**Department of Electrical and Electronic Engineering**



Embedded Systems Project 2023-24

DESIGN REPORT #1

Title: DR1--Motors

Group Number: 5

|  |  |  |
| --- | --- | --- |
| Group members: | ID Number | I confirm that this is the group’s own work. |
| Vincent Vanhegan | 10824383 |  |
| Diego Roth |  |  |
| Parimal Saha |  |  |
| Zike Xu |  |  |
| Hongzhe Cai | 11041996 |  |

Tutor: Wuqiang Yang

Date: 22/10/2023

Contents

[1. Introduction 1](#_Toc17886406)

[2. Motor characterisation 1](#_Toc17886407)

[3. Load measurements 1](#_Toc17886408)

[4. Gear ratio selection 2](#_Toc17886409)

[5. Summary 2](#_Toc17886410)

[6. References 2](#_Toc17886411)

# Introduction

The first design report is all related to the motor in the robot buggy and the body part of the report focuses on how to choose a proper gearbox through several experiment steps. This report will also briefly mention the signals used in the microcontroller to control the motor drive board.

During the experiment, the laboratory work involved tasks such as evaluating the resistance of power supply leads, analyzing the motor's performance under varying loads, estimating kinetic energy and torque constants, and determining the force required to propel the buggy on diverse surfaces while considering different weights. We got several pairs of data in the lab to support our estimate of the proper gear ratio.

Throughout the project's duration, the most important task we were talking about was the performance of the motor and the influences of the gearbox in the whole project. The choice of gearbox mainly affects the robot buggy’s speed and operational frequency. There are quite a lot of advantages and disadvantages to the gearbox. A well-designed gearbox with a proper gear ratio enables precise control over the robot buggy's speed and torque on varying terrains. Also, varying the gear ratio can help the robot buggy perform well in different scenarios. However, designing a perfect gearbox is very complex and needs several experiments and data to support it, also it would have a huge cost.

Outside the experimental hours, we are also considering the signals needed to be used between the microcontroller and the motor drive board. We might employ the Pulse Width Modulation (PWM) on the motor drive board to regulate motor speed. PWM achieves this by rapidly alternating the voltage supply, effectively managing the motor's average voltage. If necessary, the PWM signal from the microcontroller can be transformed into an analogue voltage by a low-pass filter.

# Motor characterisation

**Introduction**

During our motor characterisation investigation, our goal is to calculate the torque constant, KE, and the voltage constant, KE, which enables us to respectively determine the relationships between torque and current as well as voltage and angular speed. Along the way we shall also obtain some other values for the motor to assist in our calculations, we shall do this by measuring the voltage, current and torque of our motor in various setups to gauge and check these obtained values. We do still need to keep within the operating limits of the motor, to avoid damage or overheating, so Voltage will be limited to 5V and current to 1.4 A.

**Test 4:**

Now when stalling the motor, we vary the current measuring the terminal voltage of the motor and the required stall force.

**Experimental setup:**

The graph in Figure 1 shows the linearity of the motor’s relationship between voltage and current, which is consistent with the prior test.

|  |  |  |
| --- | --- | --- |
| Test no | Resistance (R) | Back emf (Vb) |
| 1 | 2.0655357 | 0.135857143 |
| 2 | 2.1355357 | 0.104142857 |
| 3 | 2.4839286 | -0.023 |

*Figure 1b – Tabel showing calculated values from different experimental tests.*

*Figure 1a – Graph showing the Voltage-Current of a motor when stalled.*

However, we see our value for resistance, and gradient, increase across our results. This is due to the temperature of the motor armature increasing, subsequently increasing its resistance.

Despite our values for the back emf (Vb) varying, their magnitude, |Vb|, <0.5 hence these values are negligible and can be ignored as this was mostly caused by the irregularity of motor temperatures throughout the investigation.

|  |  |  |
| --- | --- | --- |
| Test no | Torque Constant (KT) | Torque loss (TLoss) |
| 1 | 0.0041933 | 0.001118214 |
| 2 | 0.0078906 | -0.0012625 |
| 3 | 0.0069888 | -0.000144286 |

*Figure 2b – Table showing calculated values from different tests measuring torque and current.*

*Figure 2a – Graph showing the relationship between Torque and Current of the motor when stalled.*

*Figure 2c – Graph showing separate test data for Torque-Current relationships of a motor at stall.*

In Figure 2c we can see a lack of linearity in some of our recorded results, although this gives us a somewhat subtle difference in our value of KT, barring test 1. By eliminating tests 1&2 in the calculation of KT we seemingly obtain a truer value where the data obeys a linear relationship and verifies our previous tests. Yet again our y-intercept values, TLoss, have a magnitude smaller than 0.5, Hence, we can treat these values as negligible due to their minimal effect in further calculations.

**Conclusion:**

Obtaining estimates for these constants will enable us to calculate the torque output and speed of our motor to help make a more informed decision when deciding the required gearbox for the required torque for moving the buggy along and up slopes, given that our maximum slope angle is 18°.

# Load measurements

**How does this section relate to each other/the whole report/aim/objectives?**

This section considers how much tension and torque the buggy needs to drive on flat ground and slopes. The data in this part can be used to judge the ratio of the gearbox because the torque provided by the buggy's motor with the gearbox must be greater than or equal to the torque required by the buggy before the buggy can drive normally.

**Estimated forces required to drive the buggy up the slope.**

* Calculation:

In the experiment, the slope is 18°, and the mass of the buggy is 1.194 kg. The tension is 4.72N.

图示

描述已自动生成For the calculation of Friction Coefficient:

In this system, Tension = Friction + Weight\*sin (18°).

So, the Friction Coefficient is [Tension - Weight\*sin (18°)] / Weight\*cos (18°) = [4.32 – 1.194\*9.81\*sin (18°)] / 1.194\*9.81\*cos (18°) = 0.0988.

*Figure 3a – The graph of force analysis diagram of the buggy*

* Prediction:

图表, 折线图

描述已自动生成When the coefficient of friction is obtained, a buggy of any mass can be predicted on an 18° slope.

Through this graph, it can be obviously seen that the tension is proportional to the mass of the buggy, which is a linear relationship. The tension increases as the mass of the buggy increases.

Figure 3b – The graph of the tension at different masses of buggy

**Estimated forces required to drive the buggy on the flat.**

* Calculation:

Calculation of the Friction Coefficient:

In the experiment, the mass of the buggy is 1.194 kg. The tension is 1.18N.

图示

描述已自动生成

In this system, Tension = Friction.

So, the Friction Coefficient is Tension / Normal Force = 1.18/1.194\*9.81=0.101.

*Figure 4a – The graph of force analysis diagram of the buggy*

* Prediction:

When the coefficient of friction is obtained, a buggy of any mass can be predicted on flat ground.

图表, 折线图

描述已自动生成

This graph shows that the buggy is on a flat surface. The tension required by the buggy is proportional to the mass of the buggy. When the mass of the buggy increases, the tension required also increases.

*Figure 4b – The graph of the tension at different masses of buggy*

**Required torque at the wheel shafts.**

* Calculation of the buggy on the flat:

The wheel radius is 33.5 mm.

Flat: When the buggy is on a flat, the torque is Tension\*wheel radius = 1.18\*0.0335 = 0.395Nm

* Prediction of the buggy on the flat:

图表, 折线图

描述已自动生成

Through this graph, the torque is proportional to the mass of the buggy on the flat, which is a linear relationship. The torque increases as the mass of the buggy increases.

Furthermore, according to the graph, the buggy with 1.5 kg will need about 0.05Nm to drive itself on the flat.

*Figure 5a – The graph of the torque against the mass of the buggy on the flat*

* Calculation of the buggy on the ramp:

When the buggy is on a ramp with a slope of 18°, the torque is Tension\*wheel radius = 4.72 \* 0.0335 =0.158 Nm.

* Prediction of the buggy on the ramp:

图表

描述已自动生成

Through this graph, it can be clearly seen that the torque is proportional to the mass of the buggy on the ramp, which is a linear relationship. The torque increases as the mass of the buggy increases.

Furthermore, according to the graph, the buggy with 1.5 kg will need about 0.2Nm to drive itself on the ramp at 18 degrees.

*Figure 5b – The graph of the torque against the mass of the buggy on the ramp*

# Gear ratio selection

**Introduction:**

In this section of the report, the appropriate gearbox to scale the motor torque to the project requirements shall be determined. We shall also be calculating the arrangement of gear shafts within the gearbox, as well as the maximum speed of the buggy on horizontal and sloped conditions.

**Gearbox Selection:**

In the previous section, we see that for a buggy of mass 1.5kg we need 0.2 Nm of torque to move our buggy up the maximum slope incline, as we have 2 motors, we only need 0.1 Nm from each motor.

The gearbox available are all two stages which means that the gearbox inefficiency will be applied twice. Efficiency per stage is estimated at about 85%, so, two stages and therefore: 0.85 ∗ 0.85 = 0.7225 = 𝟕𝟐. 𝟐𝟓%, **Reference Motor Characterisation Slides,** therefore we shall scale the required torque as such.

|  |  |  |  |
| --- | --- | --- | --- |
| Gearbox Selection | Gearbox Gain ratio | Required scaled torque | Required Torque with gearbox inefficiency |
| 1 | 1:12 | .0083 | .011 |
| 2 | 1:15 | .0066 | .0091 |
| 3 | 1:18.75 | .0053 | .0073 |

We also determined during the motor characterisations section of our report, that the K value of our motor @ 0.07. The motor is also limited by a maximum operating current of 1.4, however, we want to keep the peak motor current between 1.2 A & 1.3 A to ensure the motor neither overheats nor is damaged.

Using the equation T = KTI – TLoss, which becomes T = KTI due to TLoss being negligible, we can calculate the torque outputs of our motor.

|  |  |  |
| --- | --- | --- |
| Current (I – Amperes) | 1.2 | 1.3 |
| Torque Output (Nm – Newton Metres) | .0084 | .0091 |

By comparing the required torque and the supplied torque of the motor within our operational current range, we can see that gearbox 2 is the most appropriate choice to achieve the required torque while not compromising on rotational speed.

**Gear Shaft Positioning:**

𝑃𝐶𝐷 = 𝑁𝑜. 𝑜𝑓𝑡𝑒𝑒𝑡ℎ ∗ 𝑀𝑂D

The MOD is the ‘module’ of the gears (your gears are all 0.5 mm module)

**Reference Procedural handbook**

Using the above equation, we can determine the distance of the intermediate shaft; we are including an extra 0.1mm to account for manufacturing tolerances.

|  |  |  |  |
| --- | --- | --- | --- |
| Selection Number | Pinion Gear | Intermediate Gear | Gear on the final drive |
| 2 | 16 tooth | 50/10 press fit gears (orange) | 48 tooth |

**Reference Procedural handbook**

From the pinion gear to the first intermediate gear, we can calculate the centre distance.

From the second intermediate gear to the press fit gear, we can calculate the secondary centre distance similarly.

If we were to arrange our gearbox purely in a straight line, we would have our pinion at coordinates (0,0) our intermediate shaft at (16.35, 0) and or press-fit gear at (30.95,0) in this configuration there is no vertical displacement between any of the gear shafts, this could be modified to take up more vertical but less horizontal space.

**Motor Speed Determination**

Using the below equation, we can calculate the rotational speed of our buggy.

**Reference Motor Characterisation slides**

where V­b is negligible and K­­E = KT

**Conclusion:**

The final choice of gearbox is selection 2, although if this proves to not provide the required motor torque due to high inefficiencies, we can always change this gearbox to selection 3 to obtain the required torque.

# Summary

After performing the experiments and analysing the results we have come to the conclusion of going ahead with gearbox selection 2 for our buggy. The group has agreed to switch to selection 3 if our current gearbox fails to provide the required motor torque.

Design Considerations

Placement of motor and gearbox-

Distance of chassis from the ground-

Other considerations

# References

1. See the section on Citations and Referencing Styles in the ESP Procedures Handbook.

Make sure that you have **read the top** of the marking scheme to look for report length etc.

Make sure that you have **read the bottom** of the marking scheme for Presentation and Penalties.

Remember to update your table of contents before submitting the report.

Aim to submit the report long before the deadline, to mitigate last-minute problems with the internet and with Blackboard.