Russia IYPT

Shaded pole

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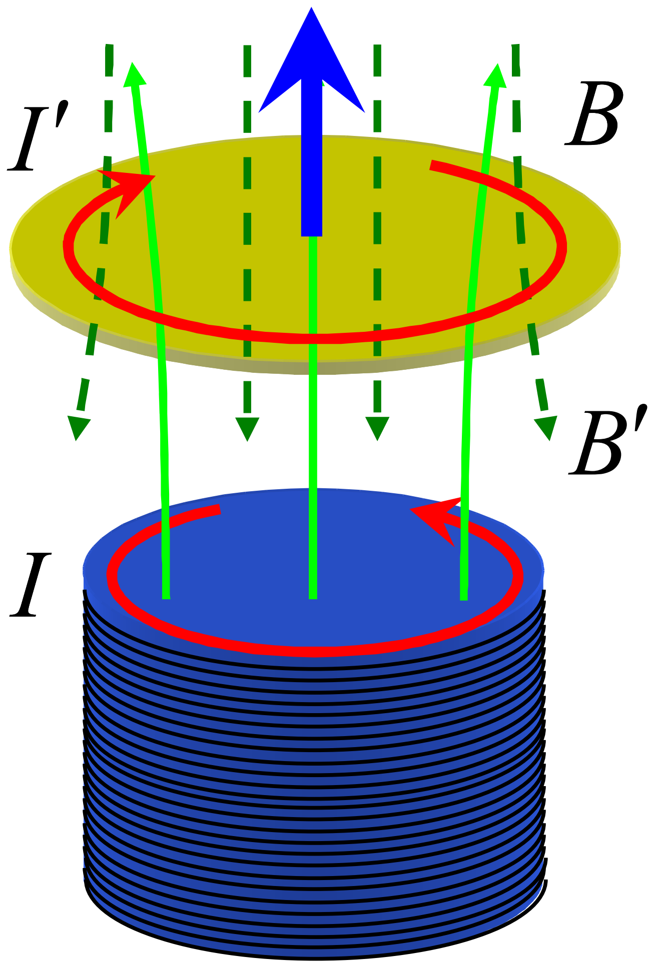
The problem

Place a non-ferromagnetic metal disk over an electromagnet powered by an AC supply. The disk will be repelled, but not rotated. However, if a non-ferromagnetic metal sheet is partially inserted between the electromagnet and the disk, the disk will rotate. Investigate the phenomenon.

Repulsion

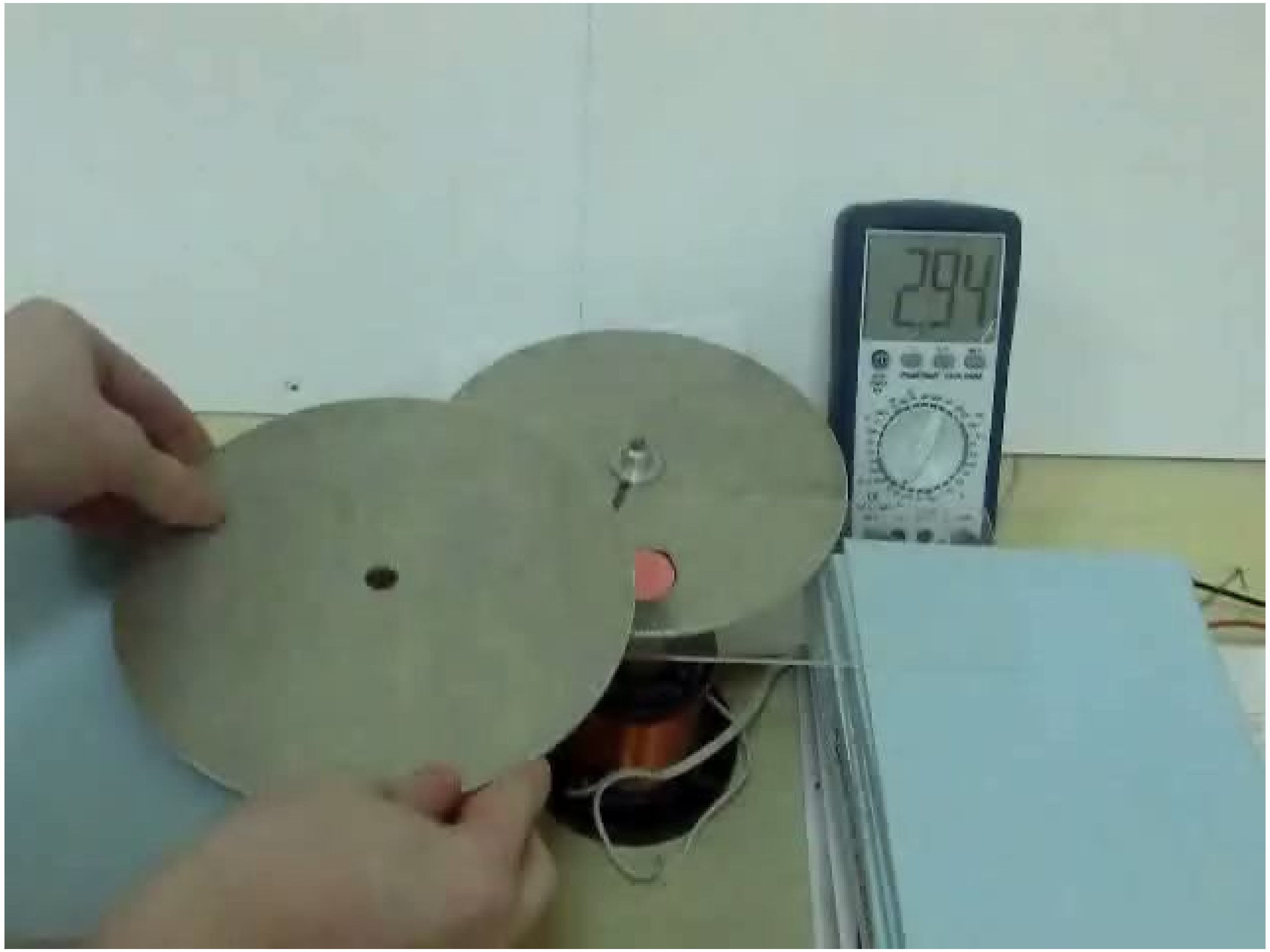
Qualitative explanation



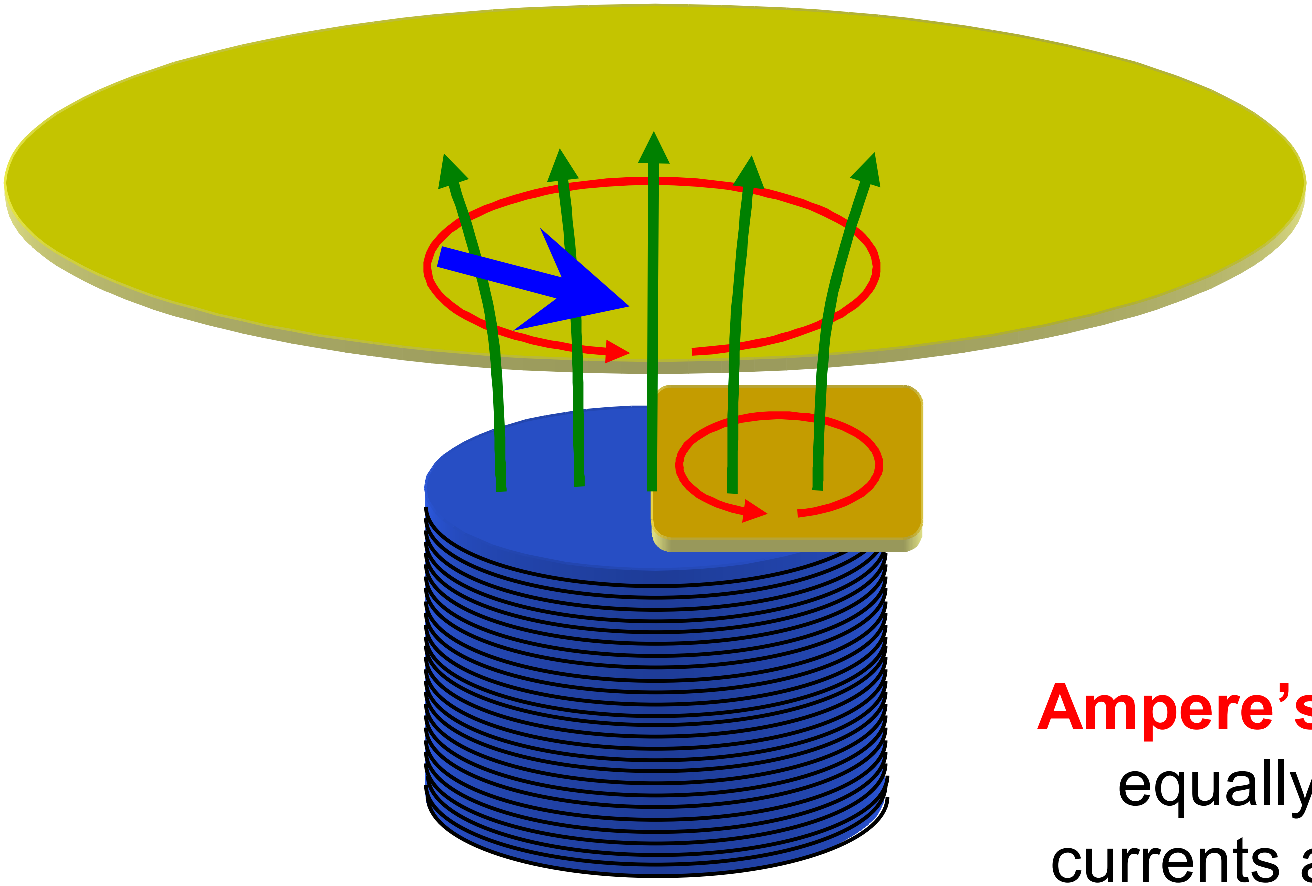
Lenz's and Faraday's laws: The direction of an induced current is always such that it will <u>oppose the change</u> which produced it.

Ampere's force law: oppositely directed currents repel from each other.

Rotation



Qualitative explanation



Ampere's force law:

equally directed currents attract each other.

Outline of the report

Speed limit

↓

Motor characteristics

↓

Updated motor

↓

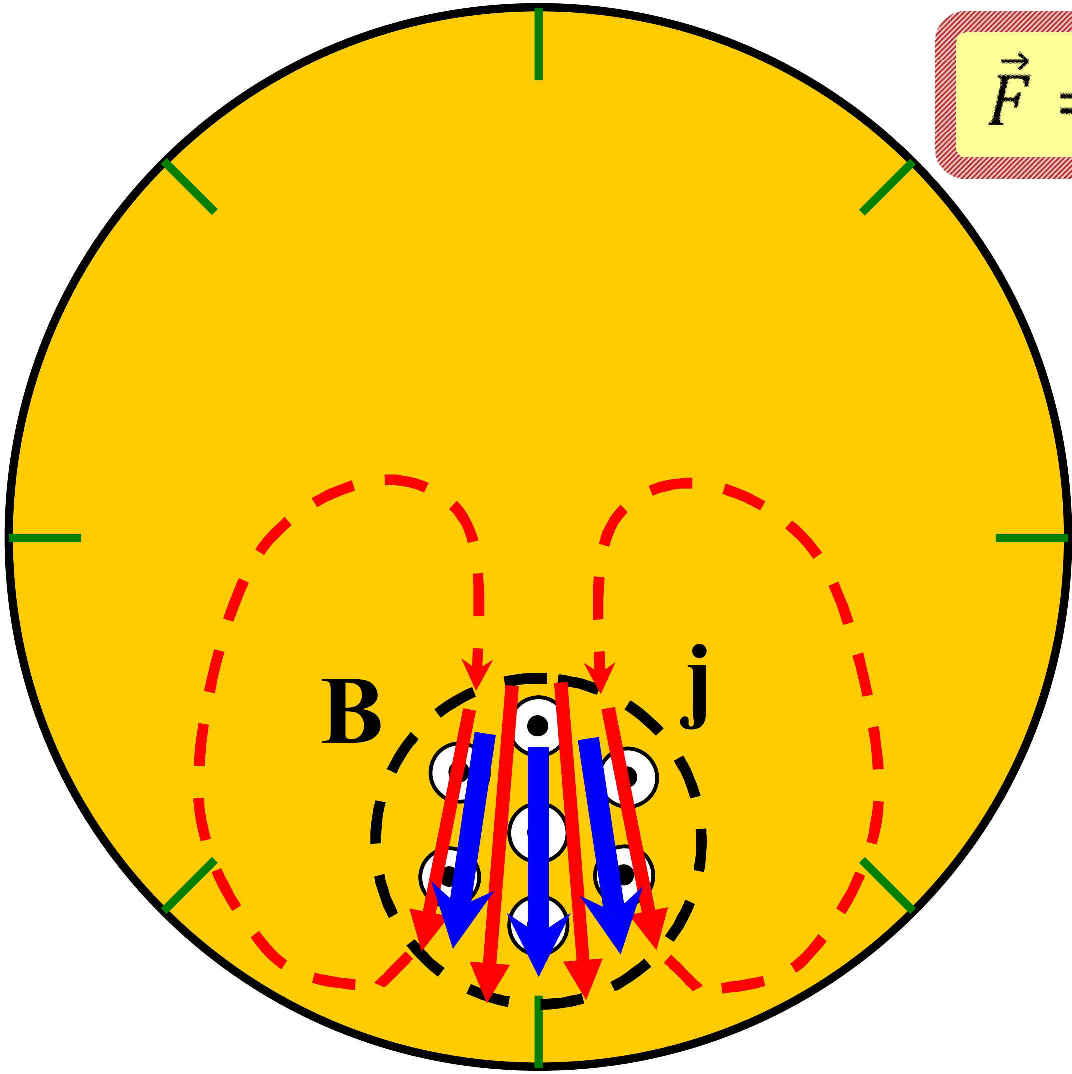
Variation of the input frequency

Limiting speed

Magnetic brakes IYPT 2014 (video)

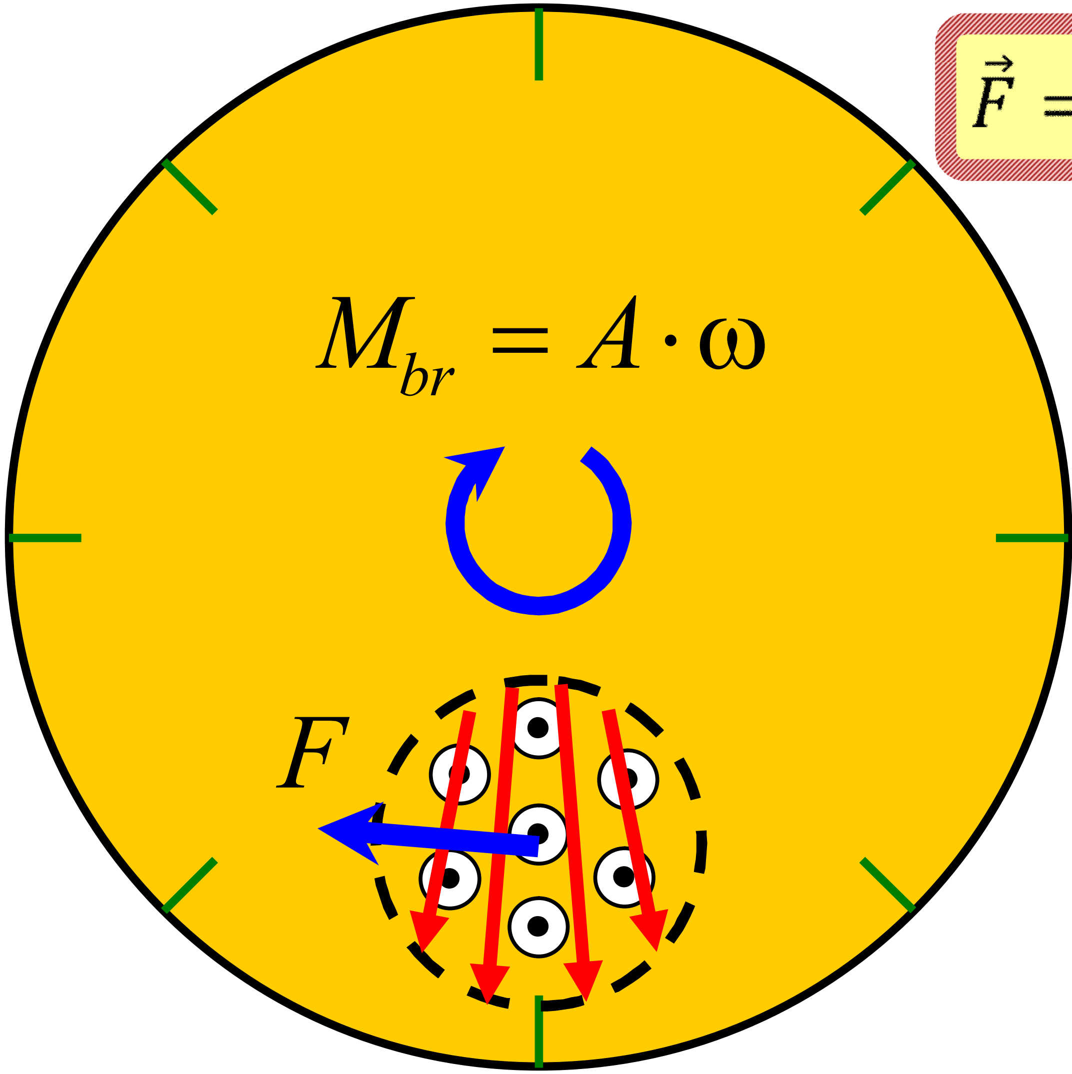
Eddy currents

$$\vec{F} = q \cdot [\vec{v} \times \vec{B}]$$



Ampere force and braking torque

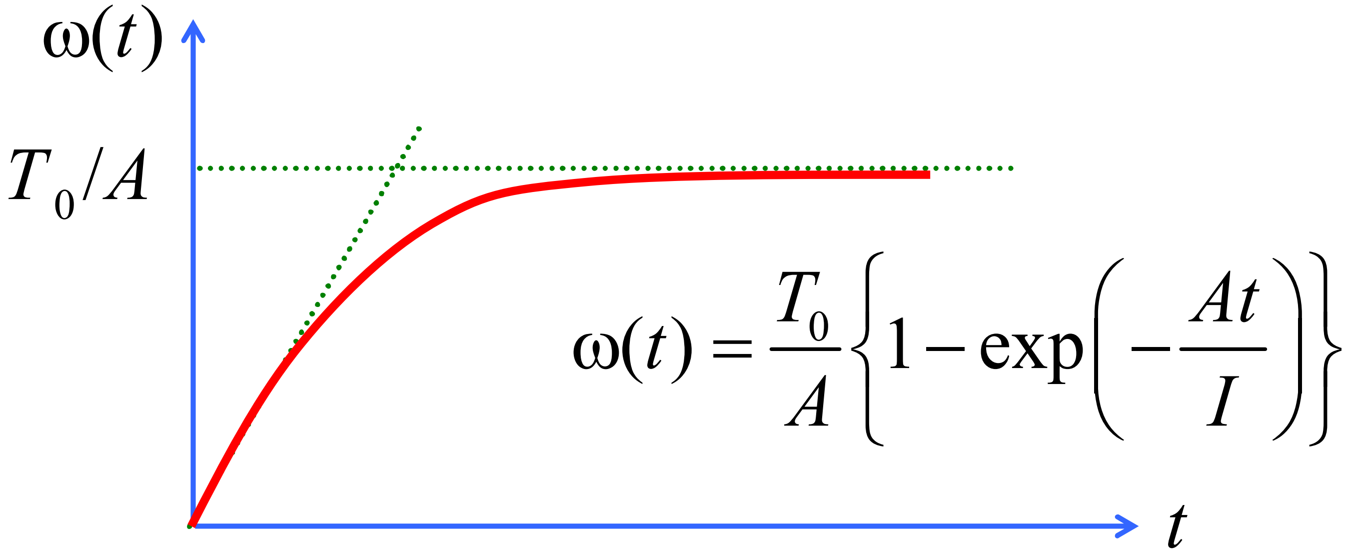
$$\vec{F} = I \cdot [\vec{dl} \times \vec{B}]$$



Angular acceleration

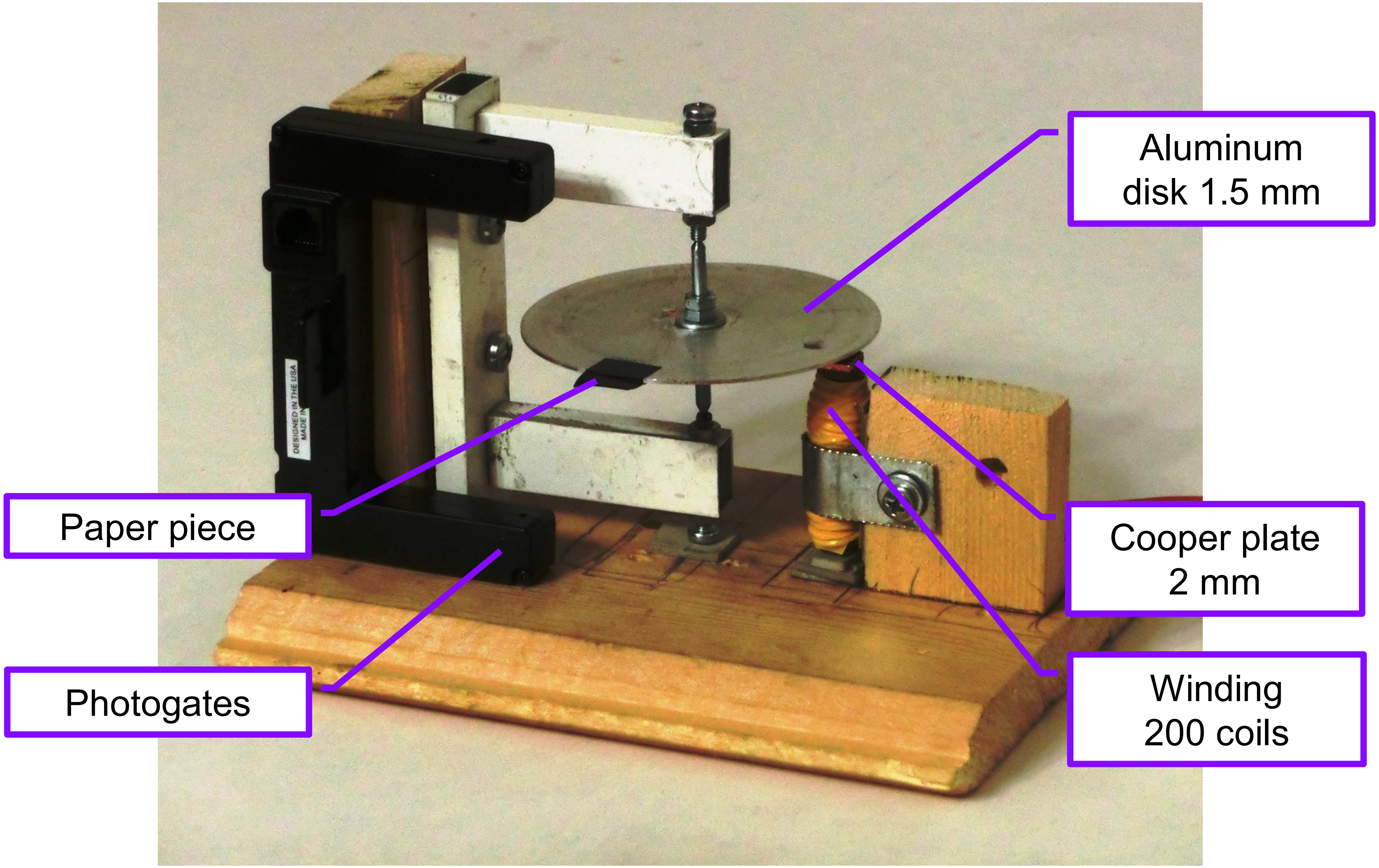
$$I\frac{d\omega}{dt} = T_{sh} - T_{fr} - T_{br}$$

$$I\frac{d\omega}{dt} = T_0 - A\omega$$

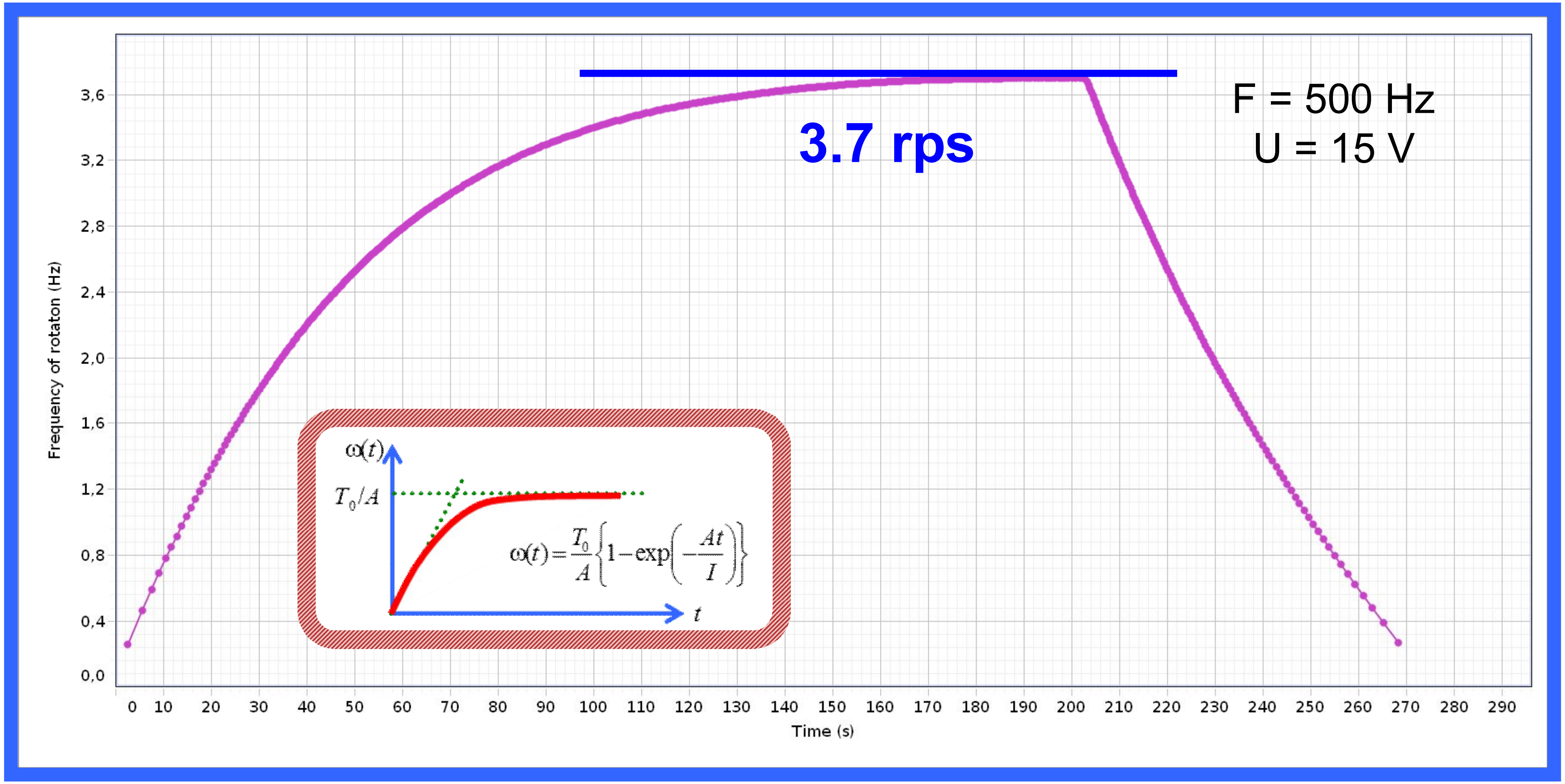


$$\omega(t) = \frac{T_0}{A}\left\{1 - \exp\left(-\frac{At}{I}\right)\right\}$$

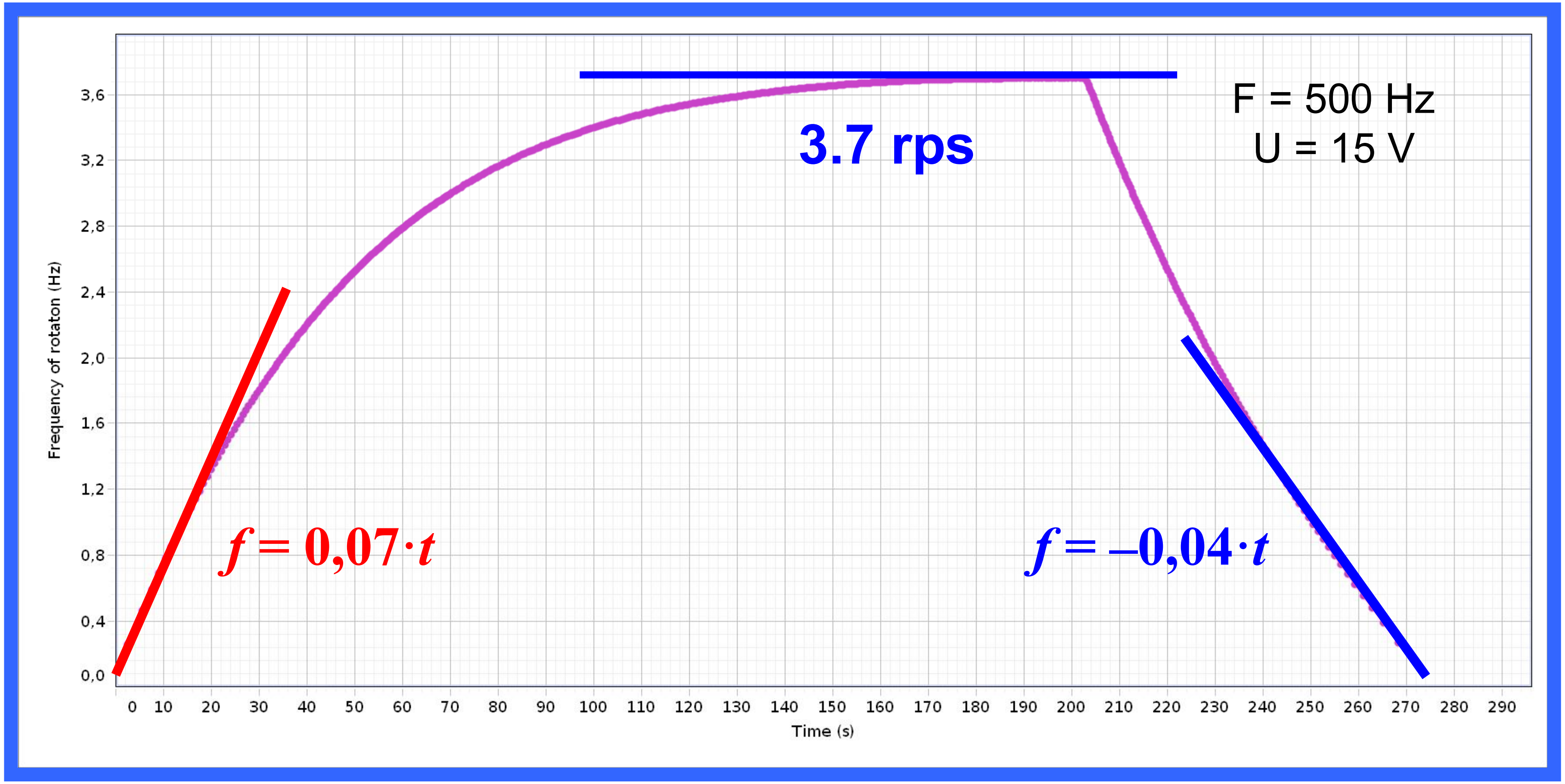
Experimental setup



Rotating speed vs. time



Acceleration and braking



$$\frac{T_{sh} - T_{fr}}{T_{fr}} = \frac{0.07}{0.04} \quad \Rightarrow \quad T_{sh} = 2.75 \cdot T_{fr}$$

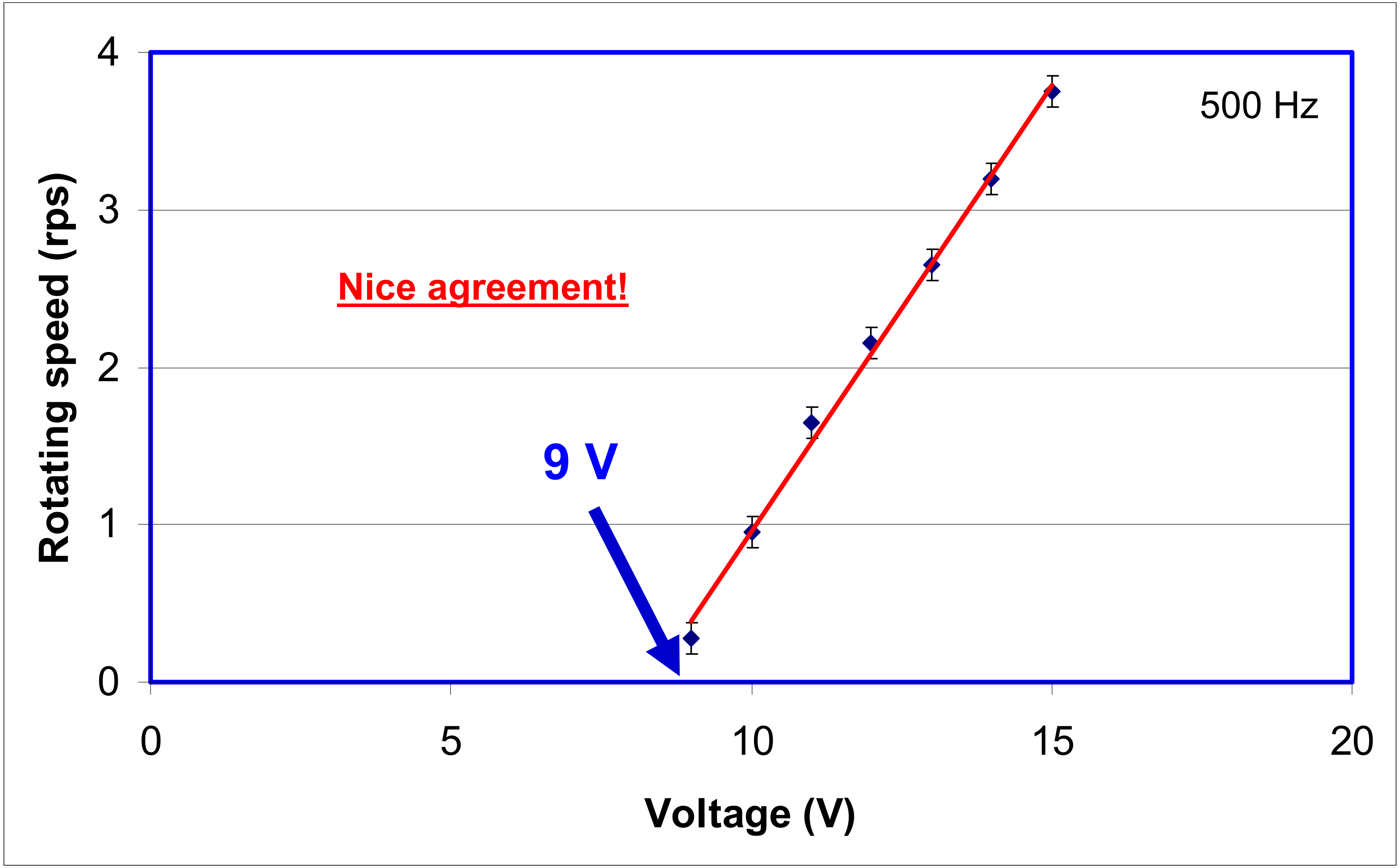
Threshold voltage

$$U = 15\text{ V} \quad \Rightarrow \quad T_{sh} = 2.75 \cdot T_{fr}$$

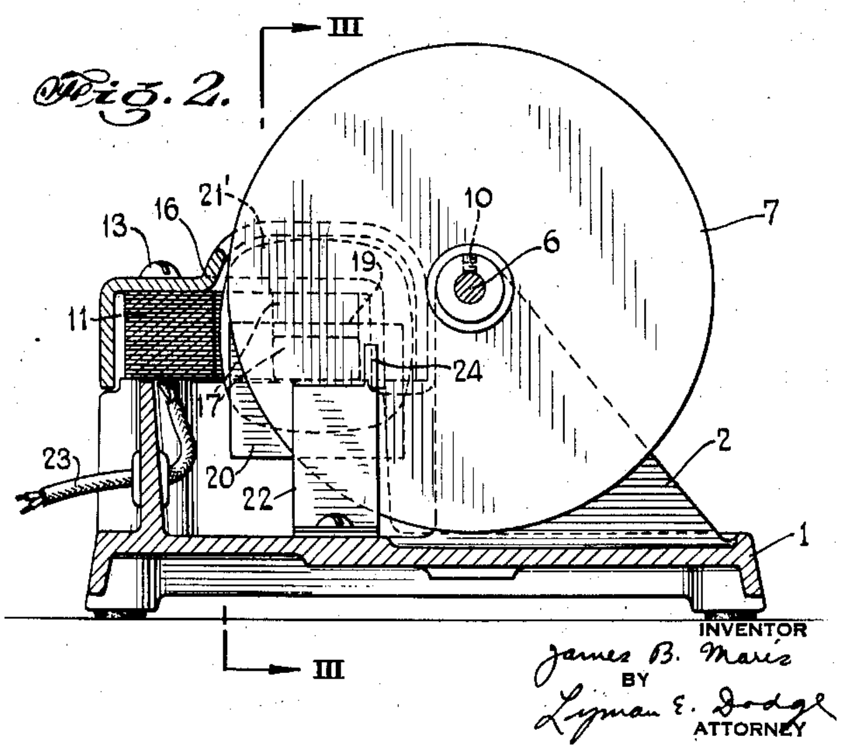
$$T_{sh} \propto U^2$$

$$T_{sh} = T_{fr} \quad \Rightarrow \quad U = \frac{15\text{ V}}{\sqrt{2.75}} = 9.0\text{ V}$$

Rotating speed vs. voltage



Shaded pole motor



J. B. Maris
US Patent 1,977,730
Oct. 23, 1934

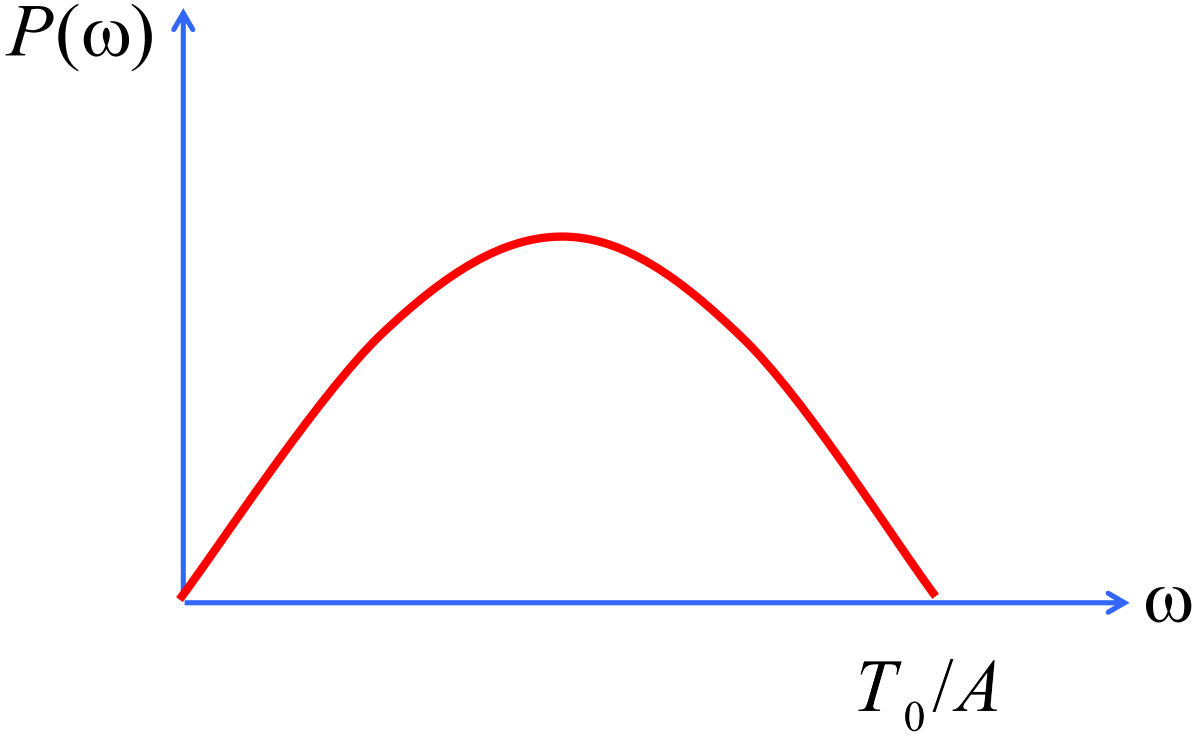
Marco aquarium air pump
1930's – 1950's

Motor characteristics

Power vs. rotating speed (theory)

$$P = T \cdot \omega = \left(T_0 - A\omega\right)\omega$$

$$I\frac{d\omega}{dt} = T_{sh} - T_{fr} - T_{br}$$



Kinetic energy

$$E = \frac{I\omega^2}{2}$$

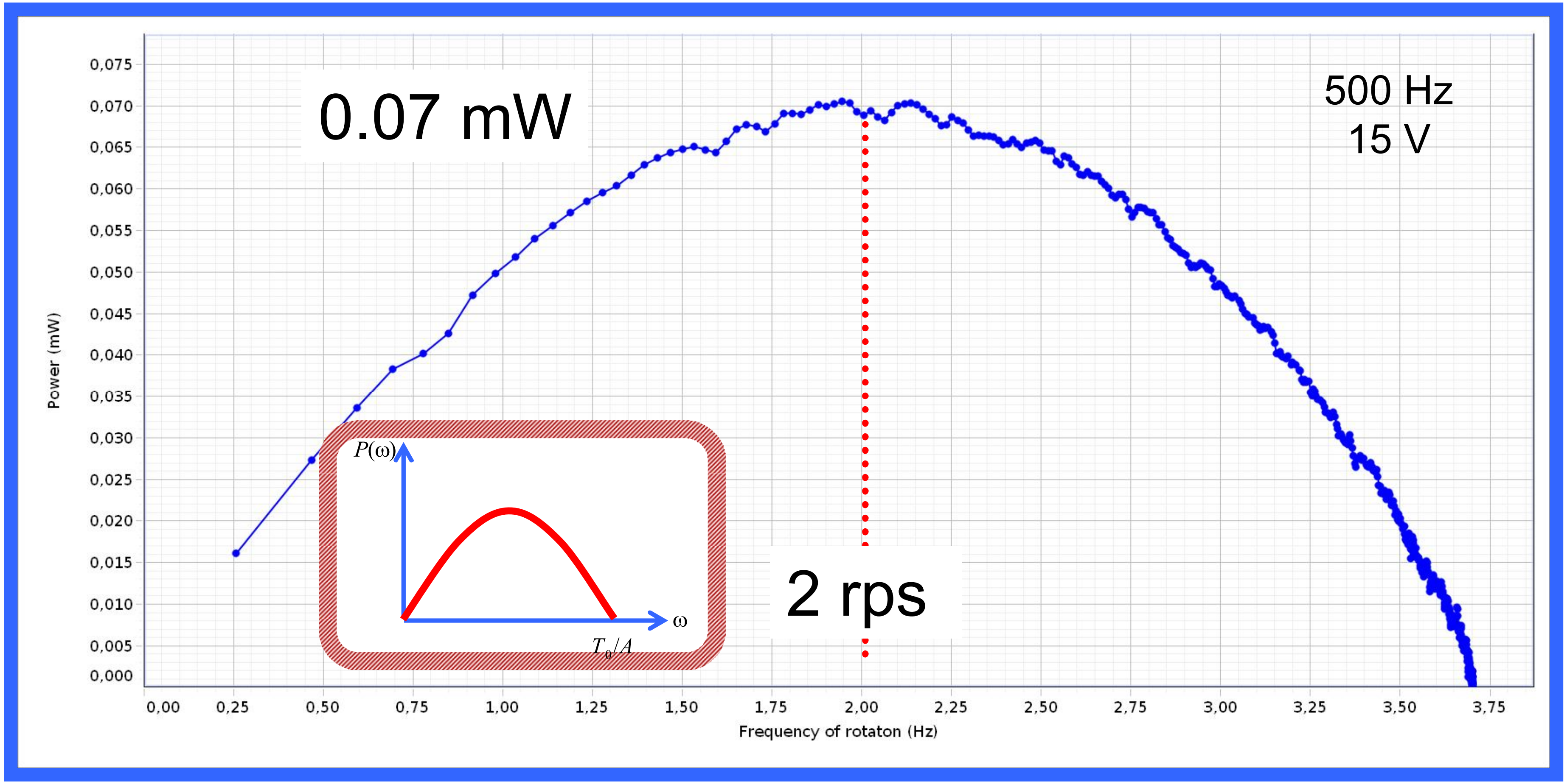
Power

$$N = \frac{dE}{dt} = I\omega\frac{d\omega}{dt}$$

Moment of inertia

$$I = \frac{mr^2}{2} = 2.2 \cdot 10^{-5}\,\mathrm{kg} \cdot \mathrm{m}^2$$

Power vs. rotating speed (exp.)



Useful power

0.07 mW

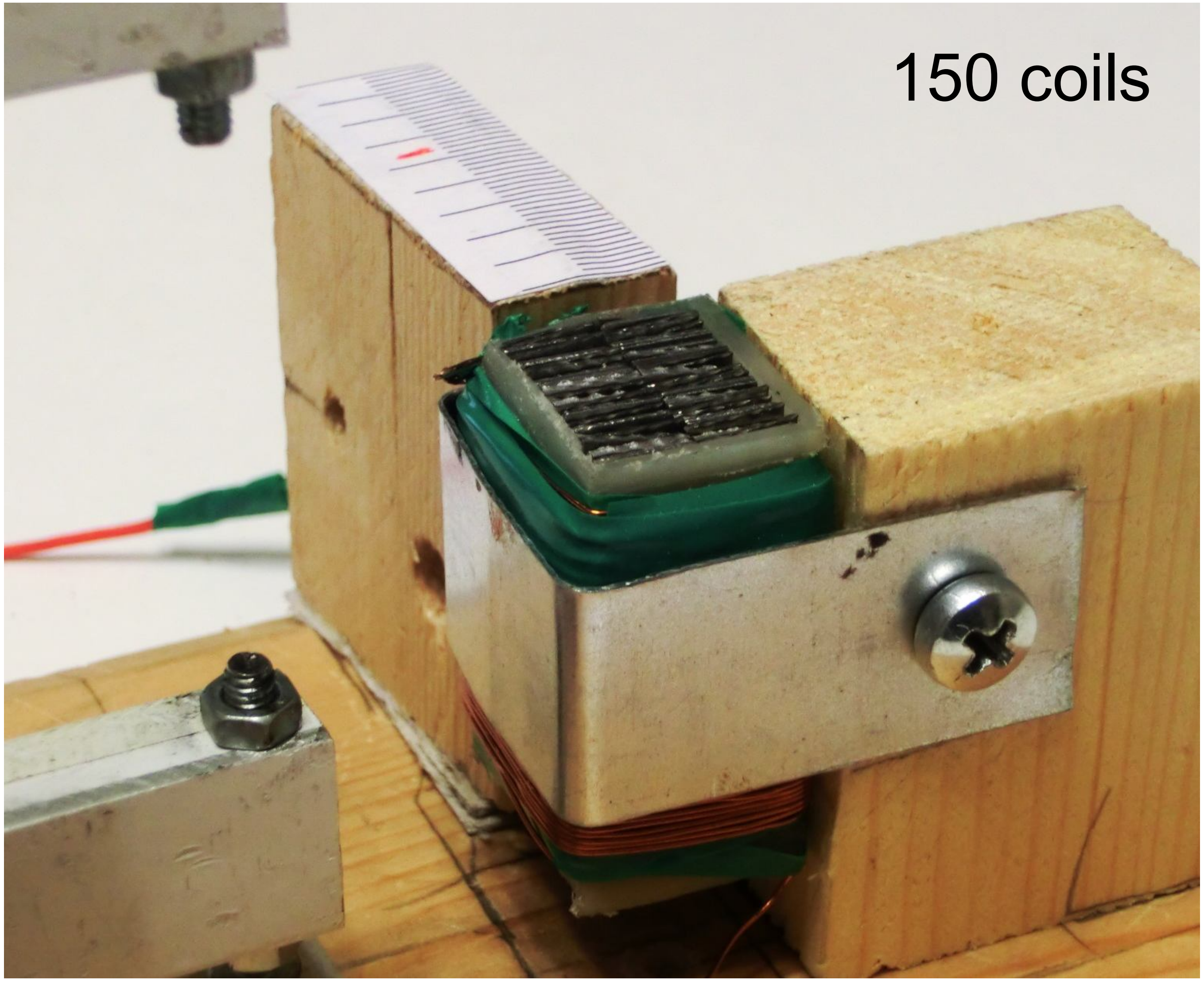
Full power

6 W

Efficiency

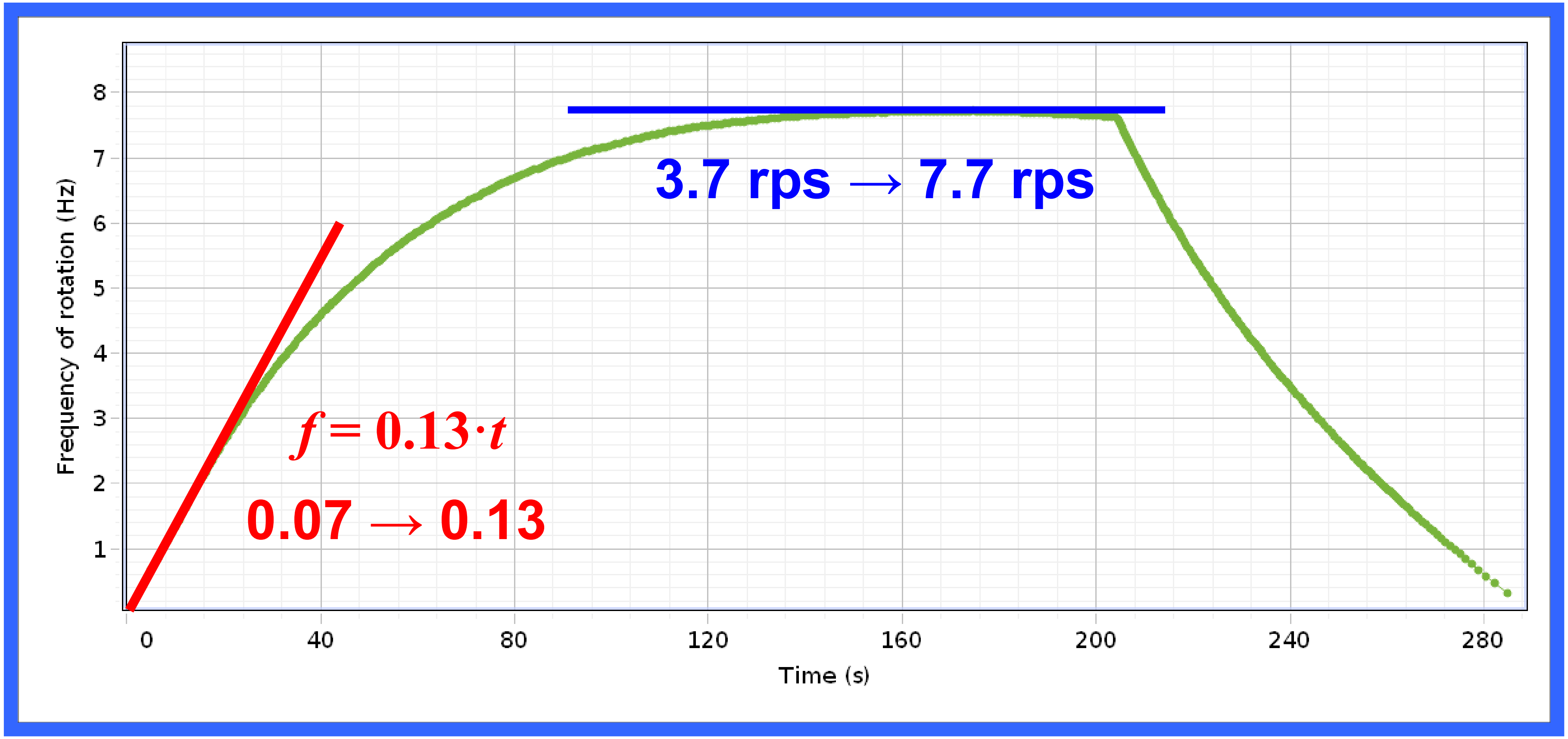
$1.1 \cdot 10^{-5}$

Updated setup with laminated core

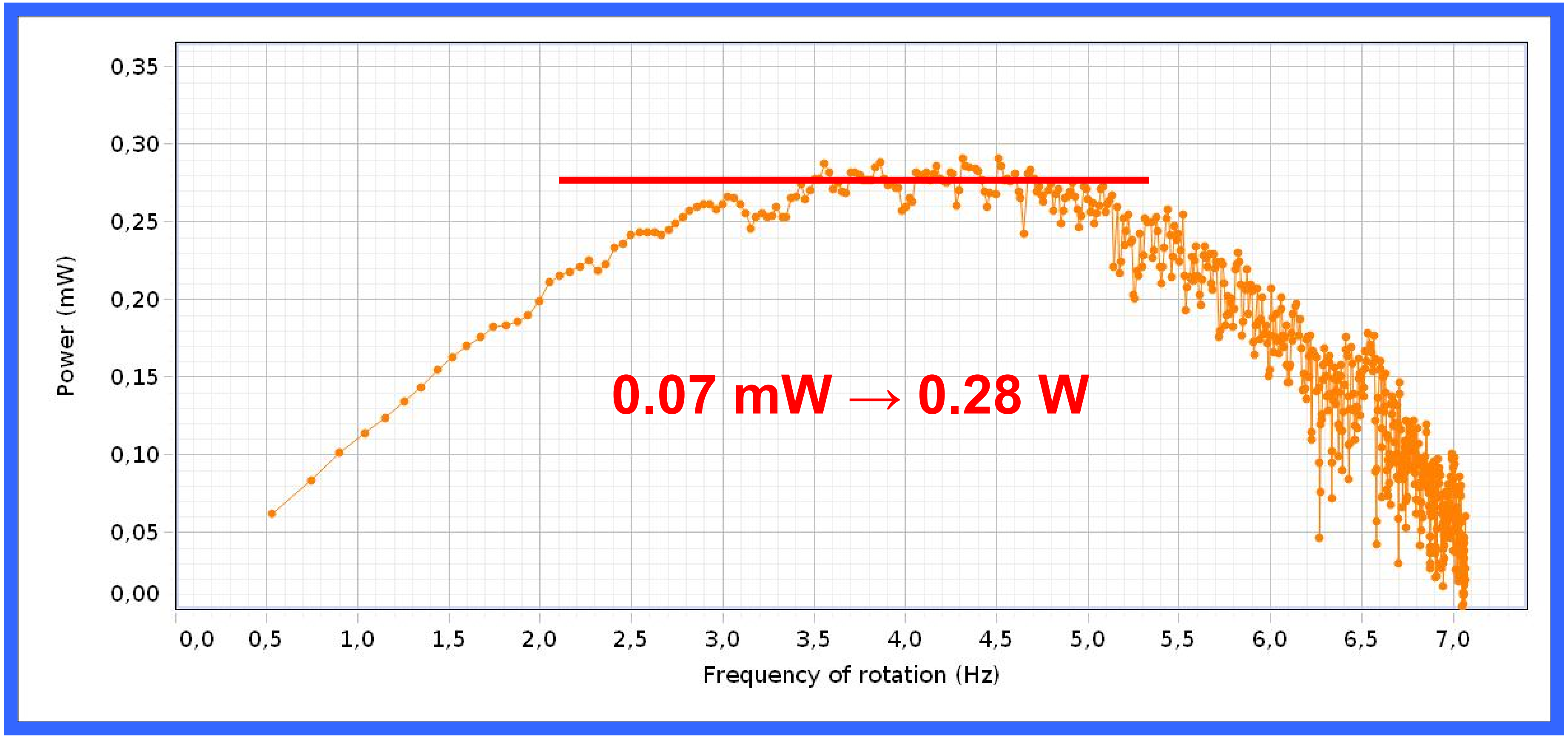


150 coils

Rotating speed vs. time



Power vs. rotating speed (exp.)



Efficiency

Useful power

$0.07\ \text{mW} \rightarrow 0.28\ \text{mW}$

Full power

$6\ \text{W} \rightarrow 4\ \text{W}$

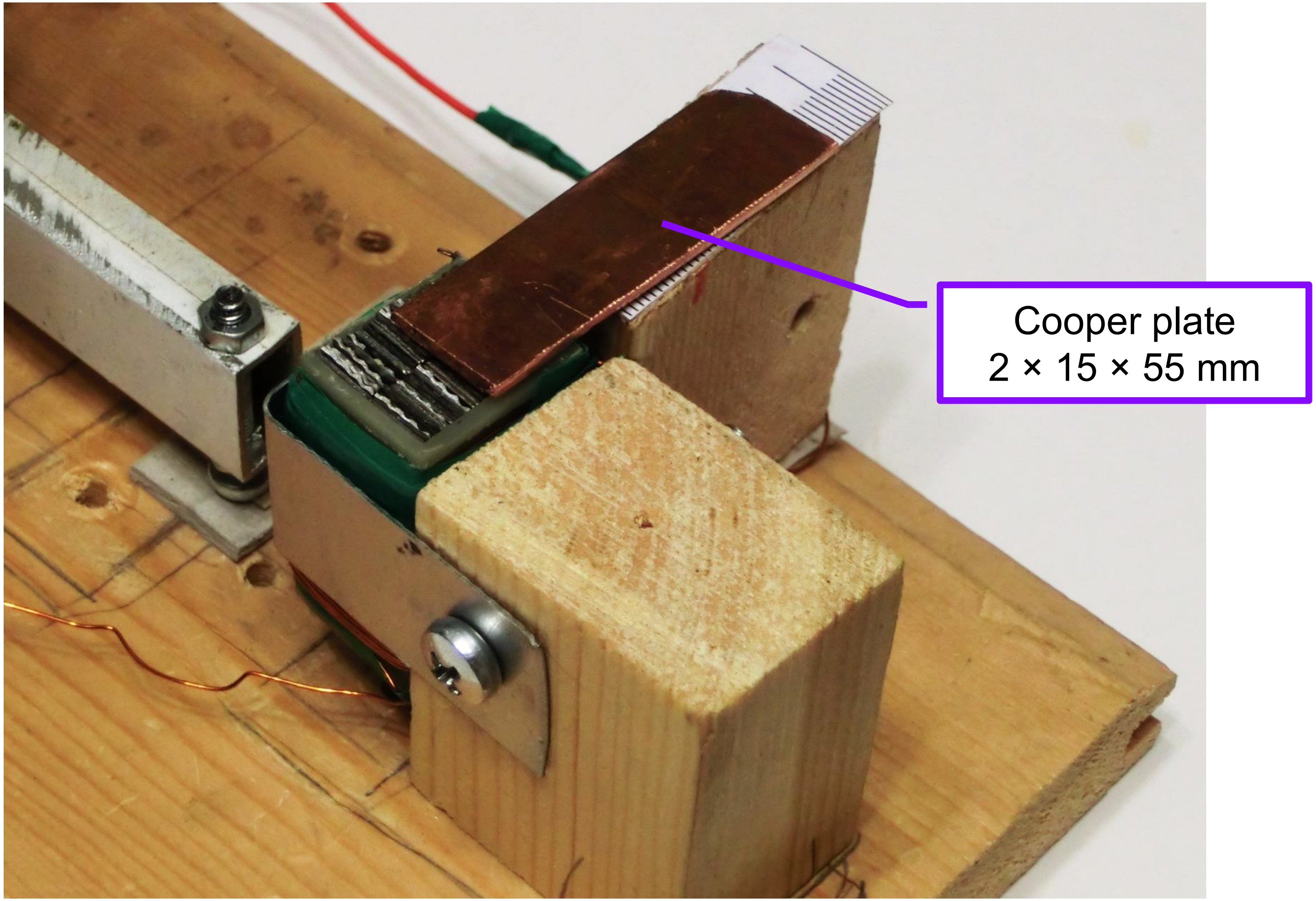
Efficiency

$1.1 \cdot 10^{-5} \rightarrow 7 \cdot 10^{-5}$

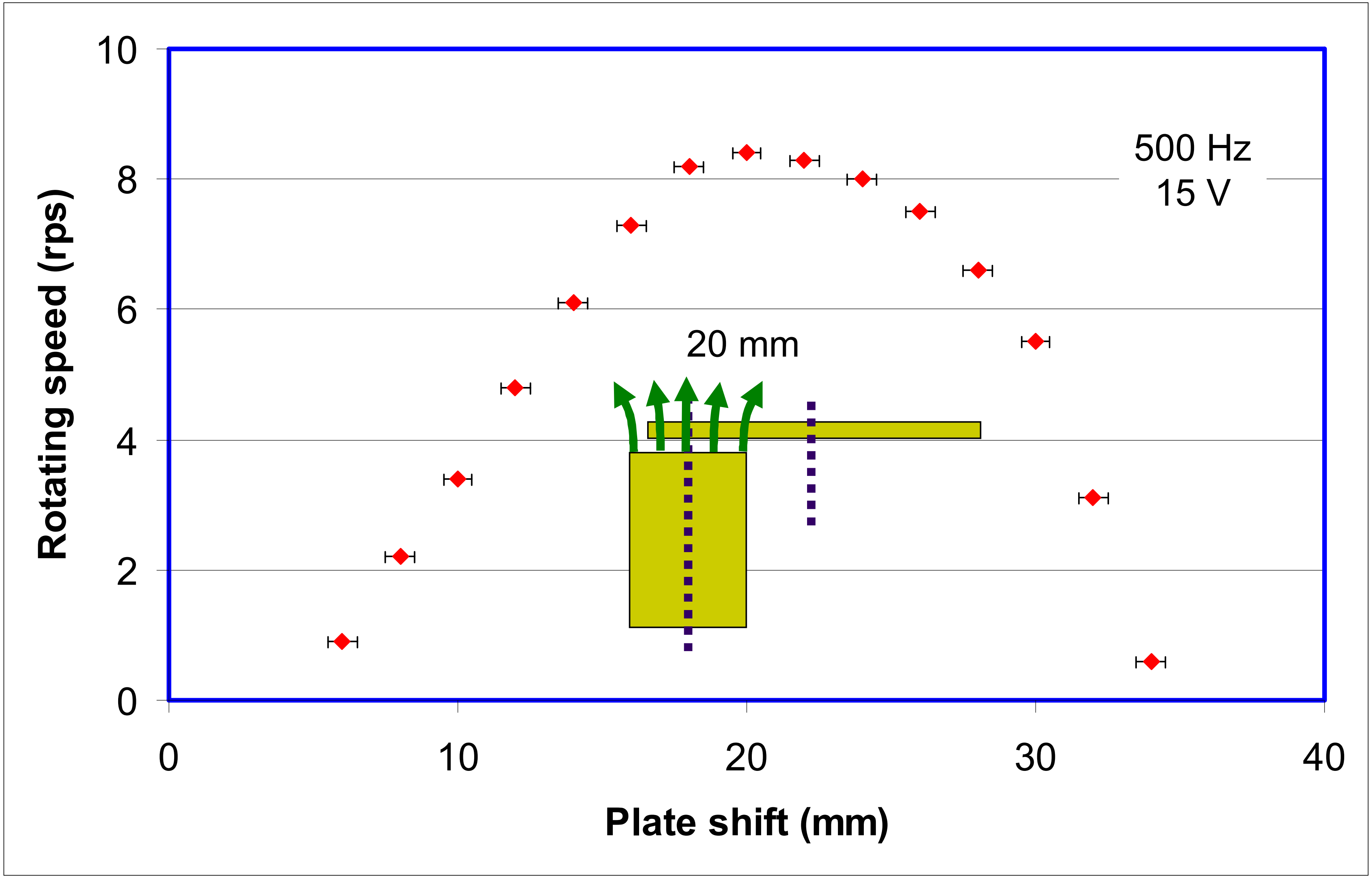
Shading degree

"…if a non-ferromagnetic metal sheet is partially inserted between the electromagnet and the disk…"

Shifted cooper plate



Angular velocity vs. plate shift



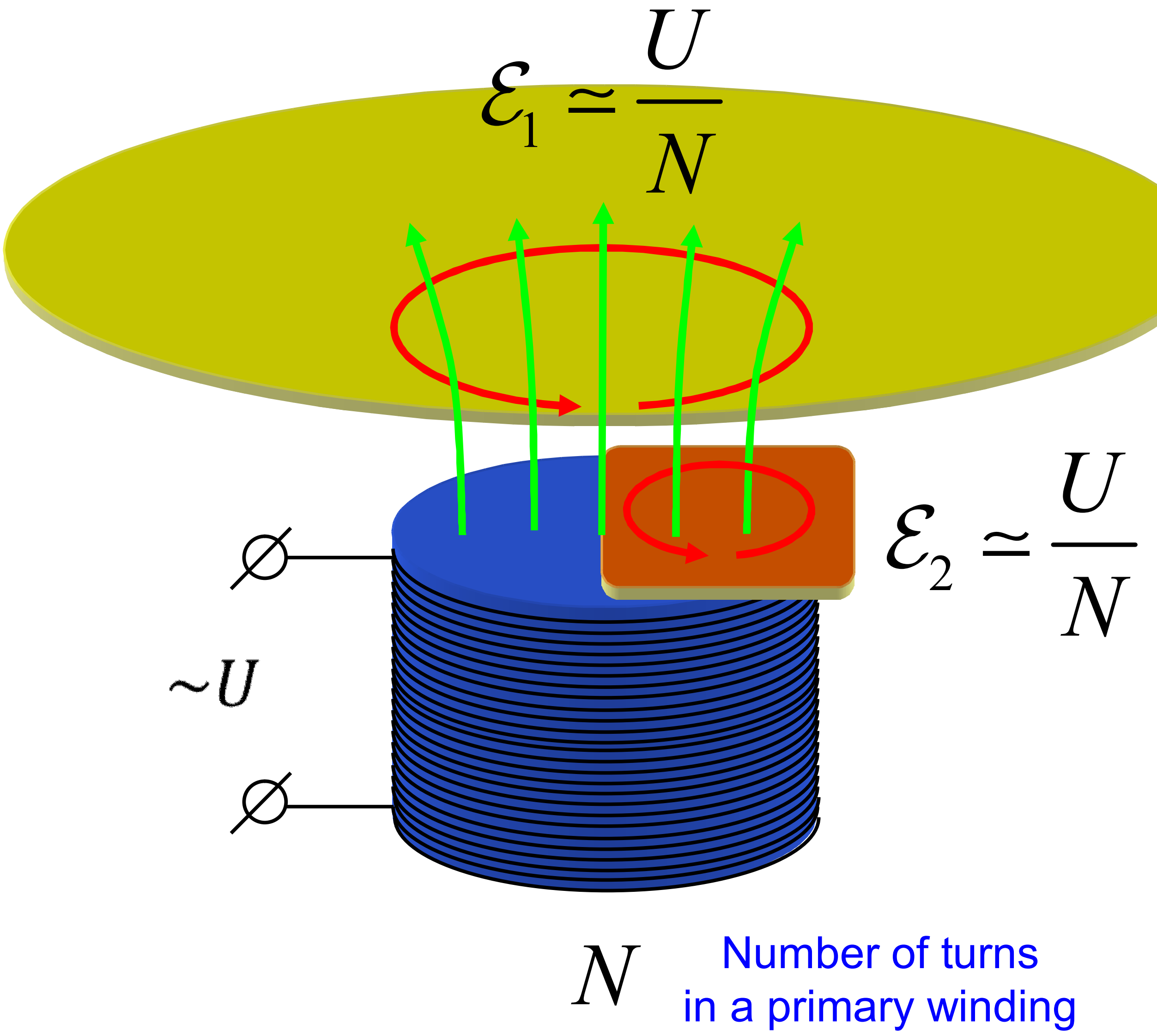
Two disks experiment

Several rotating disks also lead to an increased efficiency and power!

Theoretical model

"…powered by an AC supply…"

Shaded pole motor as transformer



Interaction of eddy currents

σ — electrical conductivity
τ — conducting plate thickness

$$I_1 \simeq \frac{\mathcal{E}_1}{R_1} \simeq \frac{U}{N} \cdot \sigma_1 \tau_1 \qquad I_2 \simeq \frac{\mathcal{E}_2}{R_2} \simeq \frac{U}{N} \cdot \sigma_2 \tau_2$$

$$F \propto I_1 I_2 \propto \frac{U^2}{N^2} \cdot \sigma_1 \sigma_2 \tau_1 \tau_2$$

Decreasing the number of turns

$$F \propto \frac{U^2}{N^2}$$

- To increase the force it is advantageous to decrease the number of turns in the primary winding.
- Therefore, with a small number of turns the resistance of a primary winding decreases and heat power increases.

Increasing the input frequency

Heat power →

$$P = \frac{1}{2} \cdot \frac{U_0^2 R}{R^2 + (\omega L)^2}$$

← Inductance

- In order to decrease heat losses at the same voltage we need to increase AC frequency.
- However at high AC frequencies skin-effect begin to play a significant role.

Variation of the input frequency

"…powered by an AC supply…"

Skin depth

Skin depth
(falling *e* times)

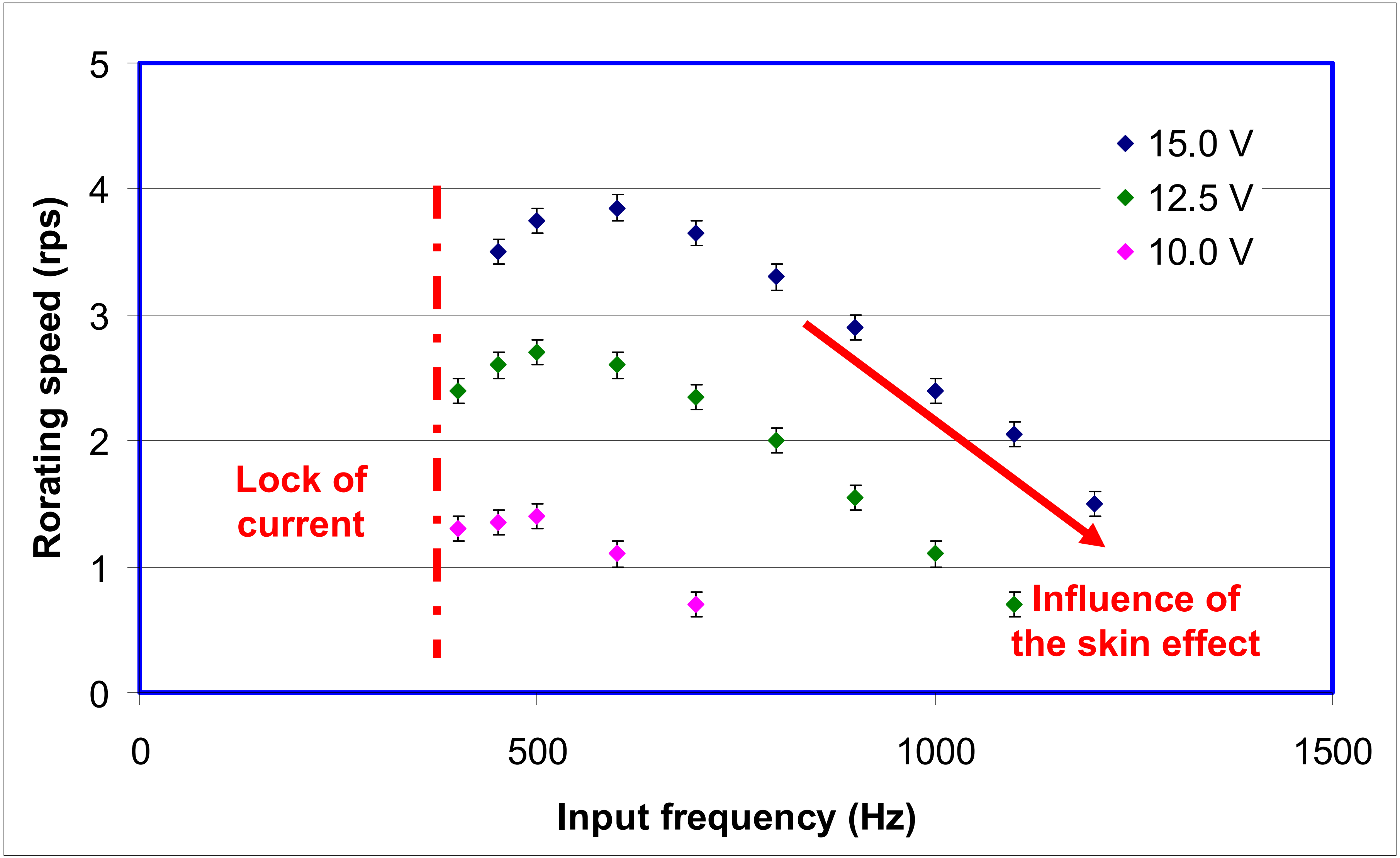
$$\delta = \sqrt{\frac{2}{\mu_0 \sigma \omega}}$$

$$\text{Aluminum: } \sigma = 3.7 \cdot 10^7 \ (\Omega \cdot \text{m})^{-1}$$

$$\text{Cooper: } \sigma = 5.8 \cdot 10^7 \ (\Omega \cdot \text{m})^{-1}$$

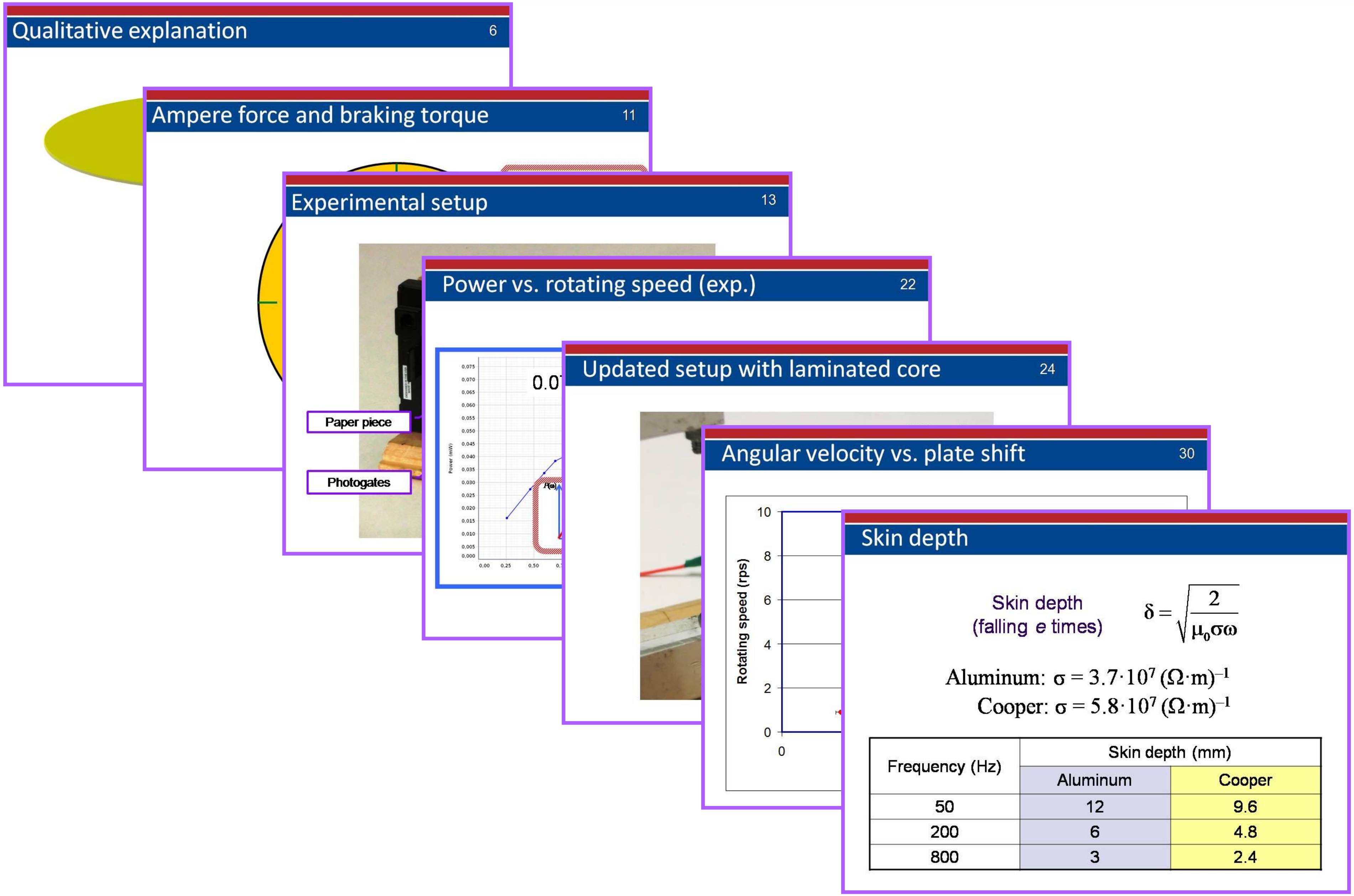
Frequency (Hz)	Skin depth (mm)	
	Aluminum	Cooper
50	12	9.6
200	6	4.8
800	3	2.4

Rotating speed vs. input frequency



Summary

Conclusions



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Thank you for your attention!