EE 251 - PRINCIPLE OF ELECTRICAL MESUREMENT

SENSOR DESIGN

MINI PROJECT

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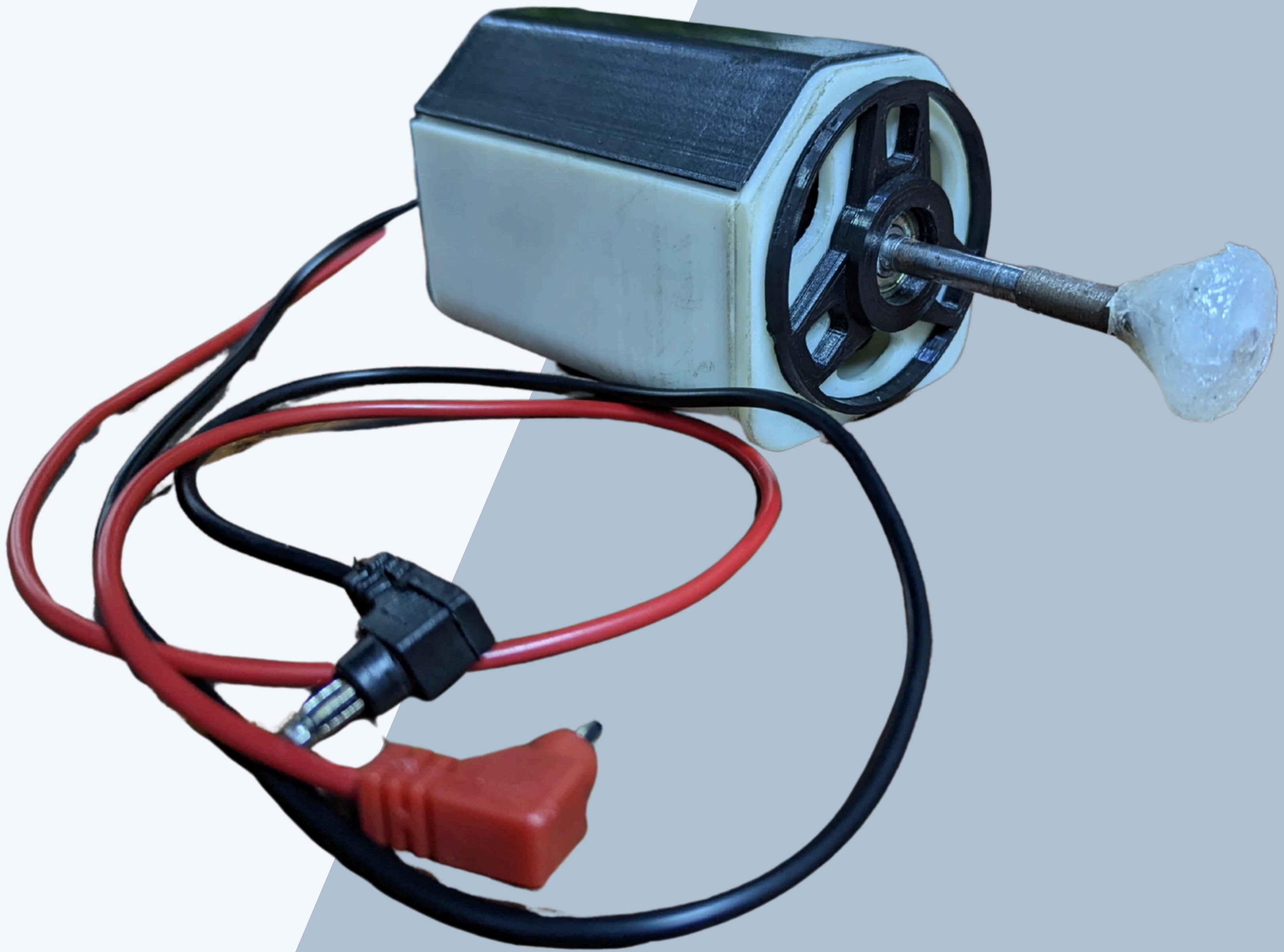
Introduction

An RPM (Revolutions Per Minute) sensor is a device used to measure the rotational speed of a moving component, such as a motor shaft or a rotating wheel. It provides real-time feedback on speed, ensuring optimal performance and efficiency in various systems.

Our RPM sensor is designed to measure the rotational speed of a moving system using electromagnetic induction.



Importance of RPM Sensors in Industries

RPM sensors play a critical role in multiple industries:

- Automotive
- Robotics
- Aerospace
- Manufacturing
- Energy & Power Generation
- Medical Equipment

Working Principle

Our RPM sensor operates based on Faraday's Law of Electromagnetic Induction

Faraday's Law of Electromagnetic Induction states that a changing magnetic field induces an electric current in a conductor.

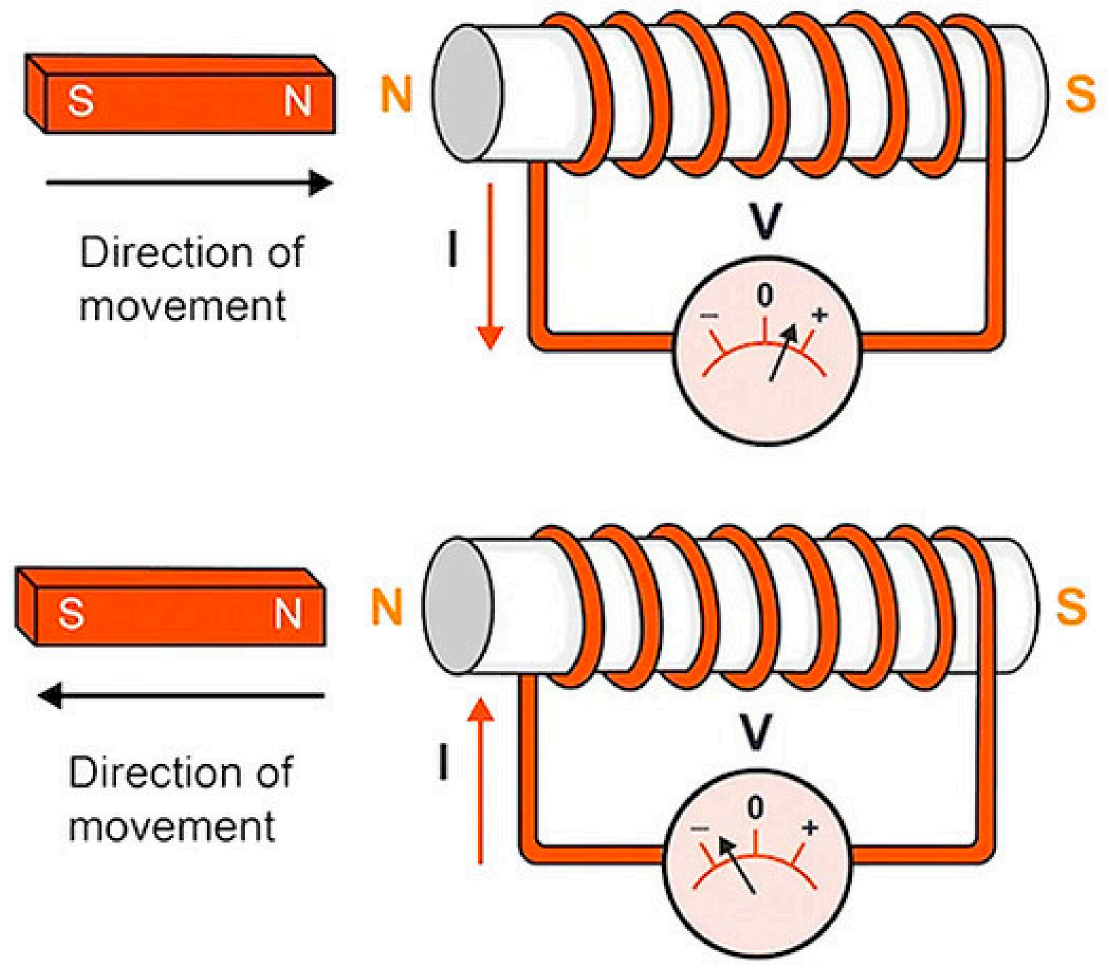
On the other hand,

When the magnetic field around a conductor changes, it produces an electromotive force (EMF) that drives an electric current.

$$\mathcal{E} = -N\frac{d\Phi}{dt}$$

Where:

- $\mathcal{E}$ = Induced EMF (V)
- N = Number of turns in the coil
- Φ = Magnetic flux (Weber, Wb)
- t = Time (s)



Our Design

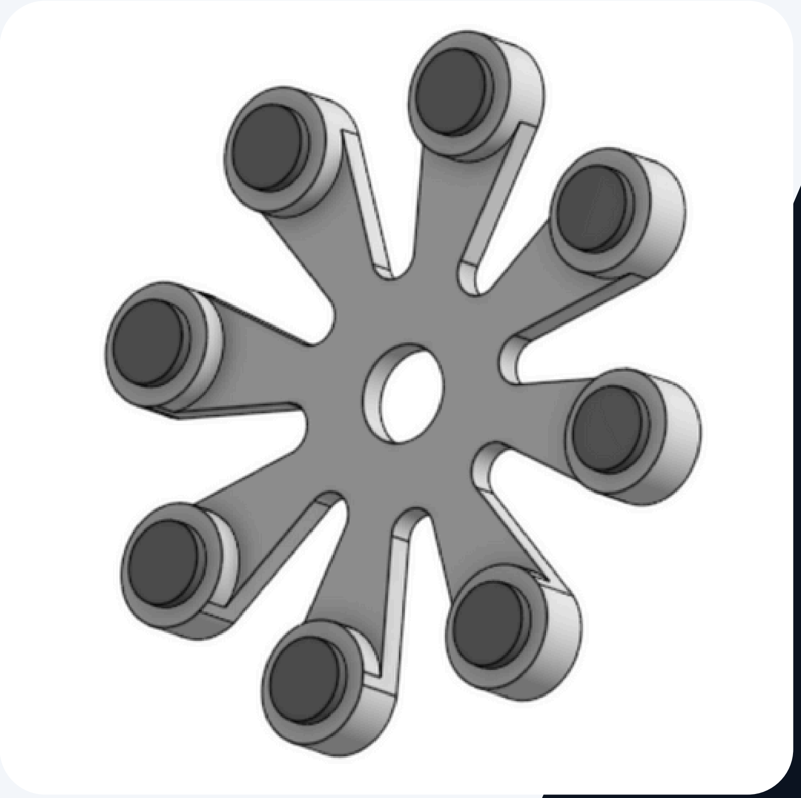
Our RPM sensor is designed to measure the rotational speed of a moving system using electromagnetic induction. It consists of 8 stationary coils and 16 rotating magnets positioned parallel to the coils.

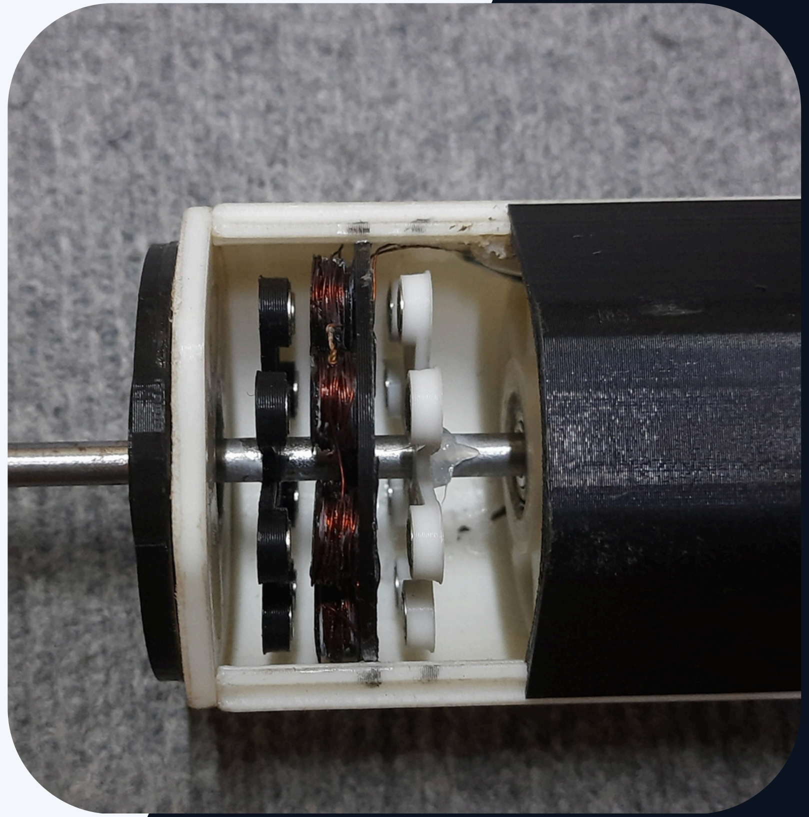
As the magnets pass over the coils, they induce a voltage proportional to the rotational speed, allowing us to accurately determine the RPM.

This sensor provides a highly reliable and precise method for measuring rotational speed, making it suitable for applications in industrial automation, motor control, and robotics.

Our Design consists of,

- 16 Neodymium magnets.
- 8 copper 30 SWG coils, each with 20 windings.
- Magnets are evenly distributed on two rotating components, with each component holding eight magnets.
- The magnets are mounted with opposite polarities and parallel to the coils to enhance the magnetic field through the coils.
- The coils are arranged in a circular pattern and remain stationary.
- The coils are connected in series, allowing for the maximum induced voltage by adding the induced voltages from each coil.





How we calculated the Number of turns of the coil should be,

$$v = -N \times \frac{d\varphi}{dt}$$

Since,

$$\varphi = BA$$

$$\frac{d\varphi}{dt} = BAf$$

$$v = NBAf$$

$$A = \pi r^2 \quad f = \frac{RPM}{60} \times 4$$

Substituting for the main equation,

$$v = N \times \pi r^2 \times B \times \frac{RPM}{60} \times 4 \longrightarrow N = \frac{60\, v}{4 \times B \times \pi r^2 \times RPM}$$

We aimed to obtain about 50mV reading for 750 RPM

$$B \approx 0.65\, T$$

$$N = \frac{60 \times 50 \times 10^{-3}}{4 \times 0.65 \times \pi \times 0.005^2 \times 750}$$

$$N \approx 19.8 \approx 20\ turns$$

Specification

Technical Specifications

- Dimensions : 160mm x 65mm x 60 mm
- Weight : 130 g
- Range : 10 r.p.m. - 3500 r.p.m
- Accuracy : +- 5.195 r.p.m.
- Operating Temparature : 0℃ - 80℃

- Material : Neodymium Magnets
  30 SWG copper coil
  PLA Cover

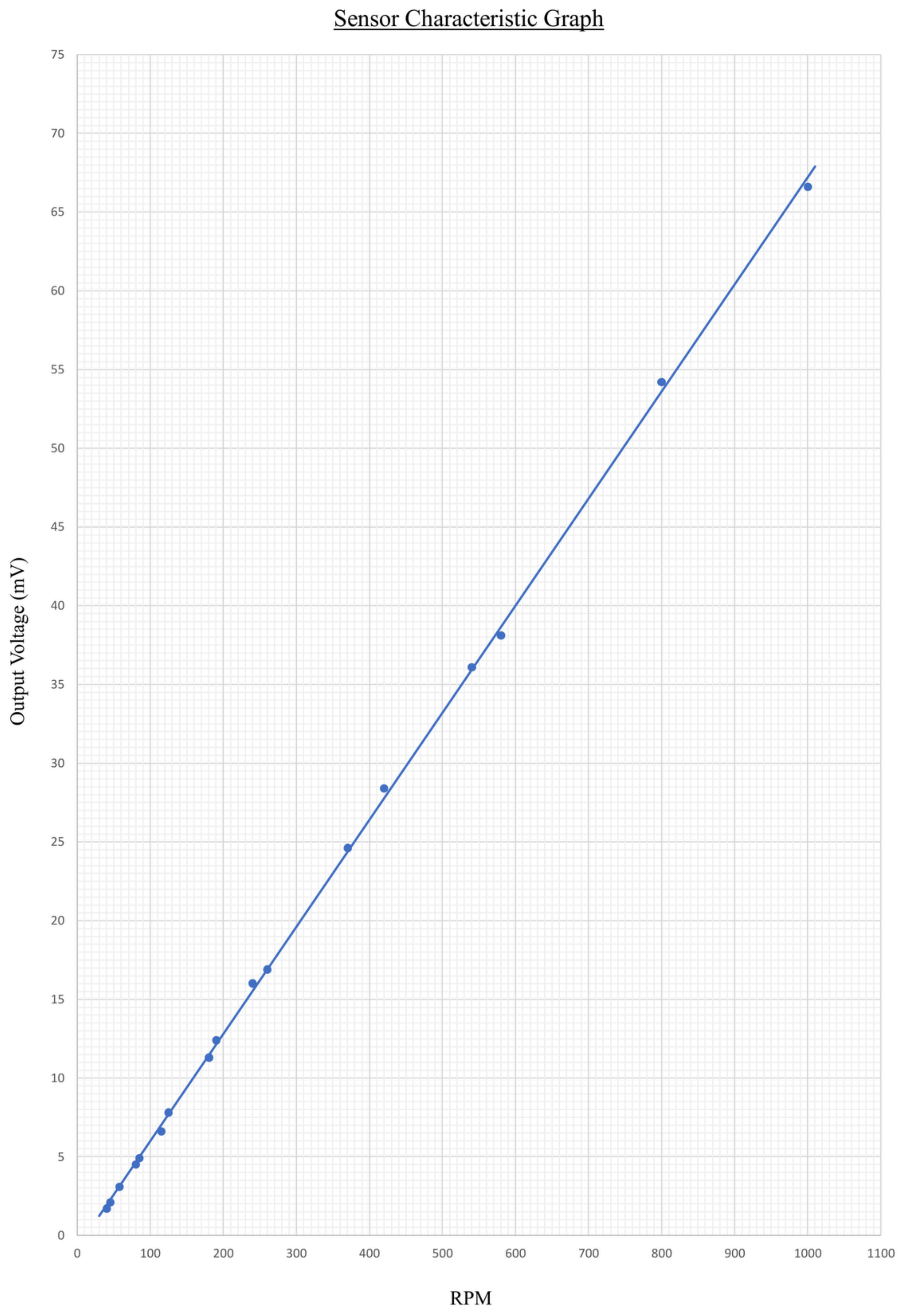
Characteristics

Observed characteristics

- Zero Order
- Small Non Linearity
- Small Zero Offset
- No Hysteresis

$$Sensitivity = \frac{\partial y}{\partial x} = 0.068\ mV/RPM$$

RPM Value	Voltage(mV)
40	1.7
45	2.1
58	3.1
80	4.5
85	4.9
115	6.6
125	7.8
180	11.3
190	12.4
240	16
260	16.9
370	24.6
420	28.4
540	36.1
580	38.1
800	54.2
1000	66.6

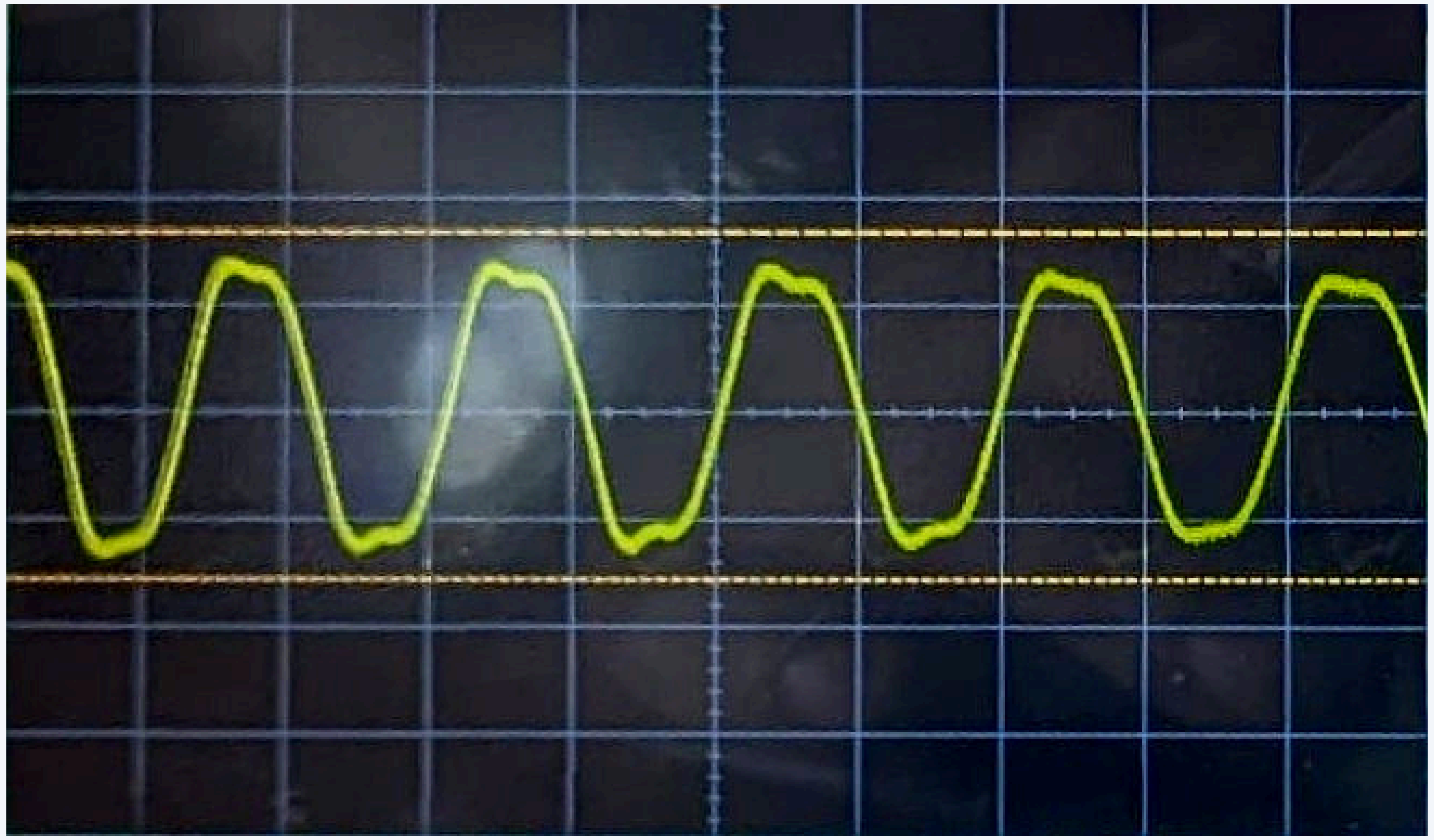


Calculated Linear Transfer Function

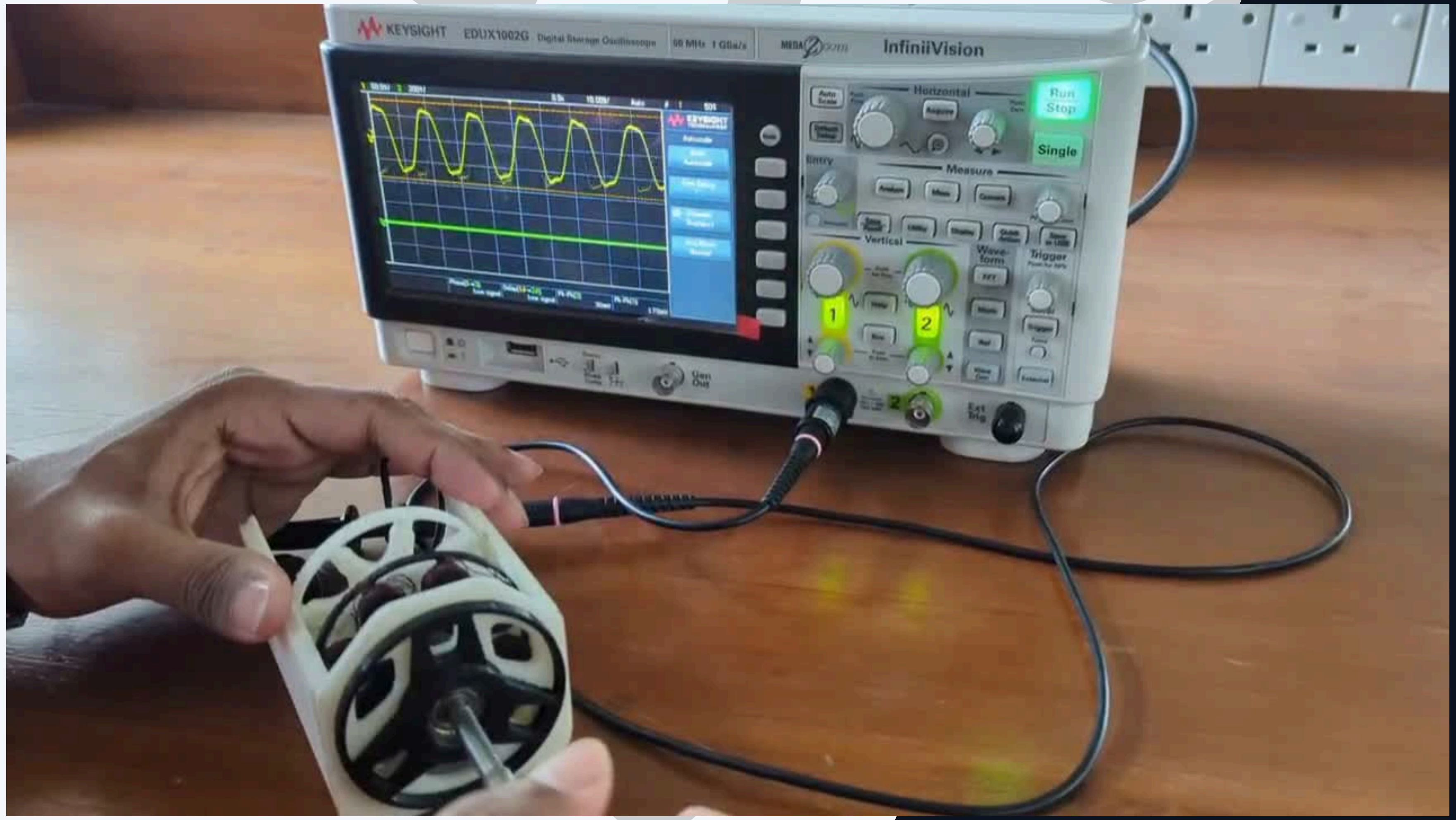
$$y = 0.068x - 0.7976$$

Characteristics

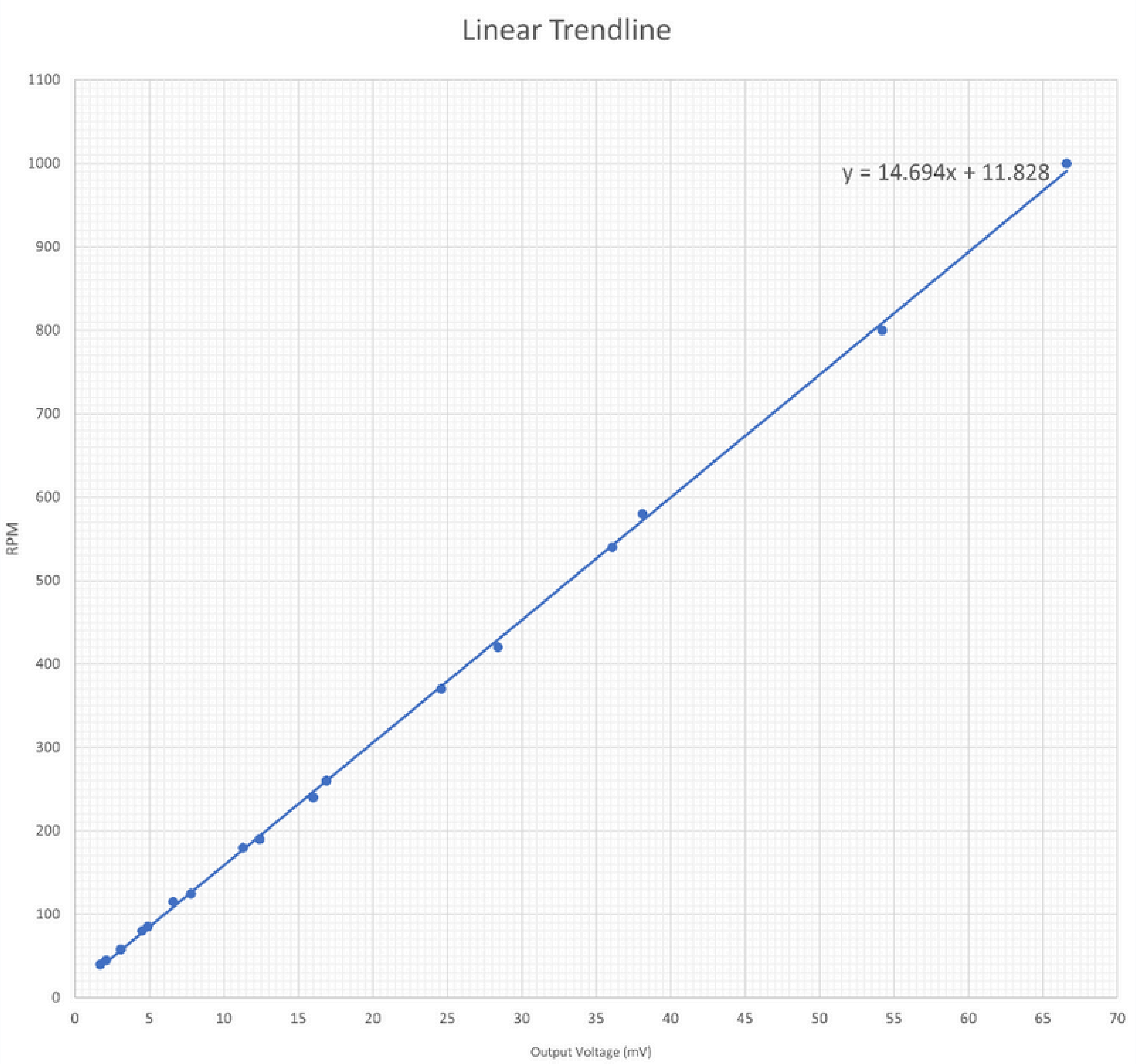
Output Waveform



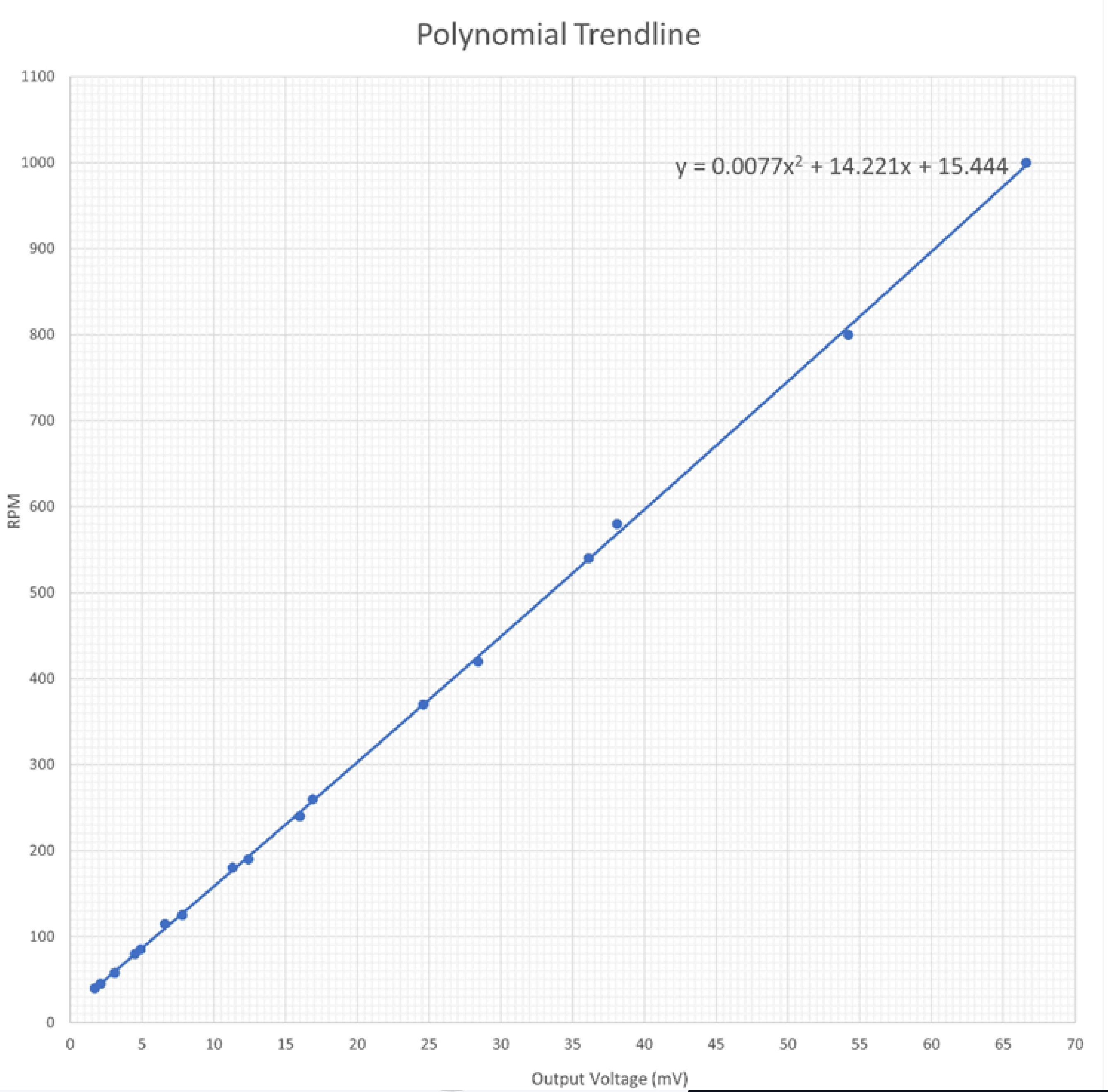
Dynamic Characteristics



Input Estimation from Output



$RMSE = 5.195$



$RMSE = 4.441$

Input Estimation from Output

Root Mean Square Error Calculation Formula

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}}$$

A polynomial fit is the best fit, but a linear fit is also considerable. Since the error in the polynomial fit is 5.195 and in the linear fit is 4.441, the difference is only about 0.7. Therefore, we can use the linear model as V is proportional to ω (RPM).

Calibration

Why Calibration is Necessary?

- Ensures accurate and reliable readings.
- Eliminates measurement errors.
- Improves the performance and consistency of the RPM meter.

Calibration

Calibration Process:

- A lathe machine is used to generate known RPM values.
- These known RPM values are input to the RPM meter.
- The meter measures the output voltage corresponding to each RPM value.
- 20 calibration data points are recorded.
- A calibration curve is created to map voltage to RPM.

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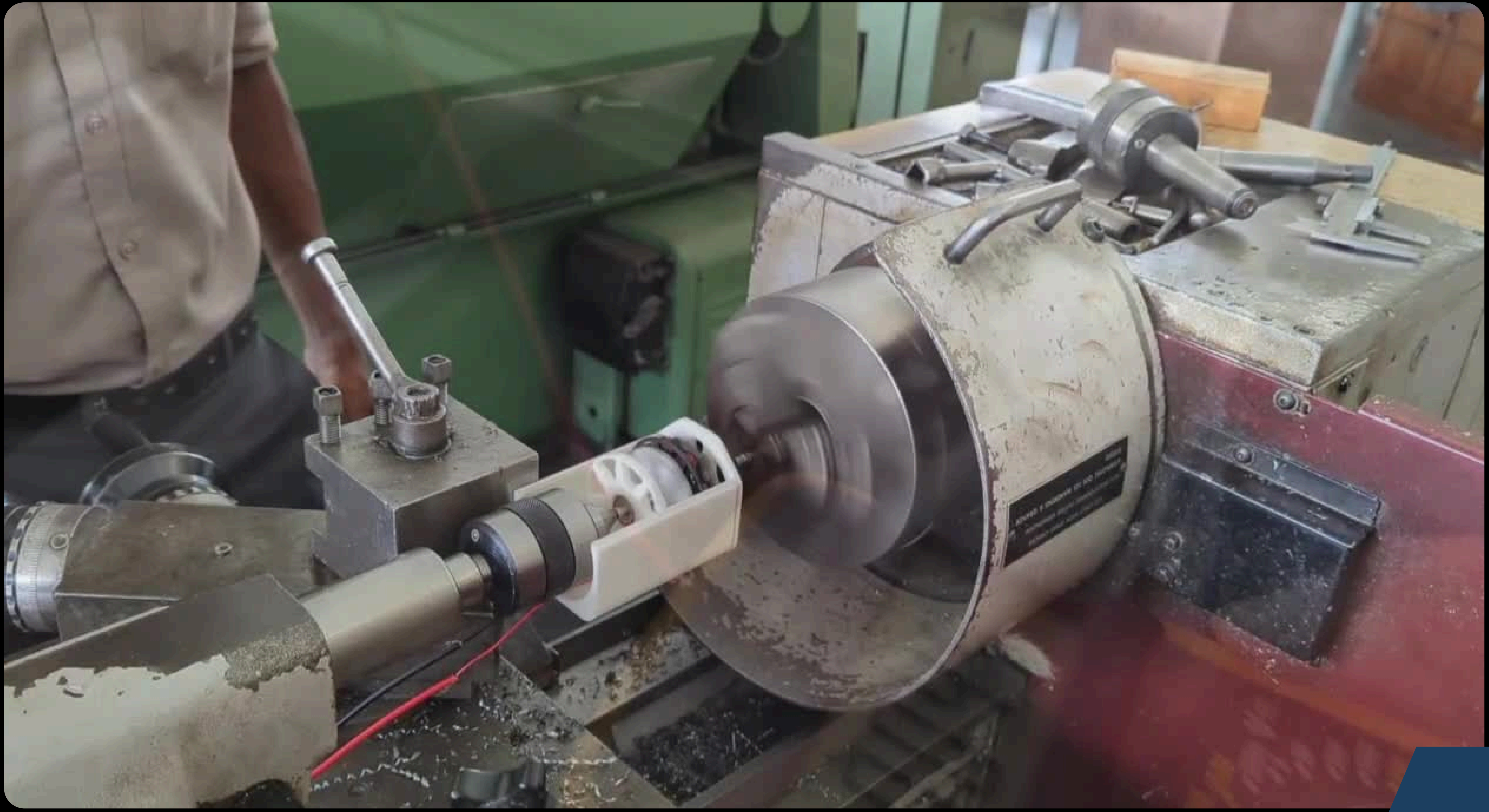
CALIBRATION PROCESS



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Future Developments

- Use an amplifier circuit to obtain a better-amplified output signal and measure smaller RPM values.
- Increase coil count for better resolution.
- Improve signal processing algorithms to reduce noise.
- Enhance the linearity of the sensor output by using a larger number of calibration data points.
- Implement a digital display or wireless data transmission for real-time monitoring.

Conclusion

Our RPM meter is designed to convert rotational energy into electrical energy, making it an efficient and reliable measurement tool. It operates as an active transducer, meaning it does not require an external power supply; instead, it measures the output voltage and converts it into RPM. This makes the device both cost-effective and easy to use. With its simple yet effective design, our RPM sensor is ideal monitoring the RPM for motors, fans, and other rotating machinery. Future improvements, such as signal amplification and better calibration, can further enhance its accuracy and performance.

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Thank You!

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