofluid in a magnetic field, it is able to hold a more stable film as well.
  - These experimental bearings have a few drawbacks however - ferrofluid is more expensive and the magnets will attract ferromagnetic debris. In addition, the use of multiple magnets in a bearing can create unnecessary friction as the magnets within the bearings are attracted to other each other and the other rolling elements.
- Furthermore, there is still more to explore, especially related to the longevity and starvation of ferrofluid compared to other lubricants.

# References

1. Holmberg K, Erdemir A. (2017), *The impact of tribology on energy use and CO2 emission globally and in combustion engine and electric cars*, <https://doi.org/10.1016/j.triboint.2019.03.024>
2. Xu et al. (2020), *Ferrofluid lubrication for ball bearings to avoid starvation*, <https://doi.org/10.1108/ILT-04-2020-0132>
3. Ingram Tribology Ltd. (n.d.). Stribeck curves. Ingram Tribology. <https://ingramtribology.com/stribeck-curves/>