Individual Analytical Analysis

Capstone Team
Flying Squirrels

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Introduction

The purpose of this analysis is to help with the selection of certain different parts of the Flying Squirrel robot. The goal of the flying squirrel capstone project is the spiritual successor of the HAMSTER capstone project whose goal was to create an affordable stroke rehabilitation robot that people can purchase and set up in their home. While we still share the same goal the hamster was a 2D robot only capable of moving across the table while the Flying squirrel aims to break into that third dimension. For this specific analysis we will be focusing specifically on the lower half of the robot. The two analysis that will be done in this report will be for lead screw specification and ball bearing life cycle. The importance of the lead screw calculations is that it is our lifting mechanism to expand into that last dimension. As for the ball bearing life cycle calculations we are using loose ball bearing as the robot's wheel so calculating how long they will last is important to use to see if we must move in a different direction for our wheels. These topics were approved both by Carson Pete and the Client Dr. Ravaian.

Lead Screw Specifications

Assumptions and Variables

- v = 1 m/s   Linear speed required
- n = 50 rev/s   Rotational speed
- F = 25 N   Applied Load
- η = .4   Efficiency
- E = 200GPa   Young's modulus of steel
- K = 2   Column effective length factor
- D = 7mm   Inner Diameter
- l = 14 in   Length of lead screw
- I – moment of inertia
- L – lead
- T – Torque Required
- F_{cr} – buckling load

The assumption above is all reasonable at this time but can be subject to change as we progress further in this project, for example the motor chosen the lift screws has 3000 RPM which translate to 50 rev/s. The reason 25 newtons were chosen for the load is because the weight of the average human forearm and the top of robot combine to roughly to a little less than 50 newtons of force so split among the two-lead screw gives us our load. Efficiency can vary depending on a wide range of factors like lead angle, coefficient of friction and nut material, but in the case of ACME lead screws efficiency typically falls within the range of 0.3 to 0.5 [1]. While looking at markets most of the affordable lead screws were made from steel so that's why steel was chosen, and the Young's modulus of steel was gotten from Shigley's Mechanical Engineering Design [2]. We are using the worst-case scenario for the K factor because with how design it is it could be reasonably as seen as fixed-free end see Figure 1.

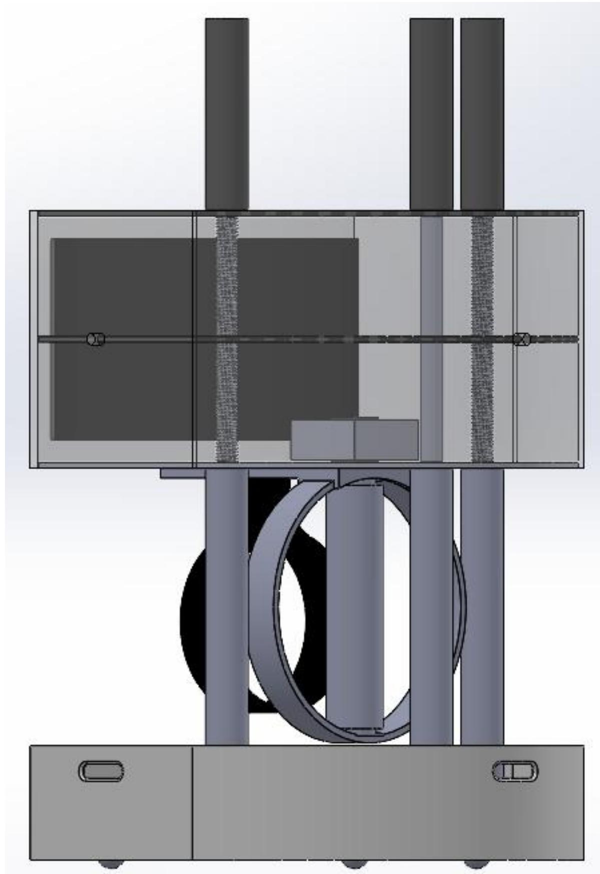

Figure 1Lead screw column comparison

$$L = \frac{v}{n} = 20mm \qquad \text{(Eqn. 1)}$$

$$T = \frac{FL}{2\pi\eta} = 0.1989\ N * m \qquad \text{(Eqn. 2)}$$

$$I = \frac{\pi D^4}{64} = 1.203 * 10^{-10} m^4 \qquad \text{(Eqn. 3)}$$

$$\text{Fcr} = \frac{\pi^2 EI}{(Kl)^2} = 469.5\ N \qquad \text{(Eqn. 4)}$$

The Lead necessary for the screw to achieve 1 m/s with the selected motor is 20mm. There are two ways to achieve this either increase the pitch of screw or increase the start or increase the starts the screw has. So, when choosing a lead screw, we will have to look for one that's either has 10 mm pitch, 2-start screw or 20 mm pitch, 1-start screw with the former being the most realistic and best option for us.

The minimum torque requirement needed for any motor chosen .1989 N*m, which obviously influences which motor we end up deciding on. The motor chosen at the beginning does for the record accomplish this minimum torque requirement.

The critical buckling load for this lead screw is 469.5 newtons this was calculated by treating it as a column used which it will be acting as such when it is extended. This which far exceeds what we need for this we should not fear the screw breaking in any situation where the robot is being handled properly.

Ball Bearing Life Cycle

Assumptions and Variables

- C = 500 N Dynamic load rating
- P =26.7 N Equivalent radial load
- p = 10/3 Life exponent
- L_{10} – Bearing life in millions of revolutions
- v = 1 m/s Linear speed required
- D = 1/2 in or 0.0127m Diameter of the ball bearing
- N – Speed
- L_{10h} – life rating in hours

Since our ball bearing is not exactly in a traditional cage as seen in figure 2 and 3 there is little info about its dynamic load rating, we are using one as it was in a traditional cage and will address this at the end of this section. For this size of bearing the dynamic load rating it can range from 500-1000N, from astbearings [3], to be on the safe side we will pick the low end this time. The same as before applies when picking a life exponent so we are picking 10/3 for as if it were a roller bearing. The client has requested a linear speed of 1 m/s, and the diameter of the ball bearing is that of the one chosen for the task of being our wheel.

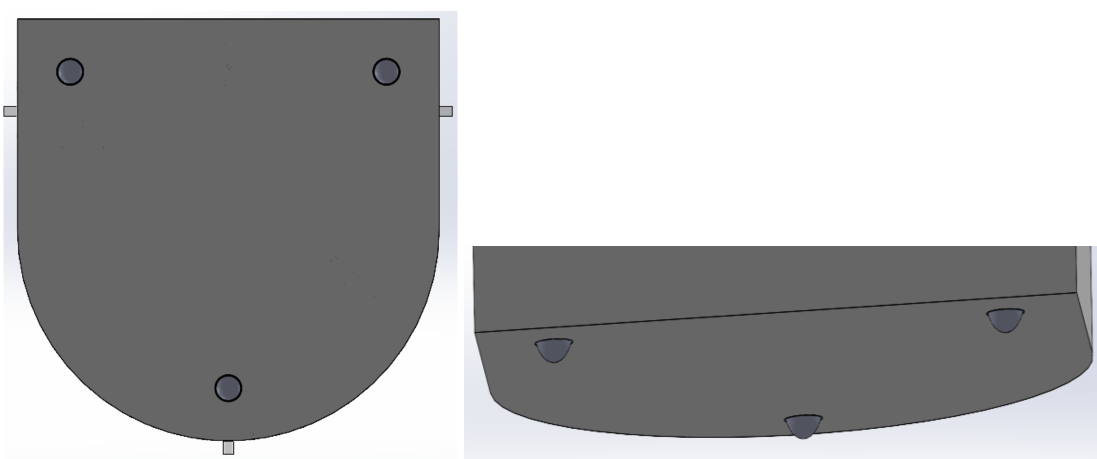

Figure 2 & 3 Ball bearing placement and orientation

$$L_{10} = (\frac{C}{P})^p = 17{,}439 * 10^6 \; revoltions \qquad \text{(Eqn. 5)}$$

$$N = \frac{v*60}{\pi*D} = 503.8\ RPM \qquad \text{(Eqn. 6)}$$

$$L_{10h} = \frac{L_{10}}{N*60} = 193{,}277\ hours \qquad \text{(Eqn. 7)}$$

Using the assumption that we made we calculated a total lifetime hour of 193,277 hours using the equations from Shigley's textbook [2] once again. But we our work is not finished just yet we made some assumption at the beginning of this that still need to be addressed. I looked for a long time to see if there was any kind of lifetime calculation for a loose Ball bearing seeing as that is the closet to our situation but there was nothing out there for me to use. So instead, I went to the websites of the actual distributors of these ball bearings and from what I can gather the best rule of thumb in not the ideal conditions a bearing lifetime can be estimated using the above equations and then taking whatever number is calculated multiplying it by half to a third. With all that being said the actual lifetime rating to my best estimation is 64,425-96,638 hours of use. Reflecting on these results that we have derived here we found that this was acceptable to us so that we can continue to use the bearing as our robots' wheels.

CONCLUSIONS

In conclusion, this analysis will provide guidance in a lot of different areas going forward. First the lead screw calculations are giving us decent guidance what we are looking for when finalize a choice for our motor for the lift screws. I have also created a small little code for this calculation to test other motors if necessary. This of course ignores the obvious that this calculation has shown us what exactly to be on the hunt for in terms of leadscrews. The ball bearing lifetime calculations not only showed us that the bearings were up to the task of being our wheels but also that they would last longer than most other components of our robot even on the low end of its range. But with all these calculation done we can be certain about these things when we go and make that final purchase on the things calculated here.

All these calculations and results satisfied the client Dr. Ravaian.

1 REFERENCES

[1] “Acme lead screws and nuts,” Roton Products, Inc., https://www.roton.com/products/acme-lead-screws-nuts/general-information).

[2] BUDYNAS, *Shigley’s Mechanical Engineering Design, 11th Edition, SI Units. (NO US Rights)*. MCGRAW-HILL EDUCATION (AS, 2020).

[3] Radial Ball Bearing Life & Load Ratings | AST Bearings, https://www.astbearings.com/radial-ball-bearings-life-and-load-ratings.html (accessed Apr. 28, 2025).

[4] “SKF Roller Bearings,” SKF, https://www.skf.com/group/products/rolling-bearings (accessed Apr. 27, 2025).

[5] “Ball bearings,” The Timken Company, https://www.timken.com/products/timken-engineered-bearings/ball/(accessed Apr. 27, 2025).

2 APPENDICES

Leadscrew Code

```
 %lead screw
%% lead of the screw
v = 1;           % m/s linear speed
n = 50;          % roational speed in rev/s equal 3000 RPM
L = v/n;         % Lead of the screw
% the lead is 20mm which means we 10mm pitch, 2 start screw
%% Torque requirements
F = 25;          % assuming the load 50 is split between the 2 screws ...
                 % 45 newtons rougly is the weight of a human forarm
nth = .4;       % average efficenfy rating for the ACME lead screw
T = (F*L)/(2*pi*nth);   %Using the simplified Torque formula we get Torque in N*m
%% critical buckling load
E = 200*10^9;    % young moudule of steel Pa
K = 2;           % K factor for a fixed-free end pillar
l = .3556;       % length in mm in inches its 14"
d = .007036;     % the inner diamter of the screw this number is place holder till we
select a lead screw
I = (pi*d^4)/64; % moment of Inertia
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