Electric Actuators (034034) project
Brushed DC motor

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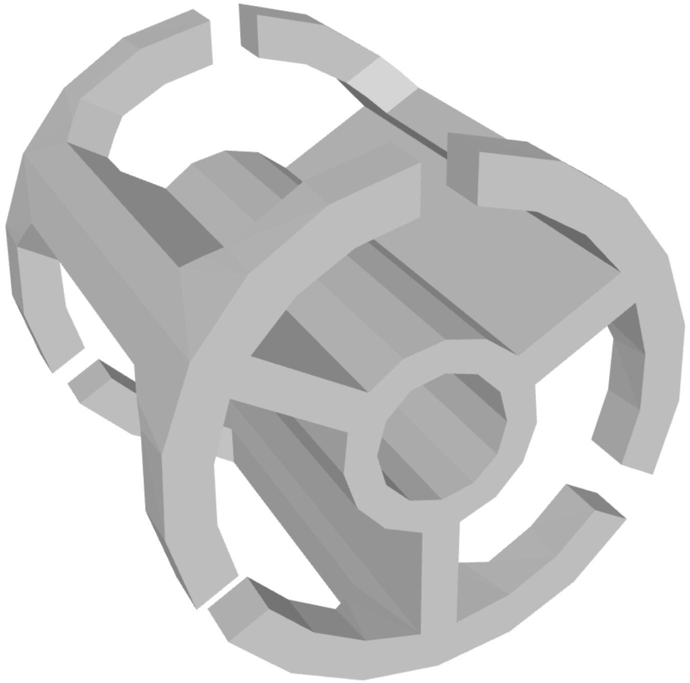
Motor Description

Armature

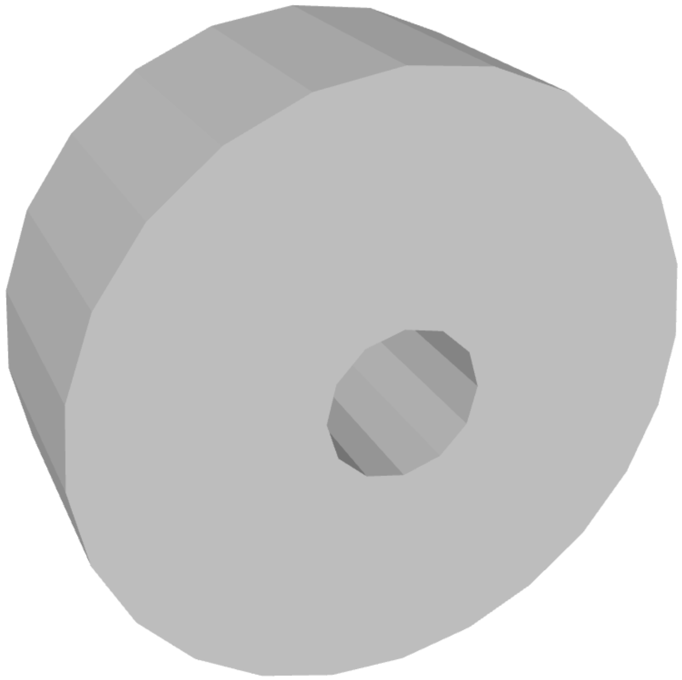
- The armature is the main rotating component of the motor, consisting of multiple coils of wire wound around a central core. It is connected to the shaft and spins during operation.
- 3 coils with 60 loops each
- Shaft goes through it, using bearings



Motor Description

Commutator

- Mounted on the motor shaft, the commutator is a segmented metal ring. Each segment is connected to one end of the armature coil. Acting as a mechanical switch, it changes the direction of current in the armature coils as the motor rotates, preventing it from stalling.



Motor Description

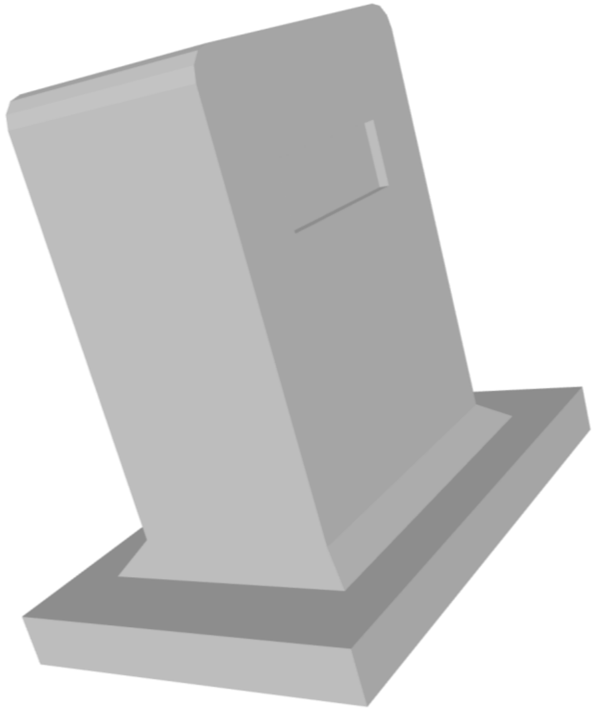
Shaft holder

- The shaft holder is a component that securely positions the motor shaft within the housing. It ensures proper alignment of the shaft, allowing it to rotate smoothly and maintain stability during operation. By keeping the shaft firmly in place, the shaft holder minimizes vibration and reduces wear on the bearings and other internal parts of the motor.

Motor Description

Stator

- The stator is the non-moving part of the motor, made up of permanent magnets or field coils that produce a magnetic field. The magnetic field from the stator interacts with that of the armature, and according to the Biot-Savart law, this interaction causes the motor shaft to rotate.



Motor Description

Mathematical model

From Kirchhoff's Law:

$$V = IR_a + E_a + \cancel{L_a}\dot{I}$$

The motor constants:

$$K = k_E\phi = k_T\phi$$

Back-EMF:

$$E_a = k_E\phi\omega = K\omega$$

Armature Torque:

$$T = k_T\phi I = KI \Longrightarrow I = {}^{T}/_{K}$$

V – Armature Voltage
E_a – Back-EMF
R_a – Armature Resistance
I – Current
L_a – Inductance (negligible)
ϕ – Magnetic Flux
ω – Angular Velocity
k_T, k_E – Motor Constants

Motor Description

Mathematical model

Solving for the angular velocity of our motor:

$$\omega = \frac{V}{K} - \frac{R}{K^2}T$$

No load velocity:

$$\omega_0 = \frac{V}{K}$$

V – Armature Voltage
E_a – Back-EMF
R_a – Armature Resistance
I – Current
L_a – Inductance (negligible)
ϕ – Magnetic Flux
ω – Angular Velocity
k_T, k_E – Motor Constants

Work progress & Challenges

We faced several challenges while building our DC motor. Initially, we planned to create a brushless motor, but after consulting with our lab advisor, we realized it wasn't the best approach for us because of need to use external controllers. We then decided to construct a brushed DC motor. Here are the key points outlining our progress and the obstacles we encountered

Work progress & Challenges

Copper Wire Insulation Issue

- We didn't realize that the copper wire ends were coated with lacquer, preventing electrical conductivity.
- Our initial motor didn't work because the current couldn't pass through the insulated wire ends.
- We used a Japanese knife to carefully remove the lacquer from the wire ends.
- We learned to use a multimeter to check if current could pass through the wires, ensuring proper conductivity.

Work progress & Challenges

Coil Winding and Testing

- We wound 60 loops per coil and stripped the insulation from the ends.
- Connected each coil to a power source to verify magnetic attraction and repulsion.
- This step confirmed that current was effectively passing through each coil.

Work progress & Challenges

Commutator Connection Challenges

- We soldered various starts and ends of wires to copper plates but faced difficulties.
- Required numerous retries and adjustments, including cutting copper plates to different sizes.
- Used a multimeter to check if the current flowed through the copper plates, as it didn't always do so initially.

Work progress & Challenges

Material Selection and Assembly

- Discovered that hot glue wasn't effective for attaching copper plates to plastic components.
- Sourced a special adhesive from a shop that successfully bonded the copper plates to the commutator.
- Gained experience in working with different materials and the best methods to join them.

Work progress & Challenges

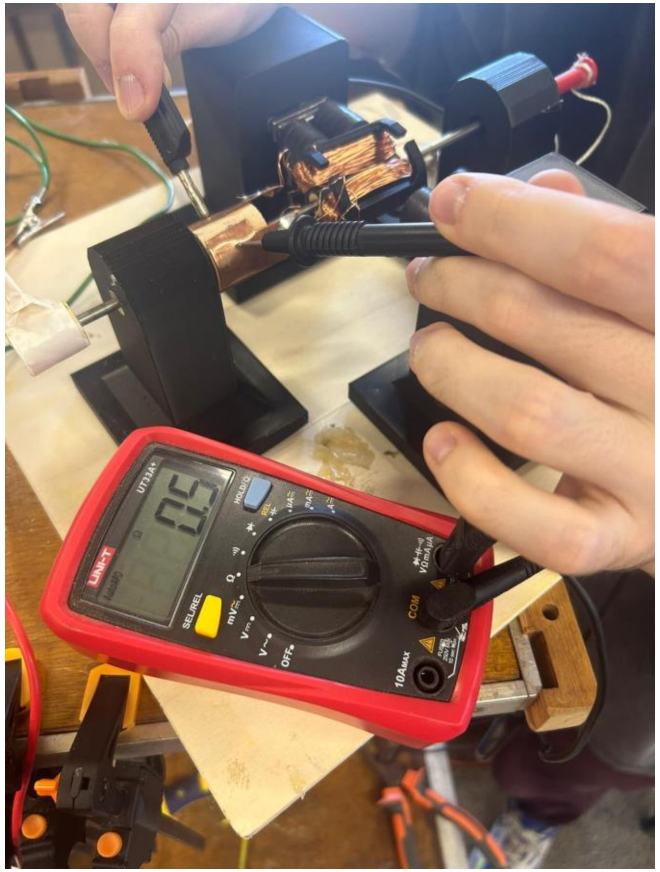
Final Assembly and Testing

- Cut a wooden plate to the required size and assembled all components onto it.
- After several attempts, we managed to get the motor to turn by holding two brushes against the commutator.
- Noted that the shaft occasionally slides over the stands, requiring periodic adjustments to reposition it.

Motor Constants

- $L_{coil} = 2 * 40{,}5 * 60 = 4{,}86\ [m]$
- $A_{wire} = \pi * \frac{0{,}0004^2}{4} = 1{,}257 * 10^{-7}[m^2]$
- $\rho_{copper} = 1{,}68 * 10^{-8}[\Omega m]$
- $R_{coil} = \rho \frac{L_{coil}}{A_{wire}} = 0{,}649\ [\Omega] \rightarrow \mathrm{R_a} = \left(\frac{1}{R_{coil}} + \frac{1}{R_{coil}}\right)^{-1}$

  $= \frac{1}{2} R_{coil} = 0{,}325\ [\Omega]$
- $R_{coil}(real) = 0.5\ [\Omega]$



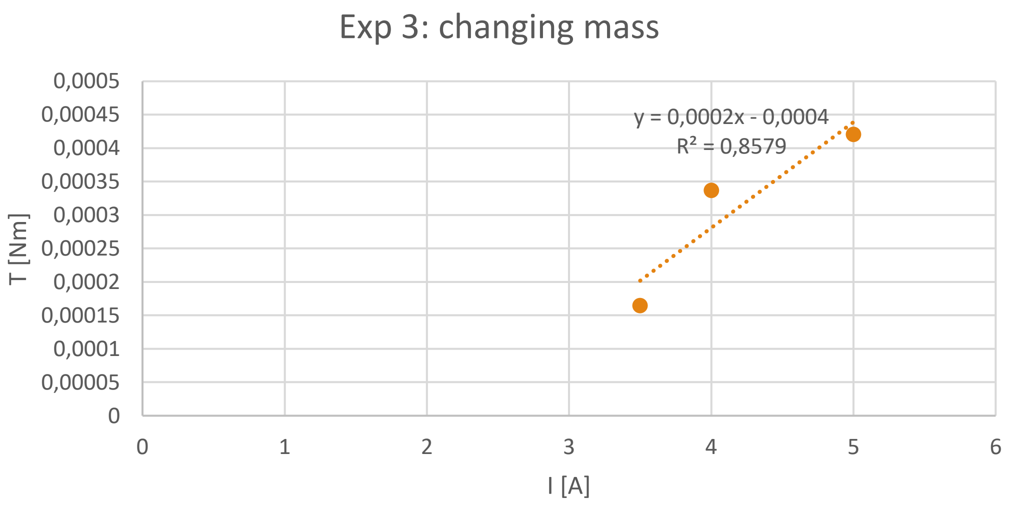
Motor Constants exp 1: No load speed

Test	$\omega_0\ [RPM]$
1	920
2	840
3	870
4	850
5	770
6	860
7	590
8	510

- To calculate the motor constant K, we will take the average no load speed of 8 experiments.
- $V_a = const = 12\ [V]$ $\qquad I_0 = const = 5\ [A]$
- average no load speed: $n_0 = 851\ [RPM]$
- $\rightarrow \omega_0 = 89{,}187 \left[\frac{rad}{s}\right]$
- $E = k_e * \omega_0 \rightarrow \boldsymbol{K_{theory}} = \frac{\boldsymbol{E}}{\boldsymbol{\omega_0}} = \frac{\boldsymbol{V_a - (I_a * R_{theory})}}{\boldsymbol{\omega_0}} = \mathbf{0.116} \left[\frac{\boldsymbol{V*s}}{\boldsymbol{rad}}\right] = \mathbf{0{,}0122} \left[\frac{\boldsymbol{V}}{\boldsymbol{RPM}}\right]$
- $E = k_e * \omega_0 \rightarrow \boldsymbol{K_{real}} = \frac{\boldsymbol{E}}{\boldsymbol{\omega_0}} = \frac{\boldsymbol{V_a - (I_a * R_{real})}}{\boldsymbol{\omega_0}} = \mathbf{0.106} \left[\frac{\boldsymbol{V*s}}{\boldsymbol{rad}}\right] = \mathbf{0{,}01116} \left[\frac{\boldsymbol{V}}{\boldsymbol{RPM}}\right]$
- $T_e = k_e * I_0 = 0{,}582\ [Nm]$
- $P_{in} = V * I = 60\ [W]$ $\qquad P_e = T_e * \omega_0 = 51{,}875\ [W]$
- $\boldsymbol{\eta_{theory}} = \frac{\boldsymbol{P_{out\_theory}}}{\boldsymbol{P_{in}}} = \mathbf{86{,}46}\ \%$ $\quad \boldsymbol{\eta_{real}} = \frac{\boldsymbol{P_{out\_real}}}{\boldsymbol{P_{in}}} = \mathbf{78{,}78}\ \%$

Motor Constants exp 2: Torque

Test	$\boldsymbol{Mass\ [kg]}$	$T_L\ [Nm]$	$I\ [A]$
1	0,0046	0,0001647	3,5
2	0,0094	0,0003366	4
3	0,01174	0,0004204	5



- 3 experiments with changing mass. Radius of the moment is $r = 0{,}00365\ [m]$.
- Current is constant $V = 12\ [V]$
- The current is read from the power supply
- Torque is calculated $T_L = m * g * r\ [Nm]$
- We also know the Torque from Theory is
  $$T_e = k_T \phi_f i_a$$
- Using linear regression, we get
  $$\boldsymbol{k_T \phi_f = K = 0{,}0002\ [\frac{Nm}{A}]}$$

Summary & Conclusions

Test	K	η
Theoretical test using no load speed and real R	$0.106\ [\frac{V*s}{rad}]$	**78,78** %
Theoretical test using no load speed and theoretical R	$0{,}116\ [\frac{V*s}{rad}]$	86,46 %
Experiment 2	$0{,}0002\ [\frac{Nm}{A}]$	1.5%

- The repeatability of the experiments were low. Lots of times we would get different answers for the same experiment. The Tachometer was very off in its display of showing $[RPM]$, which lead us to take lots of averages.
- Difference between real and theoretical resistances come from unstable contact between brushes and commutator, dirt on metal plates of commutator. Therefore, efficiency and motor constant are differed one from another.
- We tried finding the experimental efficiency with a constant mass. But the numbers did not make much sense to us. Our output of $P_{out} = T * \omega$ was too small compared to the input $P_{in} = V * I$, which gave us efficiencies in the range of = 1.3 %. Our tests can be seen in the next slide

Summary & Conclusions

(Experiment 3: constant mass, changing current)

31										
32	m [kg]	0,0046		I [A]	omega [RPM]	omega [rad/s]	T_L (m*g*r)	P_in (V*I)	P_out (T*omega)	eta efficiency
33	V [V]	12	**test 1**	3,56	300	31,416	0,00016471	42,72	0,005174526	0,012112655
34	r [m]	0,00365	**test 2**	4	355	37,1756	0,00016471	48	0,006123189	0,012756644
35	g [m/s^2]	9,81	**test 3**	4,5	430	45,0296	0,00016471	54	0,007416821	0,013734854
36	K [V/RPM]	0,0122	**test 4**	5	493,5	51,67932	0,00016471	60	0,008512096	0,014186826
37	R_a [ohm]	0,325								

Recorded videos