Mechanical Design
Shigley Loader

Assignment 1 - Gear Ratio Calculation

EME 150B

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OBJECTIVE:

This report provides the analysis used to find the motor load torque that maximizes the power output of a Mabuchi RE280 DC Motor, and the closest corresponding velocity ratio (gear ratio) available for each load case (**Table 1**). This analysis will directly affect the design of the Shigley Loader, a device used to move loads up an incline plane in a short amount of time.

Table 1: The load case for each test run the shigley loader will perform under.

Test Run	Inclination Angle, θ_k	Load, *j*
1	20^0	1 shigley
2	30^0	1 shigley
3	30^0	2 shigley
4	40^0	3 shigley
5	40^0	4 shigley
6	60^0	4 shigley
7	60^0	5 shigley

ANALYSIS:

Main Tasks:

1) Find the motor load torque that maximizes power output of the DC motor
To find motor load torque that maximizes power output of the Mabuchi RE280 DC Motor, the torque-speed characteristic equation (**Equation 2, Appendix B**) was altered keeping in mind the fundamental equation for power (P = T*n). Multiplying the whole equation for motor torque therefore yielded the equation for power (**Equation 3).** This equation was then differentiated to find the maximum power and its corresponding torque and angular velocity (T = 0.00635Nm and n = 4600rpm respectively).

2) Find the closest corresponding velocity ratio available for each load case.
The closest corresponding velocity ratio (gear ratio) available for each load case was found using the motor load torque for the maximum power output alongside **Equation 1** and the load cases' respective torque acting on the spool (see **Appendix A** for solutions). The general set up for each load case can be seen in **Figure 1**, where F_{GB} is the force acting on the spool.

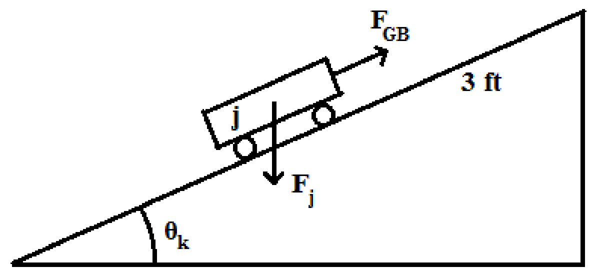


Figure 1: Free Body diagram of the forces acting on the Shigley Loader. F_GB represents the force acting on the spool

Sub Tasks:

1) Calculate the force and corresponding torque (a function of spool radius) for each load case.

A single Shigley textbook was weighed at 2.2 kg, which provided a gravitational force of 21.6 N. Using **Equation 4** with **Table 1**, the force acting on the outer edge of the spool was found for each load case. Since the radius of the spool has yet to be determined, the acting torque was left as a function of the spool radius (**Equation 5**). With the acting torque for each load case found, the velocity ratio and its corresponding torque ratio was able to be calculated (see **Appendix A** for results).

2) Calculate the theoretical time to lift each load case.

With the velocity ratio found for each load case, the theoretical time was then calculated. By multiplying the velocity ratio by the motor angular velocity for the maximum power output, the angular velocity of the spool was found. This value was converted from an angular velocity (rpm) to a linear velocity (m/s) using **Equation 6**; this also nullified the spool radius variable from the initial equation. By dividing the overall length of the ramp (3 ft/0.9144 m) by the linear velocity of the spool, the theoretical time for each load case was found (see **Appendix A** for results).

3) For one load case, check to see if the gear ratio that maximizes power output is actually the optimal solution by evaluating the times of all gear ratios.

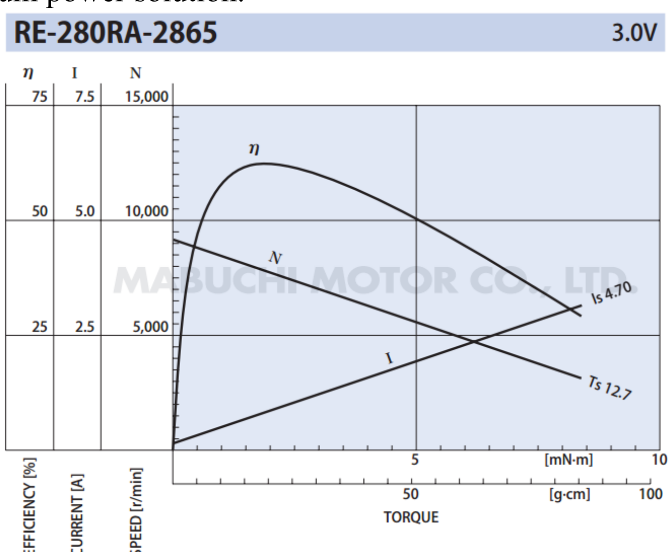
As a means to double check the velocity ratio (gear ratio) found in the previous section, additional gear ratios were analytically tested. It was found that if the gear ratio was smaller than the one found for maximum power, the Shigley Lifter was able to perform, but at a reduced lift rate. When the gear ratio was larger than the one found for maximum power, the Shigley Lifter would also perform at a slower rate, but would eventually stall/fail should the gear ratio be too large. The results for the first load case can be seen in the table on the next page (**Table 2**).

Table 2: Gear ratio comparison in respect to the maximum power gear ratio for the first load case.

Case	Velocity/Gear Ratio	Load Torque (N m)	Motor Torque (N m)	Time (s)
Below max power gear ratio	6.50E-04	7.39	0.00480415	2.53
Max Power Gear Ratio	8.59E-04	7.39	0.00198	2.20
Above max power gear ratio	2.00E-03	7.39	0.014782 (Larger than specified stall torque)	Stall

4) For one load case, compare the time for the maximum power solution to the time for the maximum efficiency solution

For reference, the theoretical lift time was also found for the motor torque that maximizes efficiency. By following the same process stated in section 1 to 3 of the analysis along with the motor torque for max efficiency provided by the manufacturer's data sheet and plot (**Figure 2**), it was found that the time for the maximum efficiency solution was roughly twice as slow as the time for the maximum power solution.



MODEL	VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY					STALL		
	OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
			r/min	A	r/min	A	mN·m	g·cm	W	mN·m	g·cm	A
RE-280RA-2865	1.5～3.0	3V CONSTANT	9200	0.16	7770	0.87	1.98	20.2	1.61	12.7	129	4.70

Figure 2: Motor specs for the Mabuchi RE280 DC Motor

Since the Shigley Hauler is designed to go through each run only once, maximum power is favored over maximum efficiency because it would provide the fastest lift time. This would not be the case should the Shigley Hauler be required to repeat a run multiple times, using a limited power reservoir; in that case, maximum motor efficiency would be the best.

Appendix A - Data Tables

Maximum Power (T = 0.00635 Nm & n = 4600 rpm)			
Torque Ratio/R	**Angular Velocity Ratio*R**	**Pitch Velocity (m/s)**	**Time (s)**
1163.94	8.59E-04	0.4138602573	2.20
1701.57	5.88E-04	0.283097089	3.22
3403.14	2.94E-04	0.1415485445	6.45
6562.50	1.52E-04	0.07340348112	12.45
8750.00	1.14E-04	0.05505261084	16.60
11788.85	8.48E-05	0.04086154514	22.37
14736.07	6.79E-05	0.03268923611	27.97

Maximum Efficiency (T = 0.00198 Nm & n = 7770 rpm)			
Torque Ratio/R	**Angular Velocity Ratio*R**	**Pitch Velocity (m/s)**	**Time (s)**
3732.85	2.68E-04	0.2178355802	4.19
5457.07	1.83E-04	0.1490083127	6.13
10914.14	9.16E-05	0.07450415636	12.27
21046.42	4.75E-05	0.03863596375	23.66
28061.89	3.56E-05	0.02897697281	31.55
37807.69	2.64E-05	0.02150749737	42.51
47259.61	2.12E-05	0.01720599789	53.14

***Note: R represents the spool radius**

Appendix B - Equations

$$\frac{T_{in}}{T_{out}} = \frac{N_{in}}{N_{out}} = \frac{n_{out}}{n_{in}} \quad \textbf{(1)}$$

$$F = jM_s sin(\theta_k) \quad \textbf{(4)}$$

$$T = T_s(1 - \frac{n}{n_0}) \quad \textbf{(2)}$$

$$T = FR \quad \textbf{(5)}$$

$$P = T_s(n - \frac{n^2}{n_0}) \quad \textbf{(3)}$$

$$v = \frac{2\pi Rn}{60} \quad \textbf{(6)}$$

Symbol	Variable	Symbol	Variable
T	Torque [N m]	j	Number of Shigley’s
N	Number of Teeth	M_s	Gravitational Force from Shigley(s) [N]
n	Angular Velocity [rpm]	θ_k	Angle of Ramp [Degree]
T_s	Stall Torque (0.0127 N m)	R	Spool Radius
n_0	No-Load Speed (9200 rpm)	v	Linear Velocity [m/s]
F	Force acting on Spool		