11

Ball Bearing Motor

Kamila Součková

11. Ball Bearing Motor

A device called a “Ball Bearing Motor” uses electrical energy to create rotational motion. On what parameters do the motor *efficiency* and the *velocity* of the rotation depend?

INTRODUCTION

What is a “Ball Bearing Motor”?

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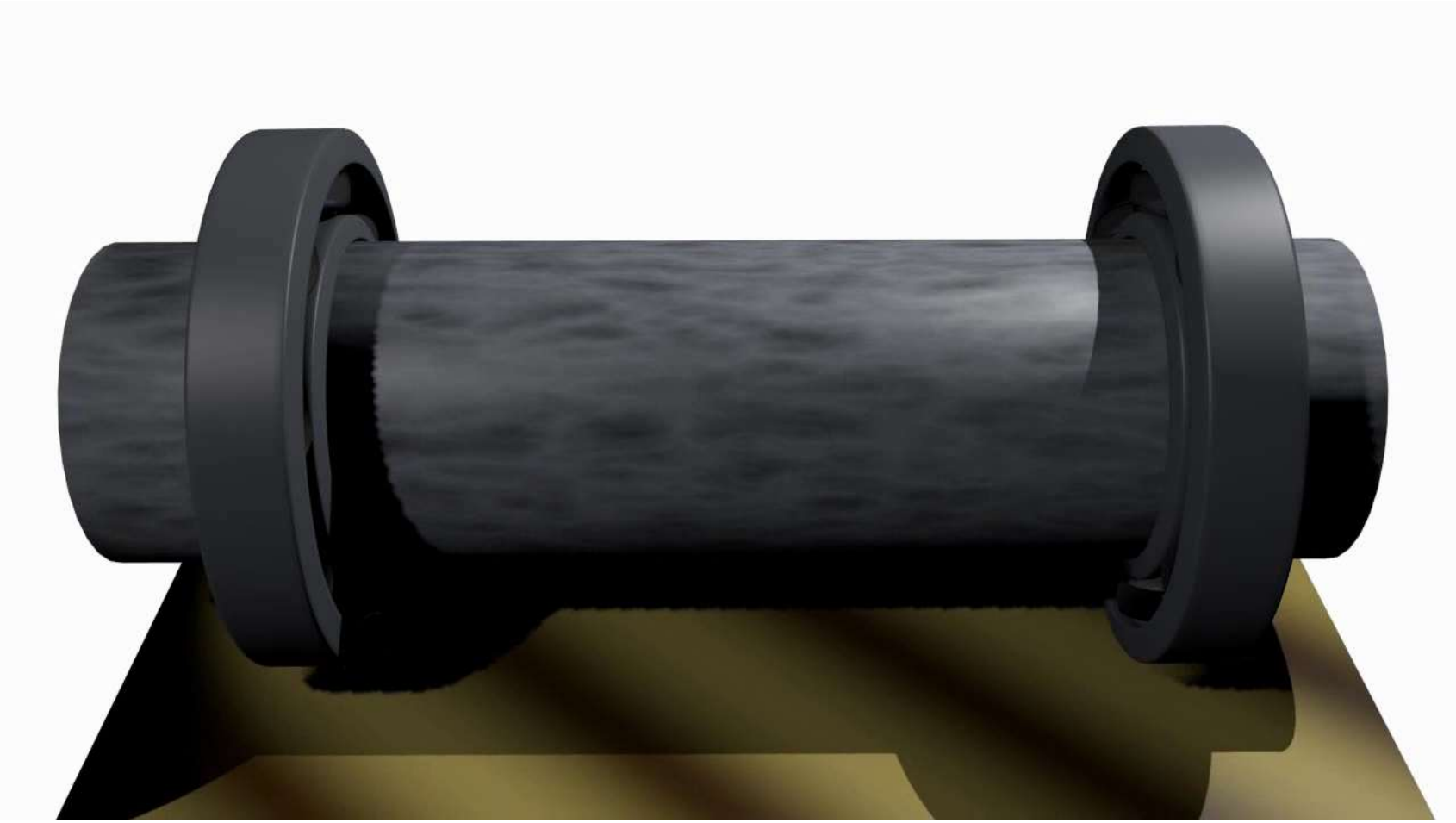
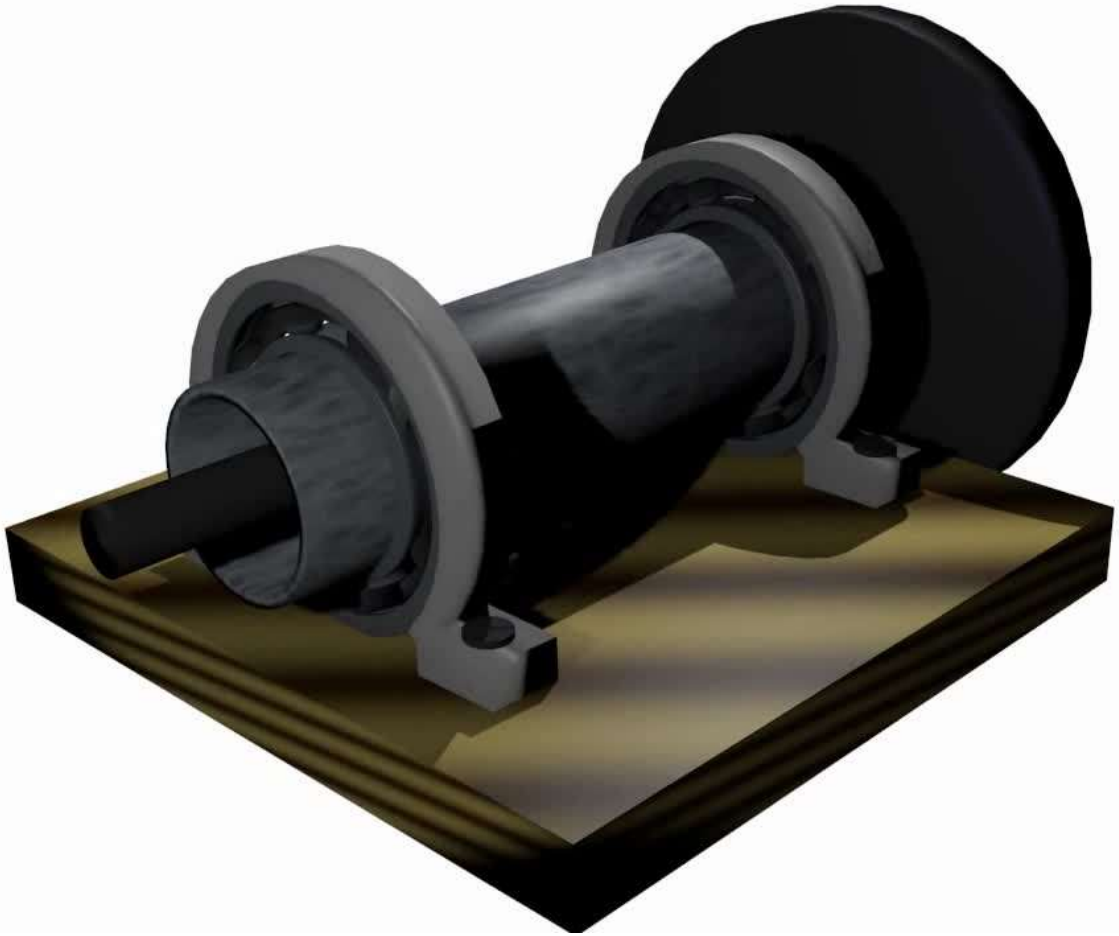
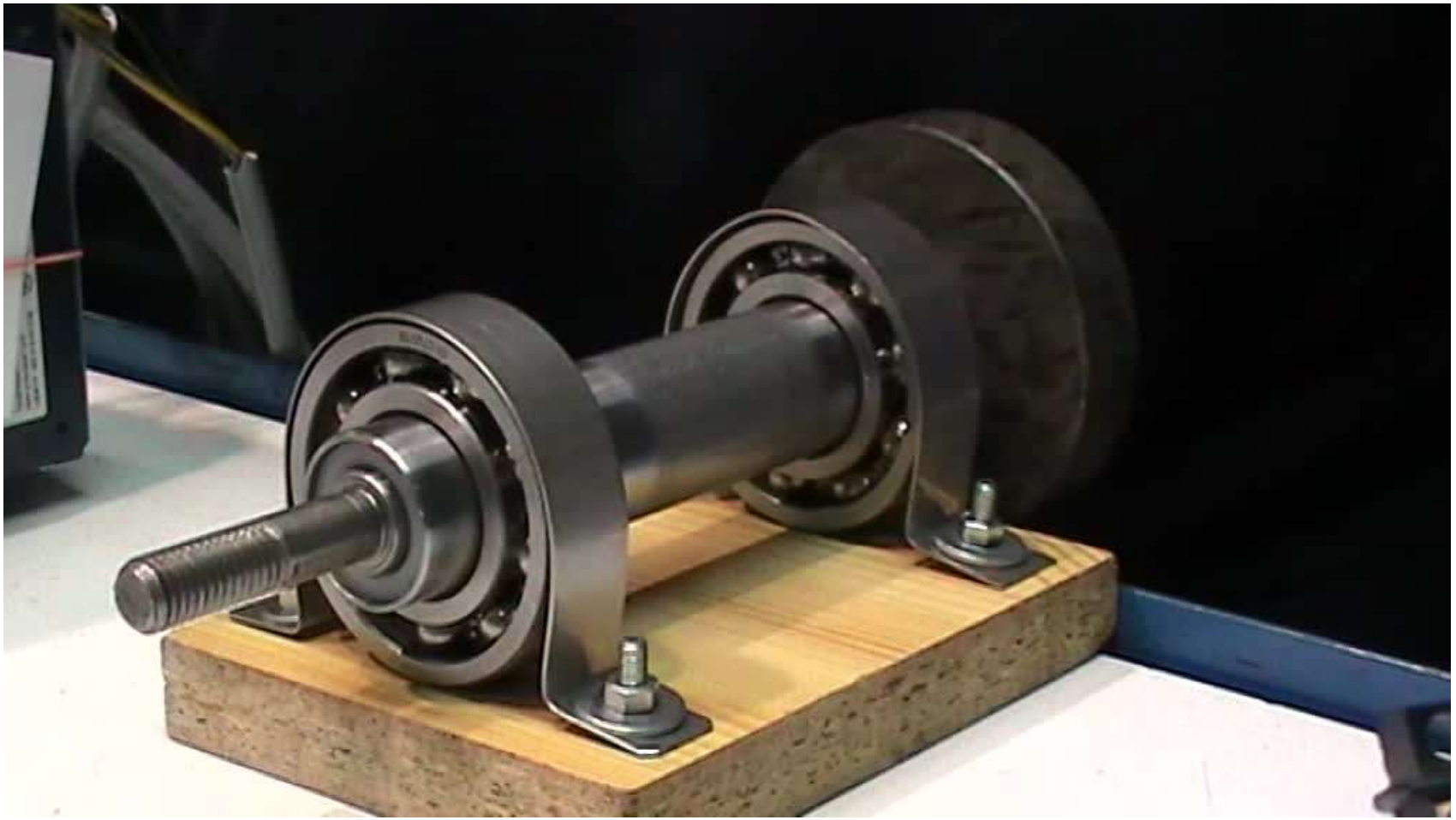


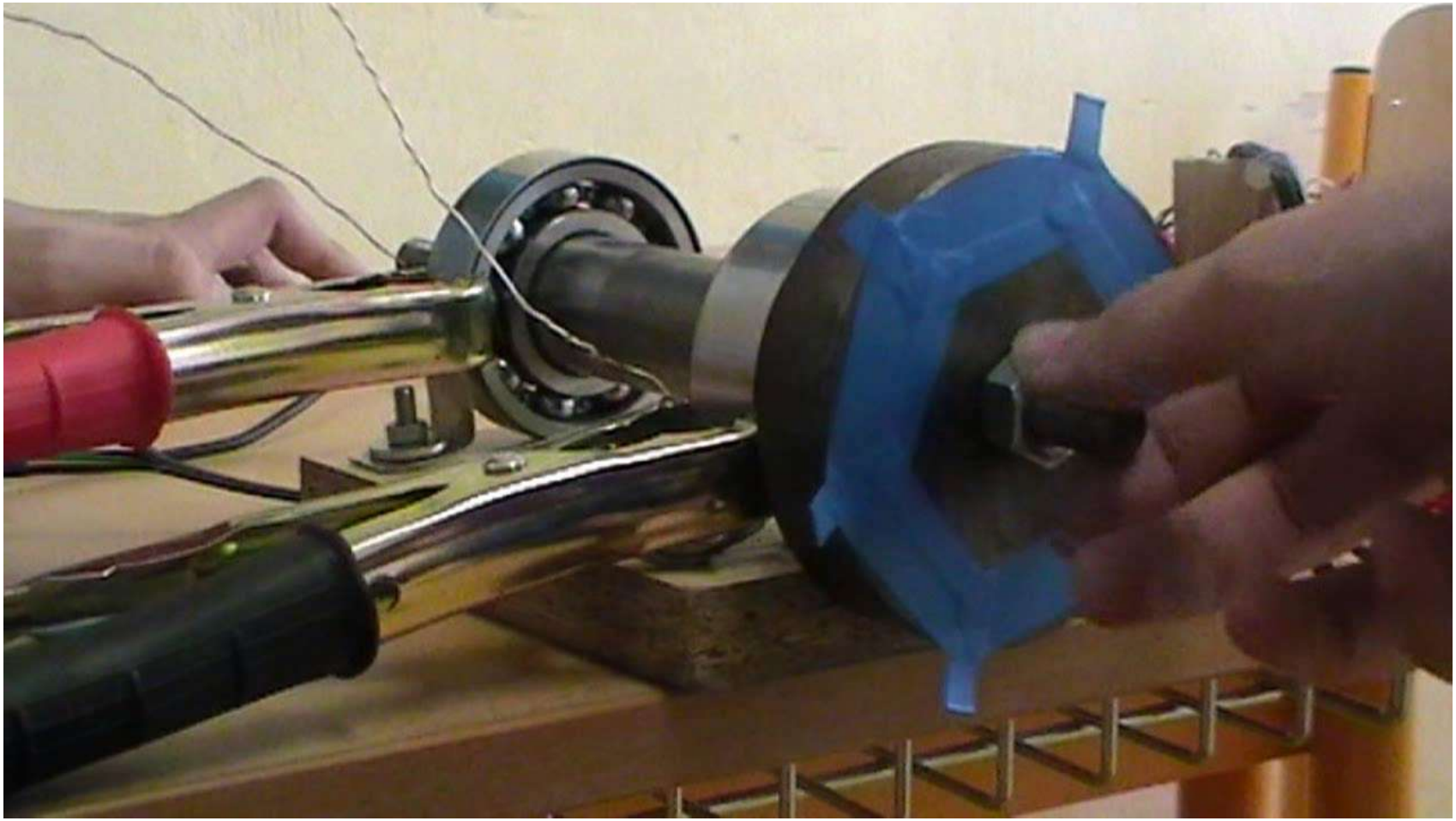
What is a “Ball Bearing Motor”?



What is a “Ball Bearing Motor”?

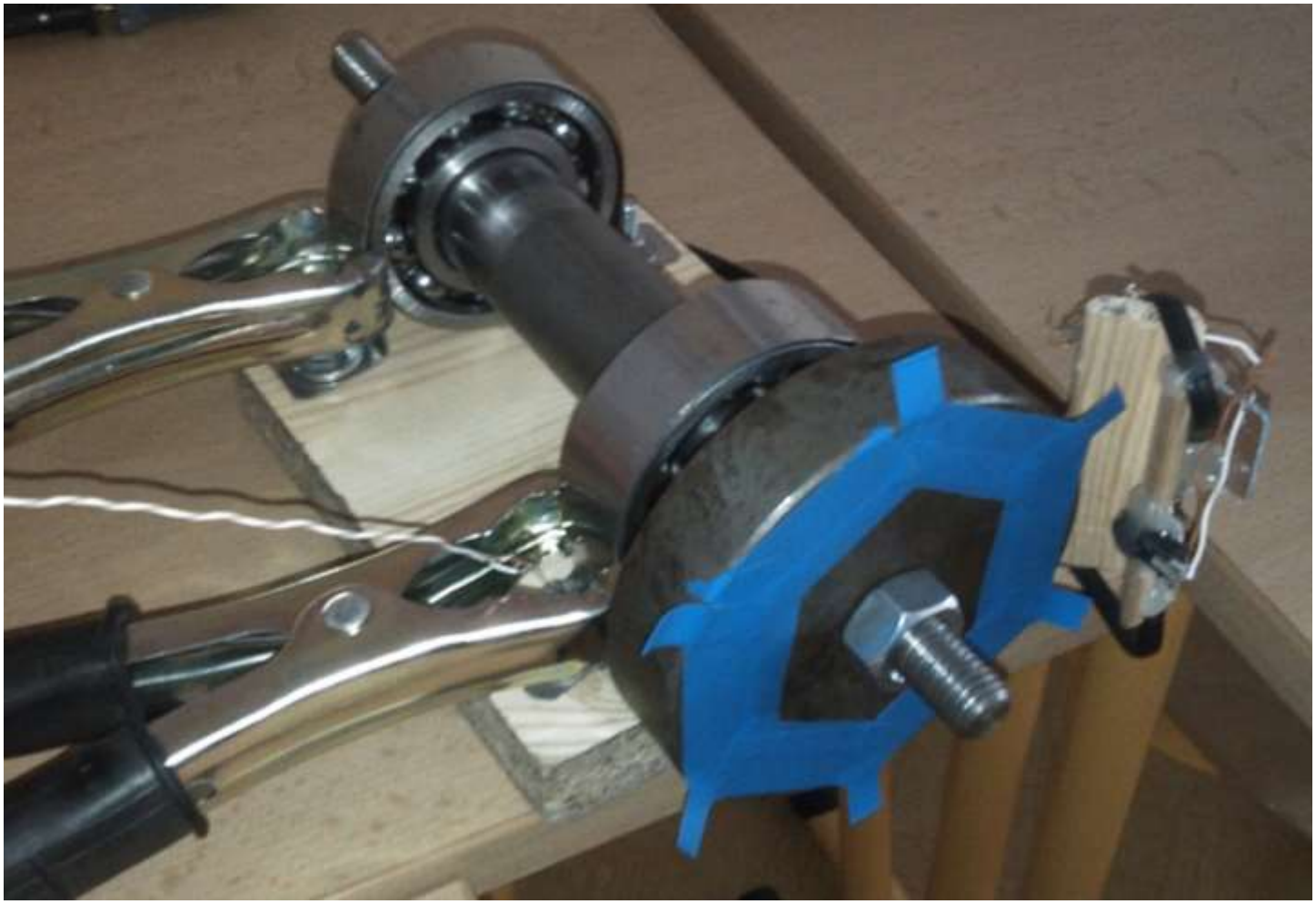


It Works!

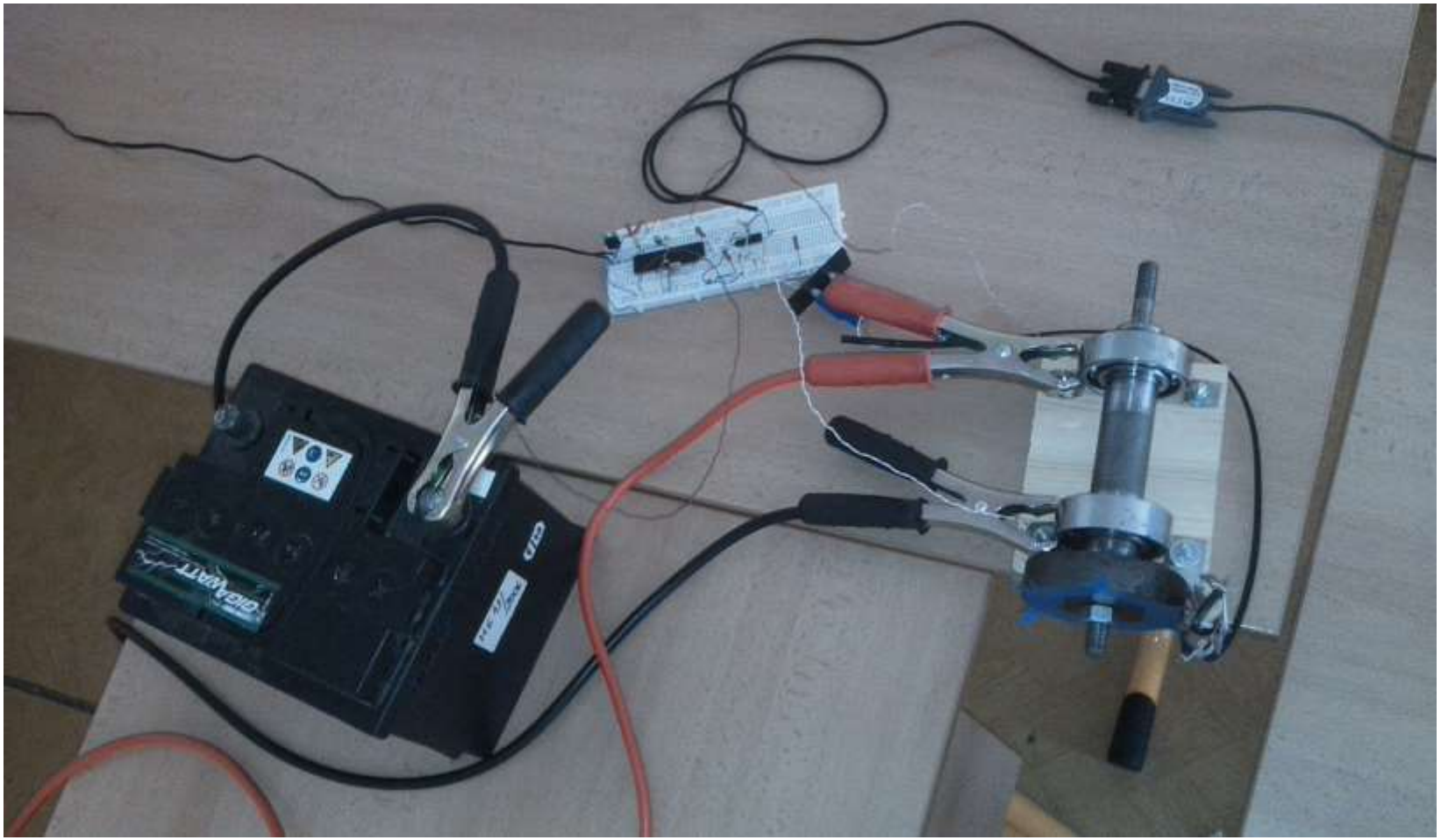


EXPERIMENTS

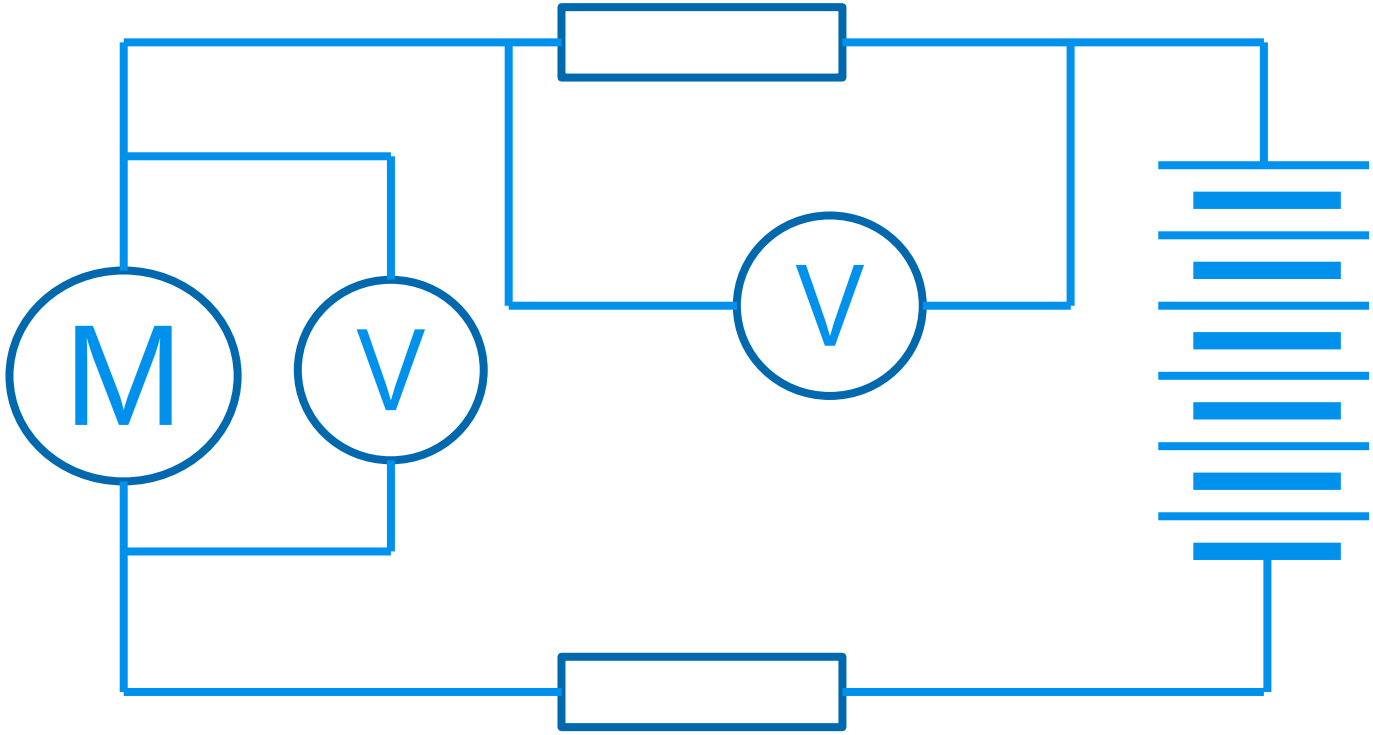
Experimental apparatus

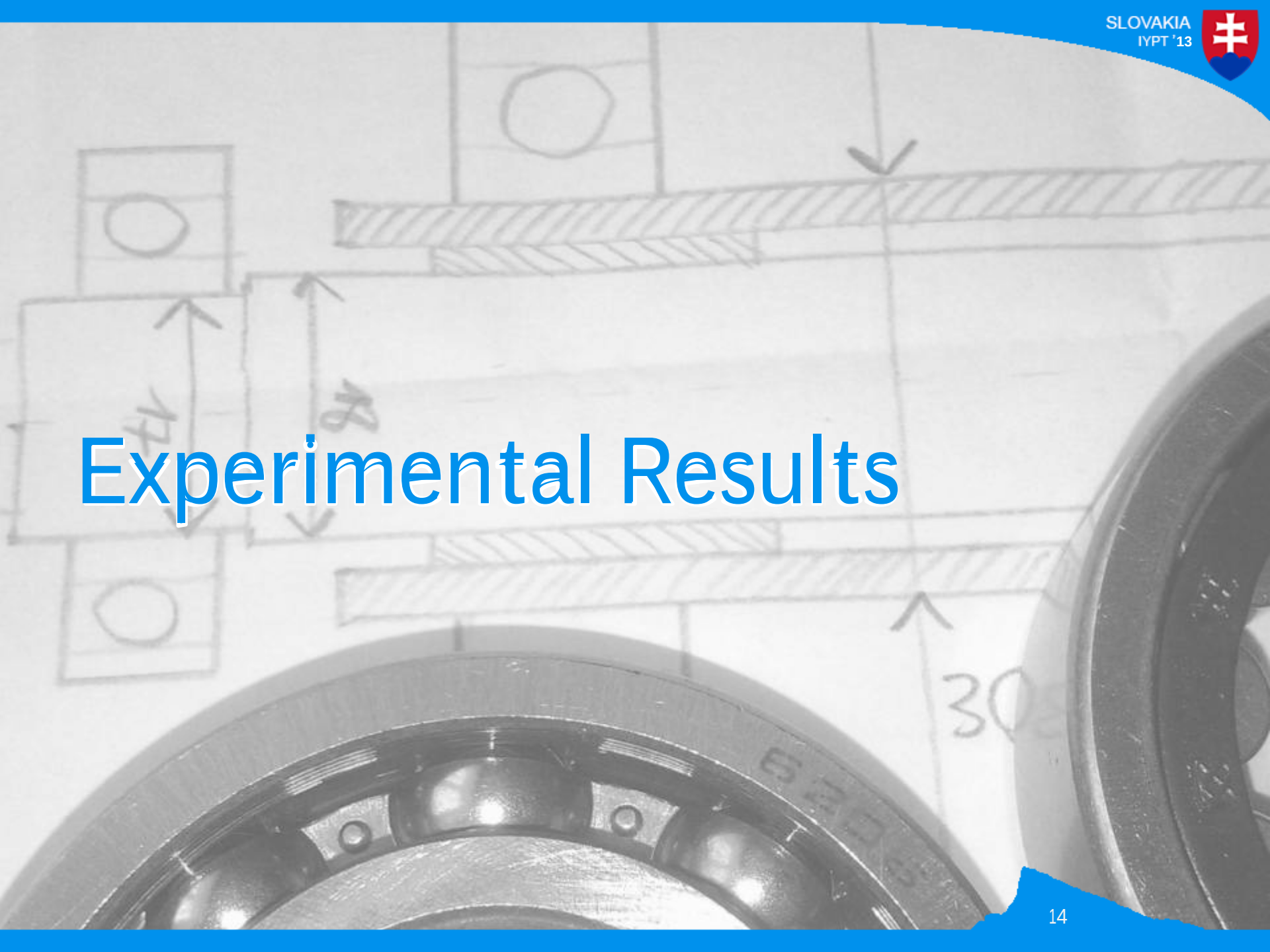


Experimental apparatus



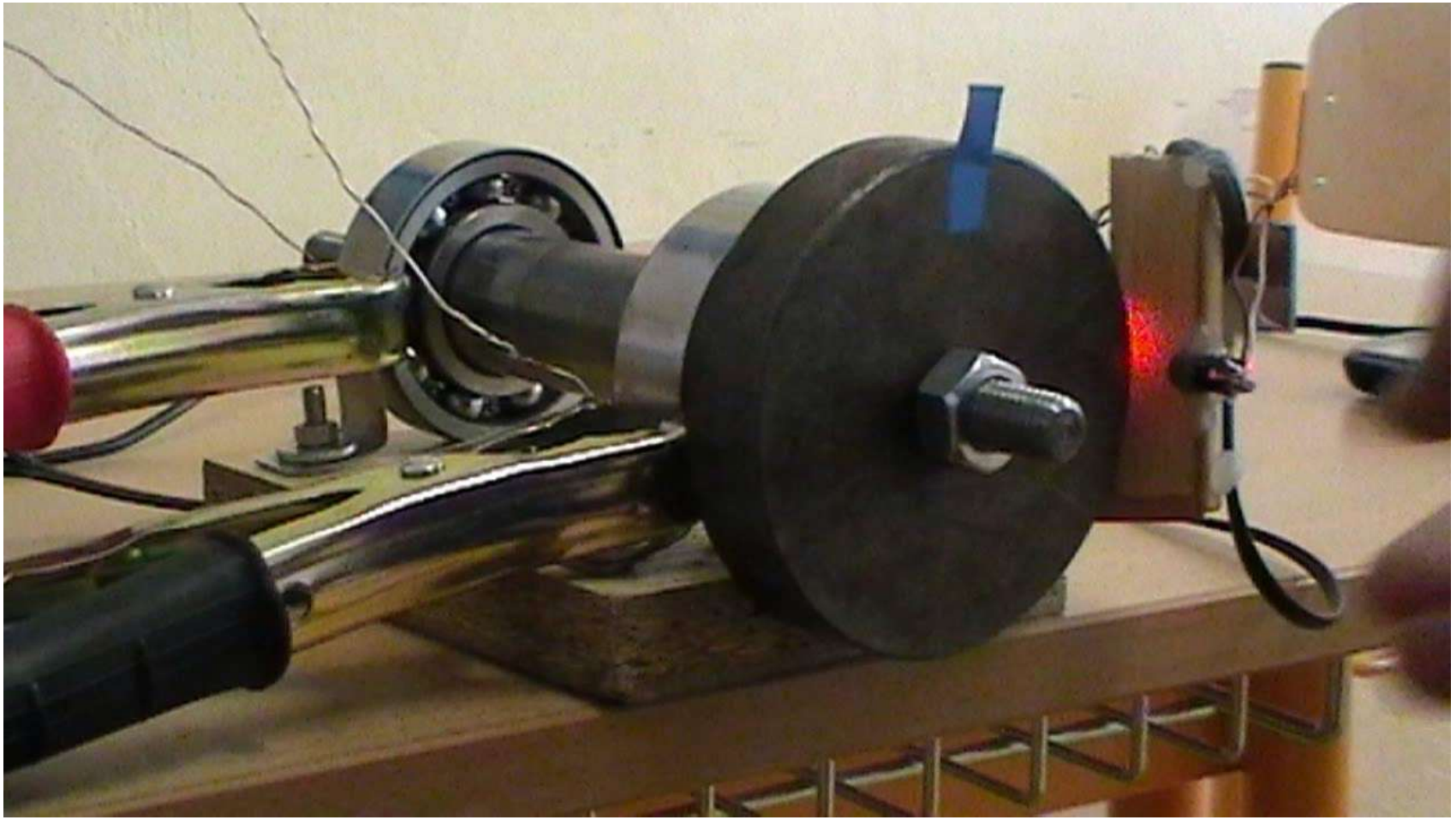
Experimental apparatus



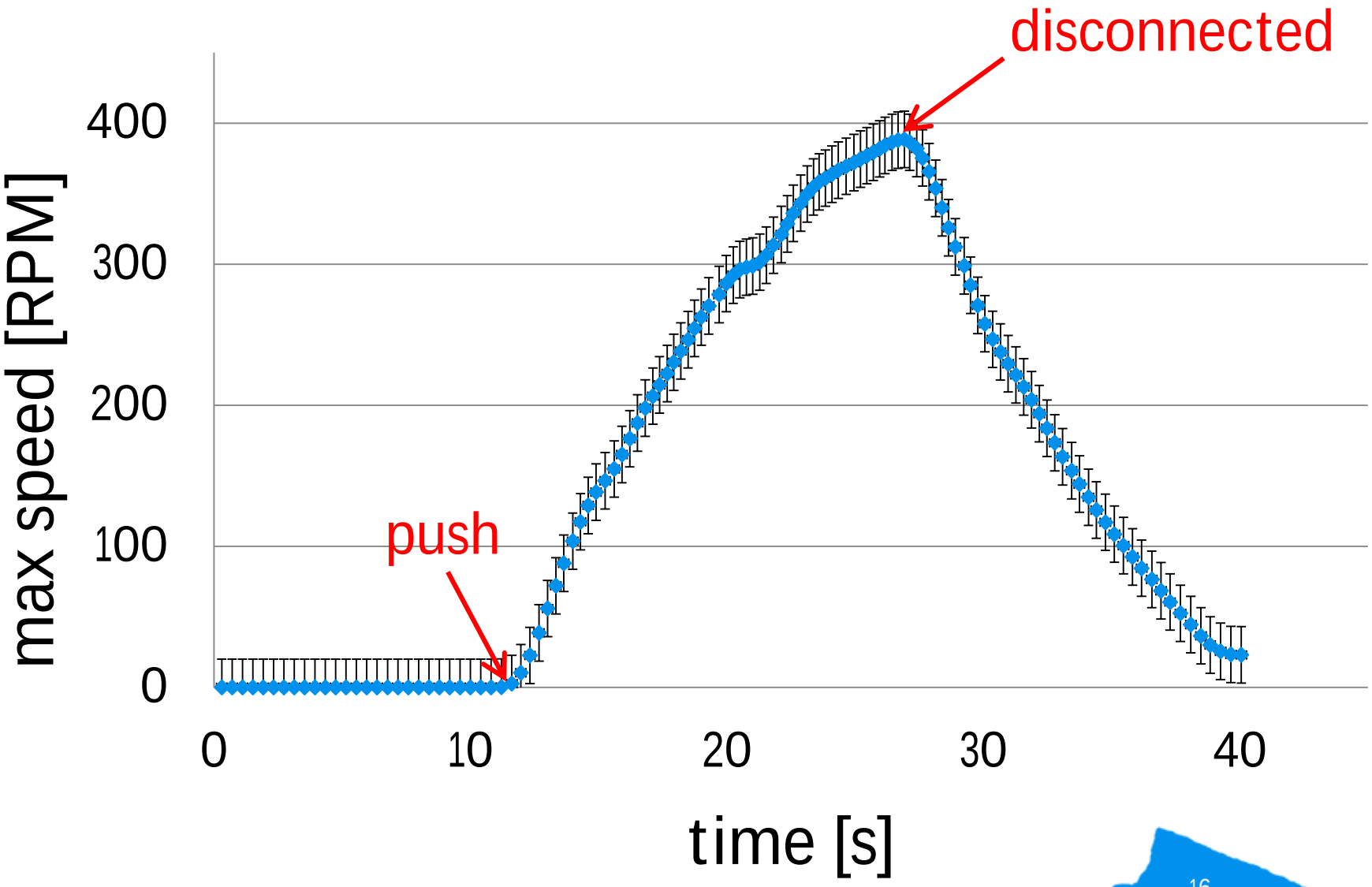


Experimental Results

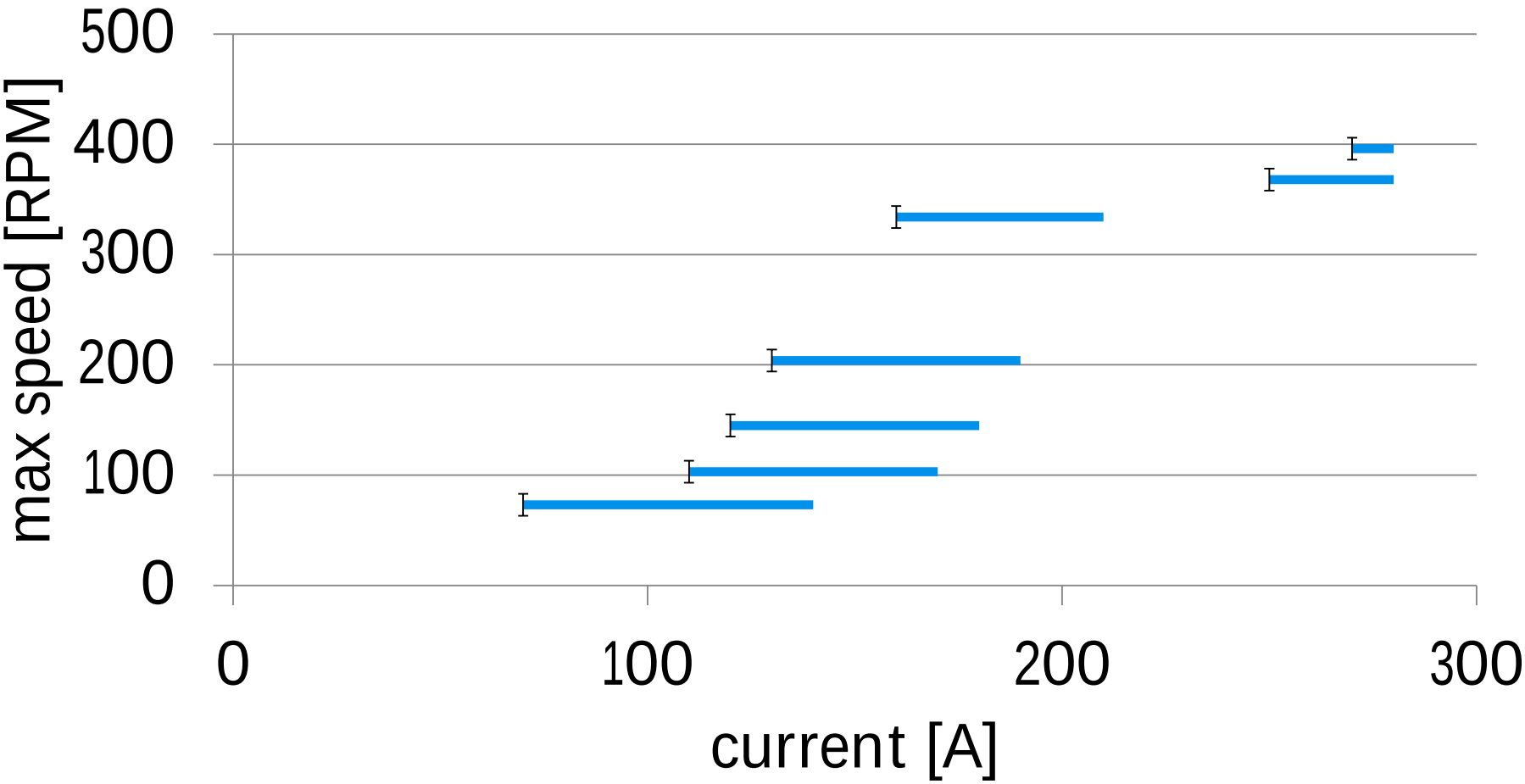
Max Speed Measurement



Max Speed Measurement

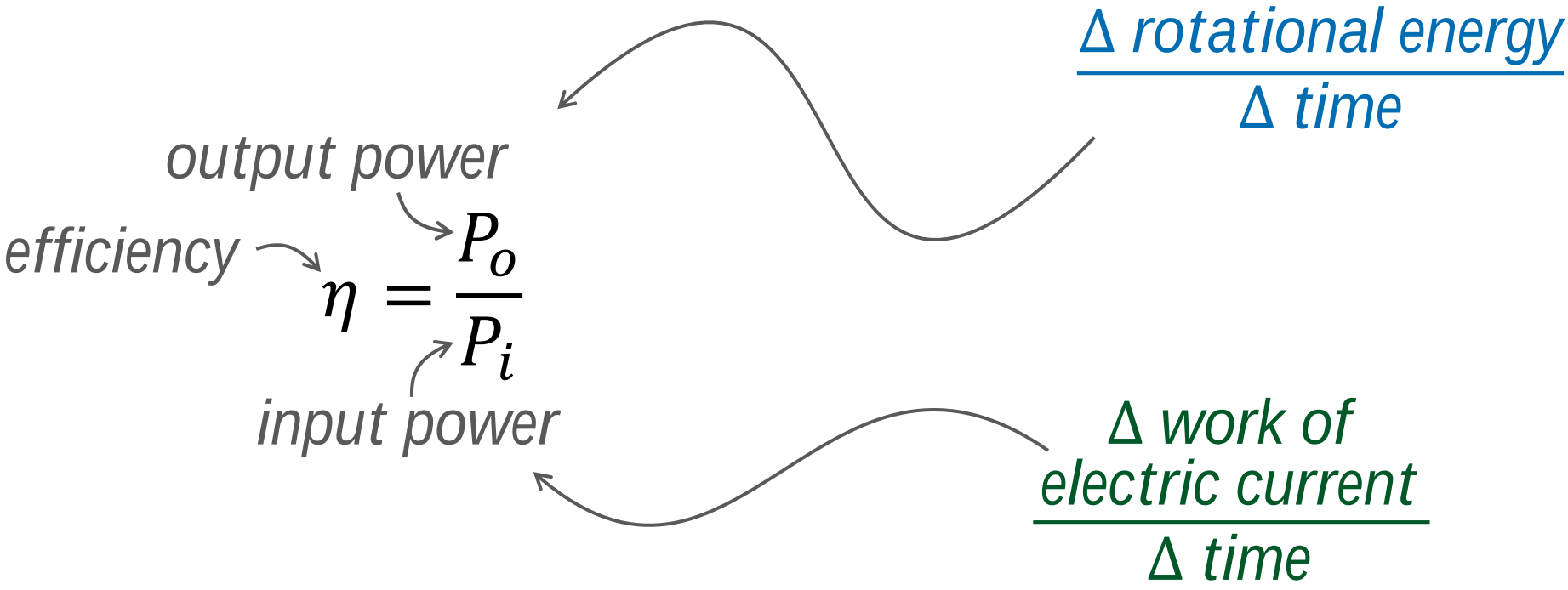


Max Speed vs. Current

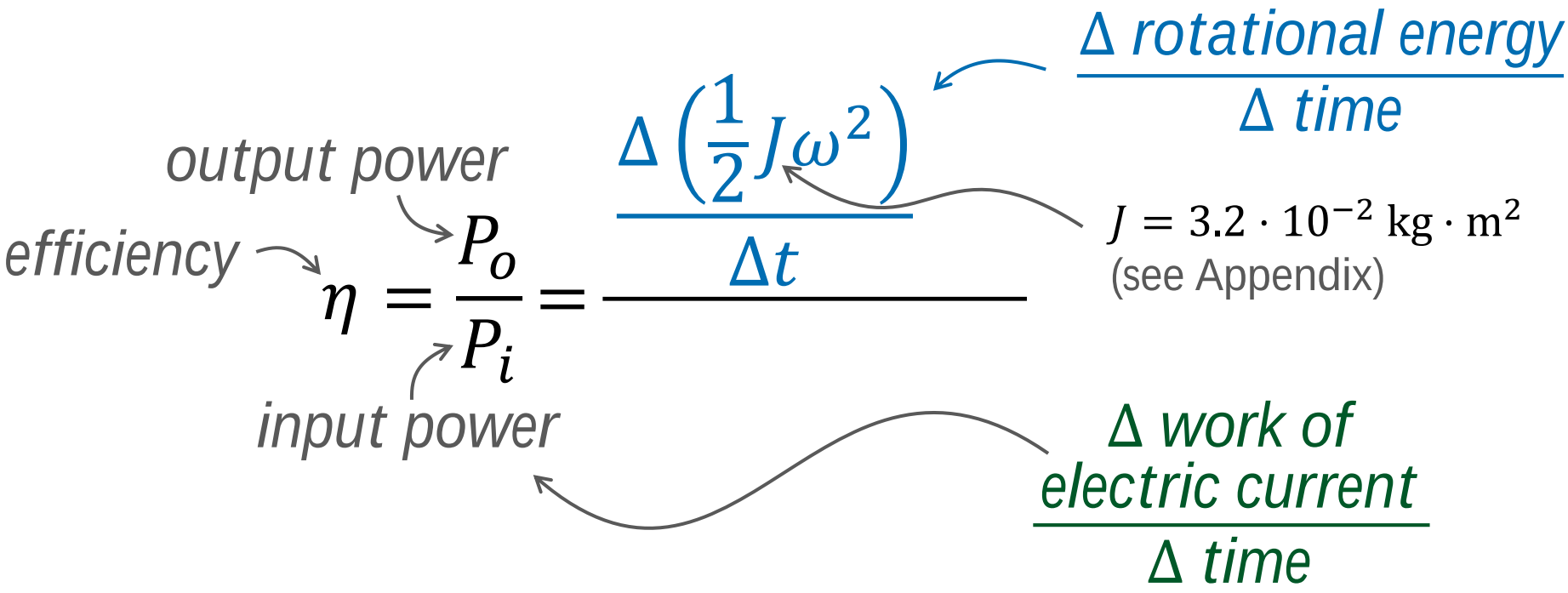


current was changing in time during experiments (battery discharging etc.)

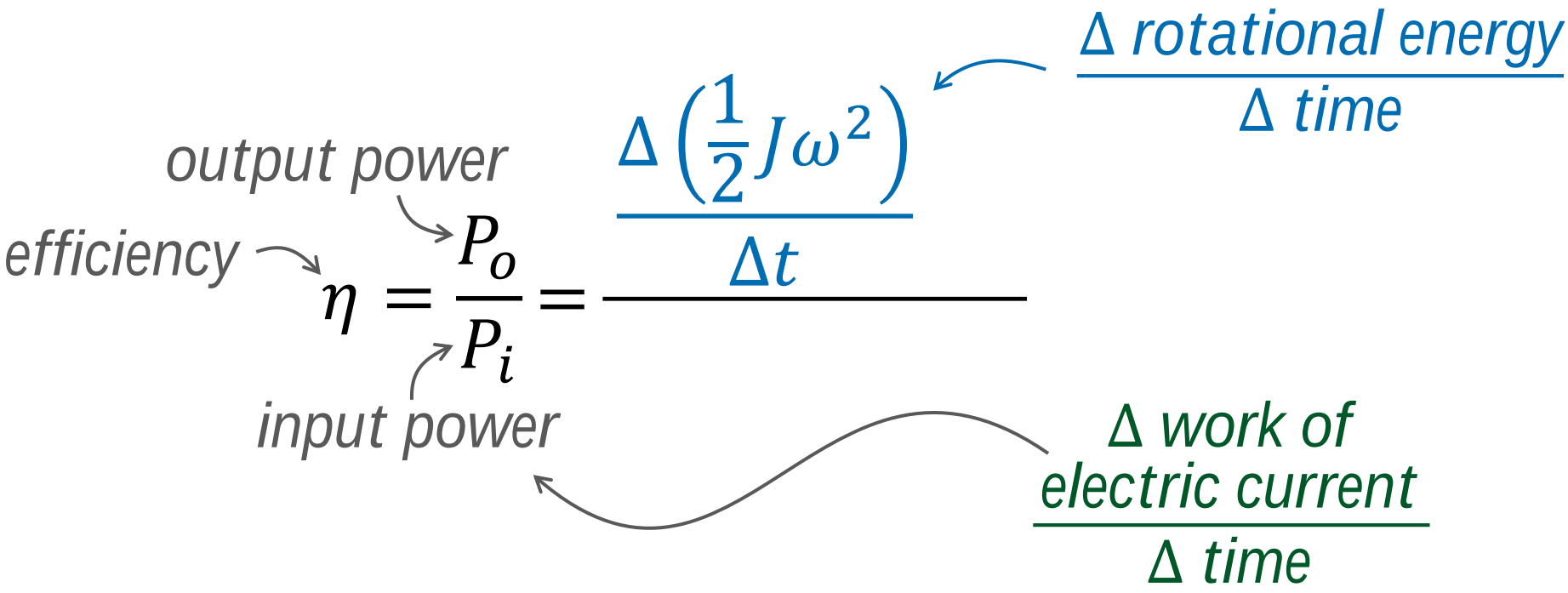
Efficiency Measurement



Efficiency Measurement



Efficiency Measurement



Efficiency Measurement

$$\text{efficiency } \eta = \frac{P_o}{P_i} = \frac{\Delta\left(\frac{1}{2}J\omega^2\right)}{\Delta t}$$

P_o: output power

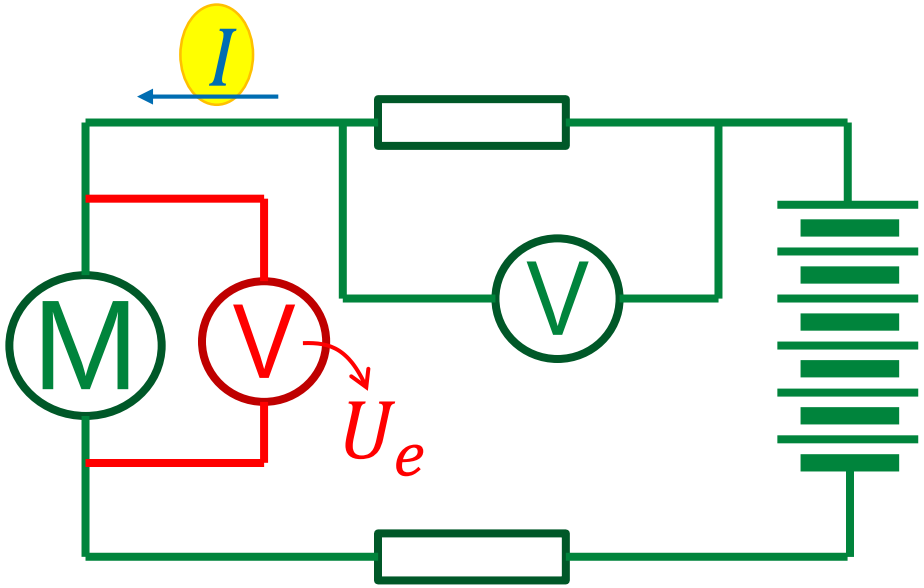
P_i: input power

$\frac{\Delta \text{ rotational energy}}{\Delta \text{ time}}$

$U_e \cdot I$

$\frac{\Delta \text{ work of electric current}}{\Delta \text{ time}}$

too large to be measured directly



Efficiency Measurement

$$\eta = \frac{P_o}{P_i} = \frac{\Delta\left(\frac{1}{2}J\omega^2\right)}{\Delta t}$$

output power

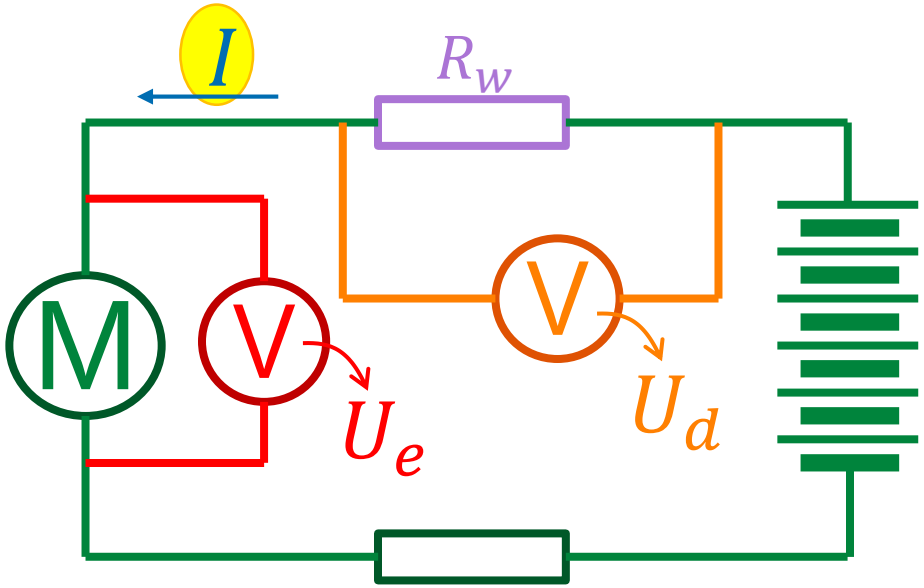
efficiency

input power

$\frac{\Delta \text{ rotational energy}}{\Delta \text{ time}}$

$U_e \cdot I$

$\frac{\Delta \text{ work of electric current}}{\Delta \text{ time}}$



too large to be measured directly → measure voltage drop on wire!

$$\Rightarrow I = \frac{U_d}{R_w}$$

Efficiency Measurement

$$\eta = \frac{P_o}{P_i} = \frac{\Delta\left(\frac{1}{2}J\omega^2\right)}{\Delta t} \Big/ U_e \cdot \frac{U_d}{R_w}$$

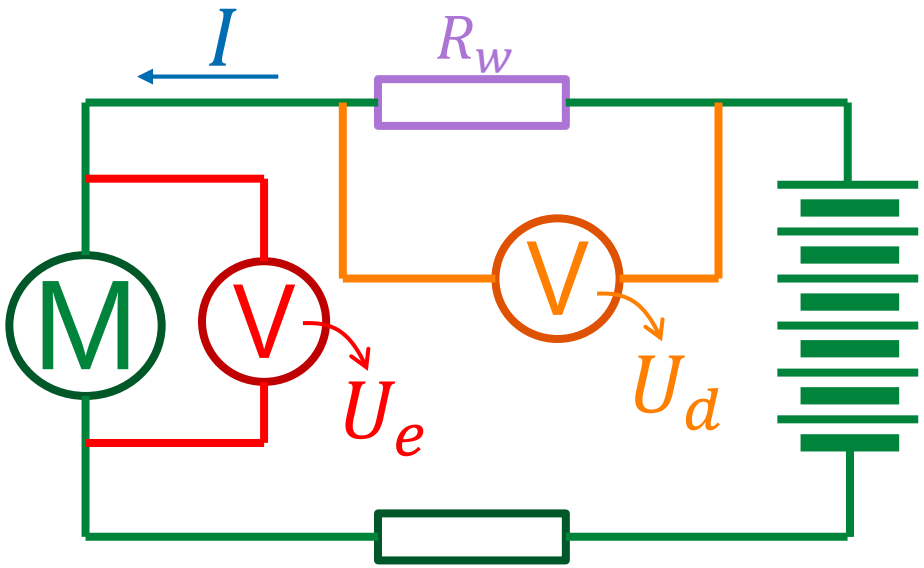
efficiency

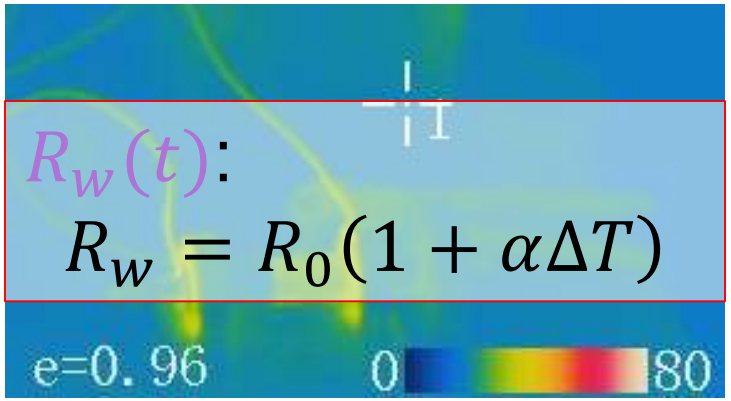
output power: P_o

input power: P_i

$\frac{\Delta \text{ rotational energy}}{\Delta \text{ time}}$

$\frac{\Delta \text{ work of electric current}}{\Delta \text{ time}}$





Efficiency Measurement

$$\eta = \frac{P_o}{P_i} = \frac{\Delta\left(\frac{1}{2}J\omega^2\right)}{\Delta t} \Big/ U_e \cdot \frac{U_d}{R_w(t)}$$

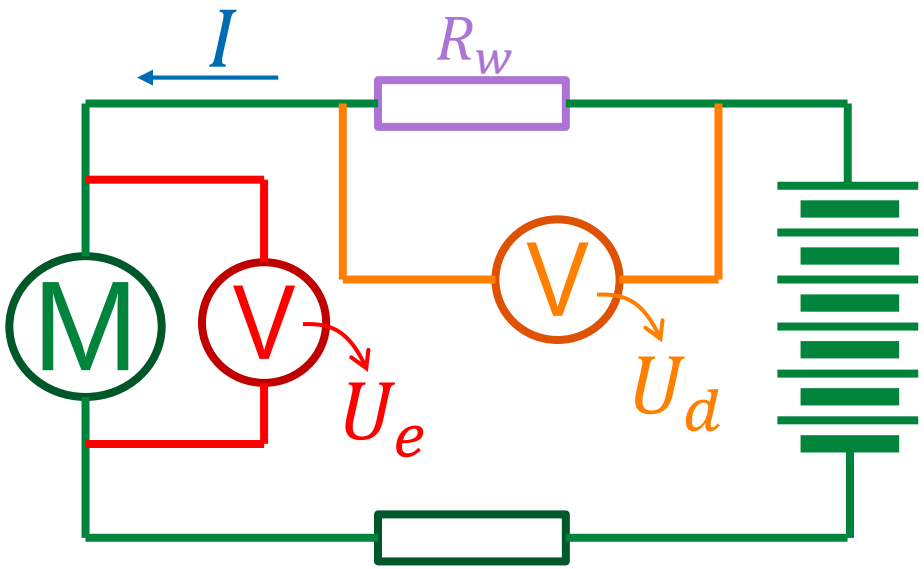
output power

efficiency

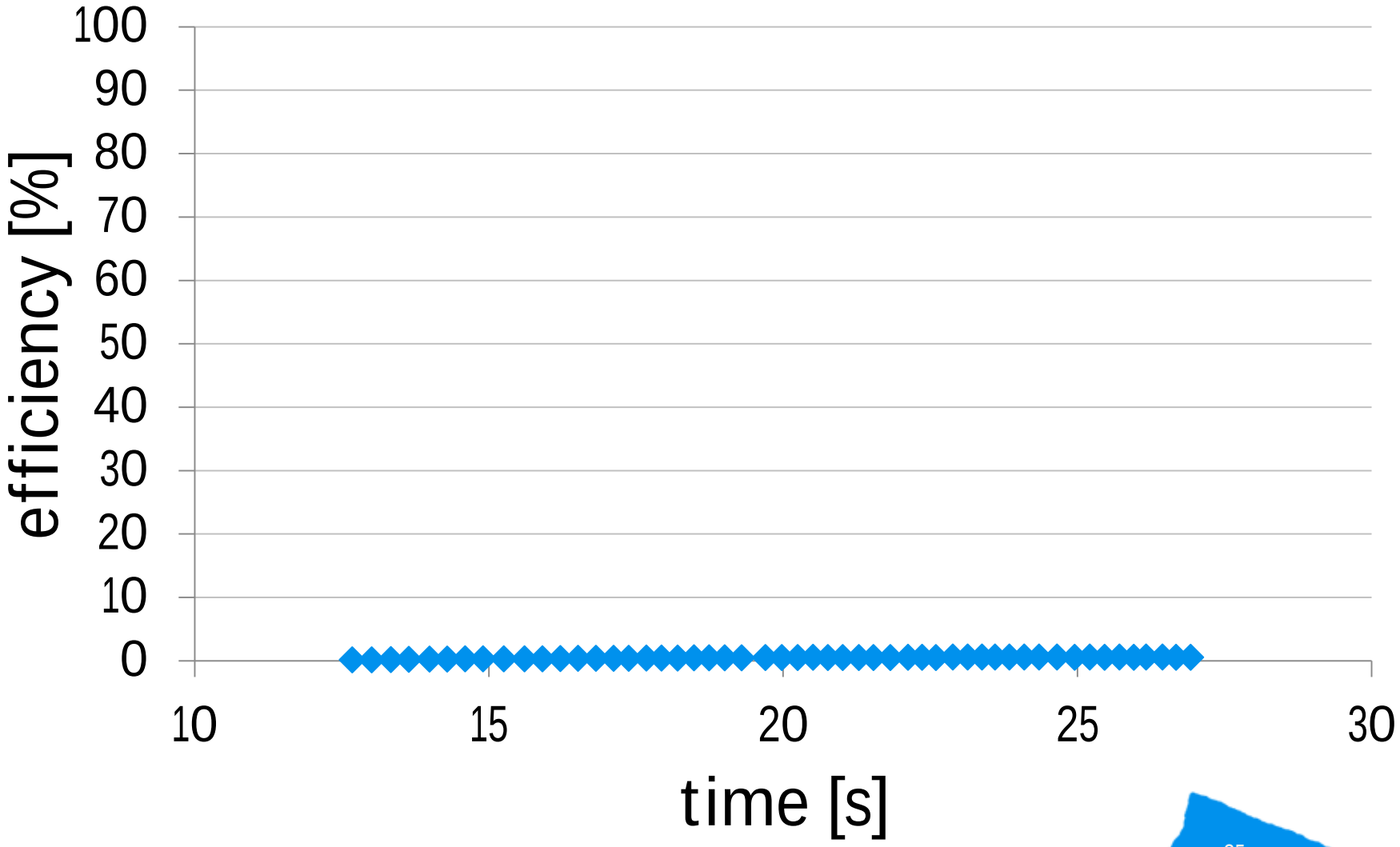
input power

$\frac{\Delta \text{ rotational energy}}{\Delta \text{ time}}$

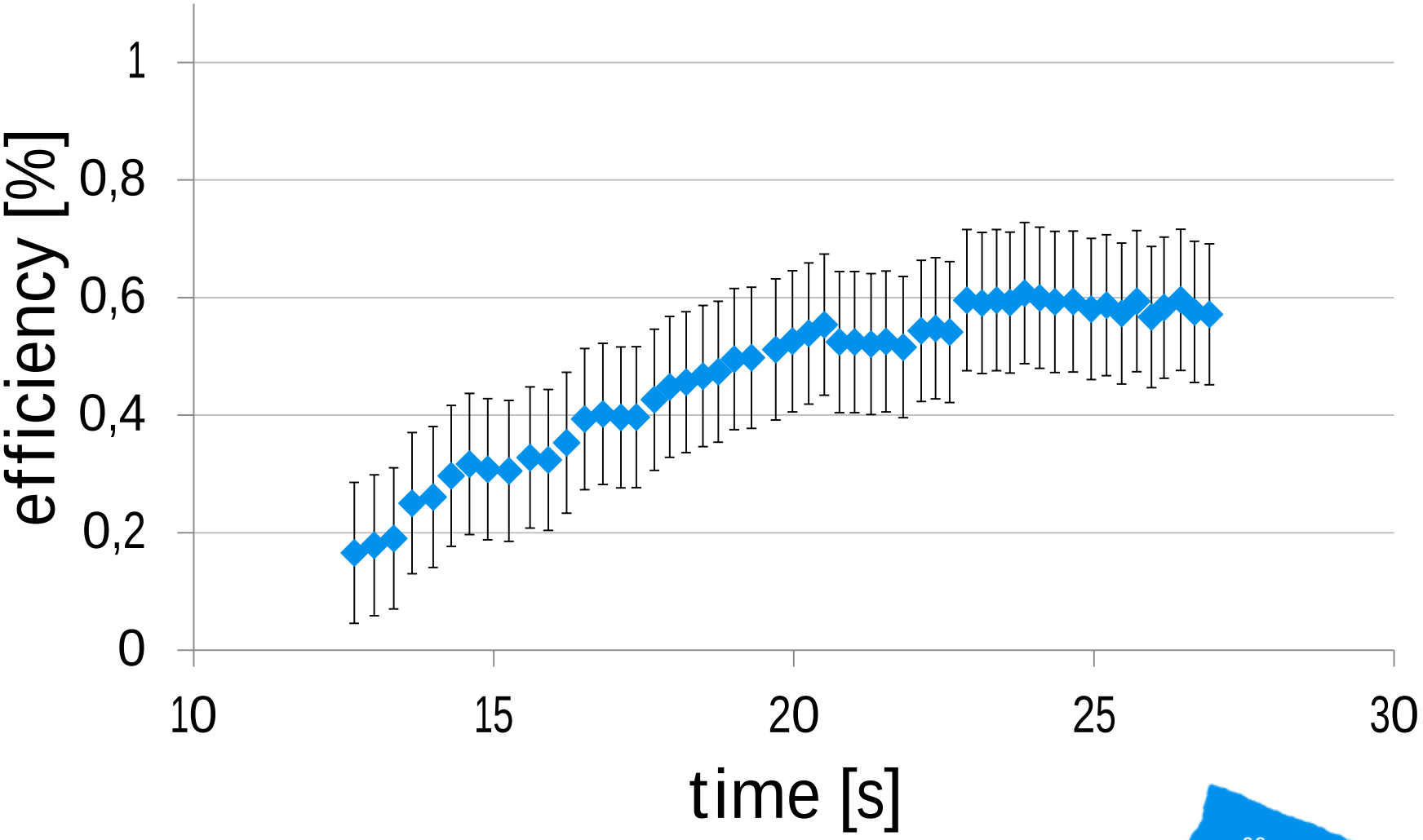
$\frac{\Delta \text{ work of electric current}}{\Delta \text{ time}}$

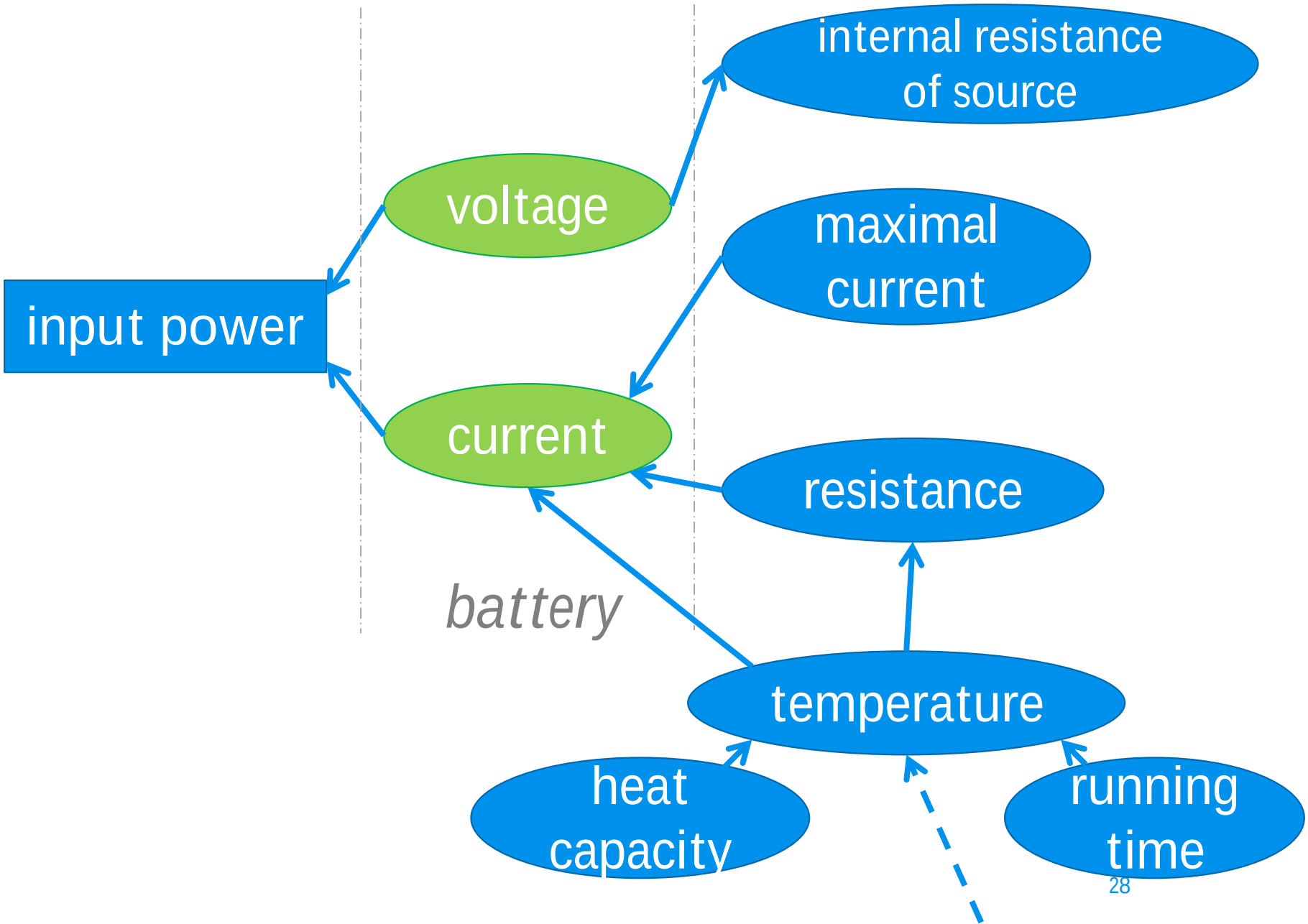


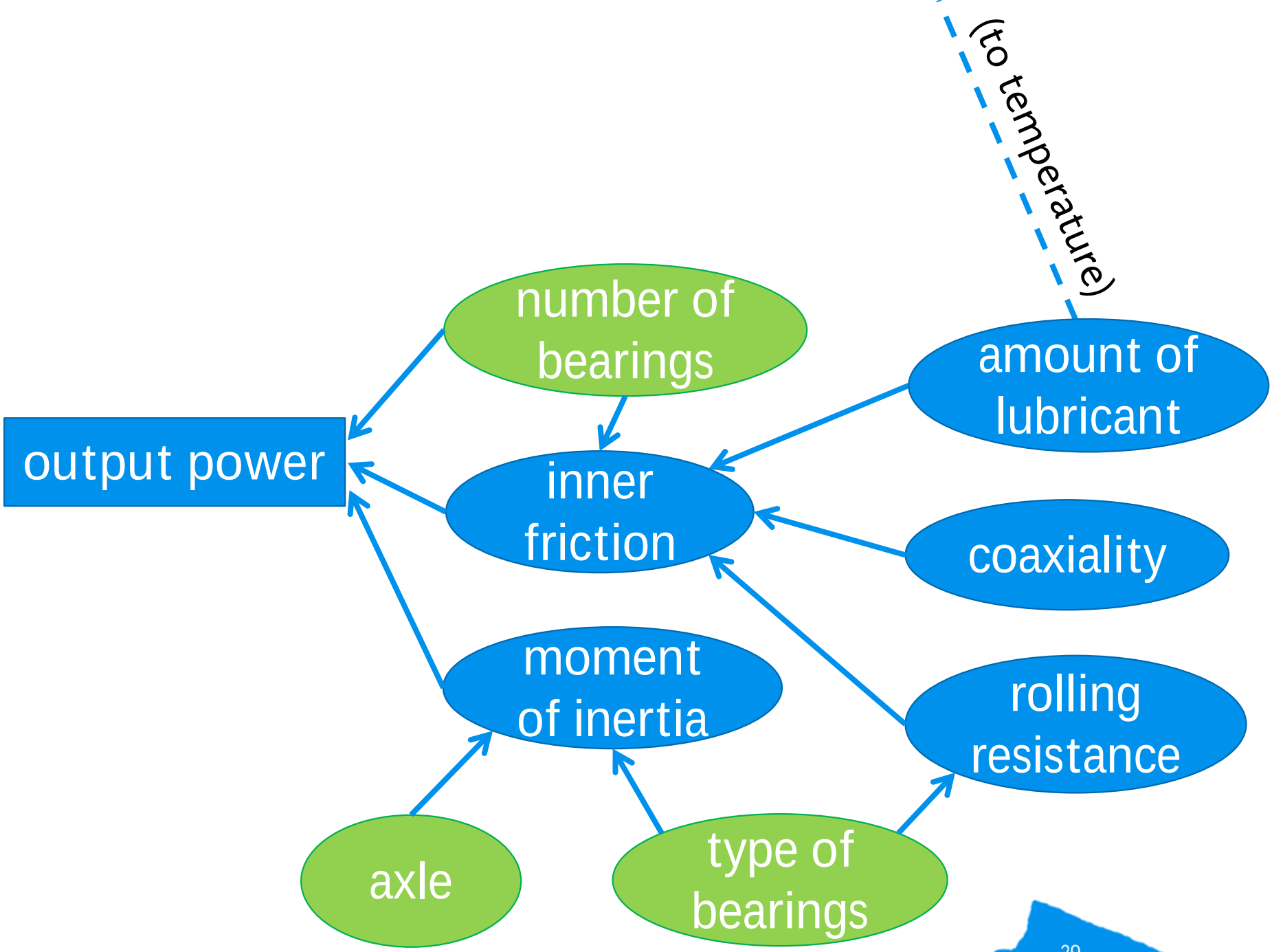
Efficiency Measurement



Efficiency Measurement



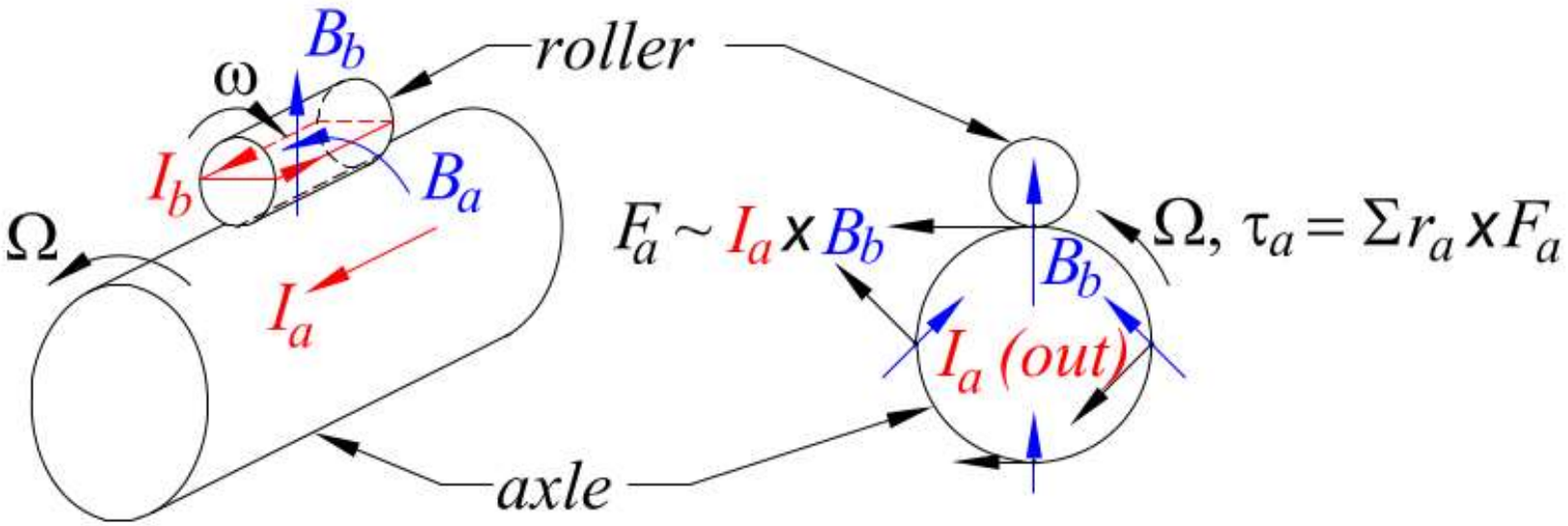

internal resistance of source
voltage
maximal current
input power
current
resistance
battery
temperature
heat capacity
running time


(to temperature)
number of bearings
amount of lubricant
output power
inner friction
coaxiality
moment of inertia
rolling resistance
axle
type of bearings

EXISTING THEORIES

Let us go a bit further...

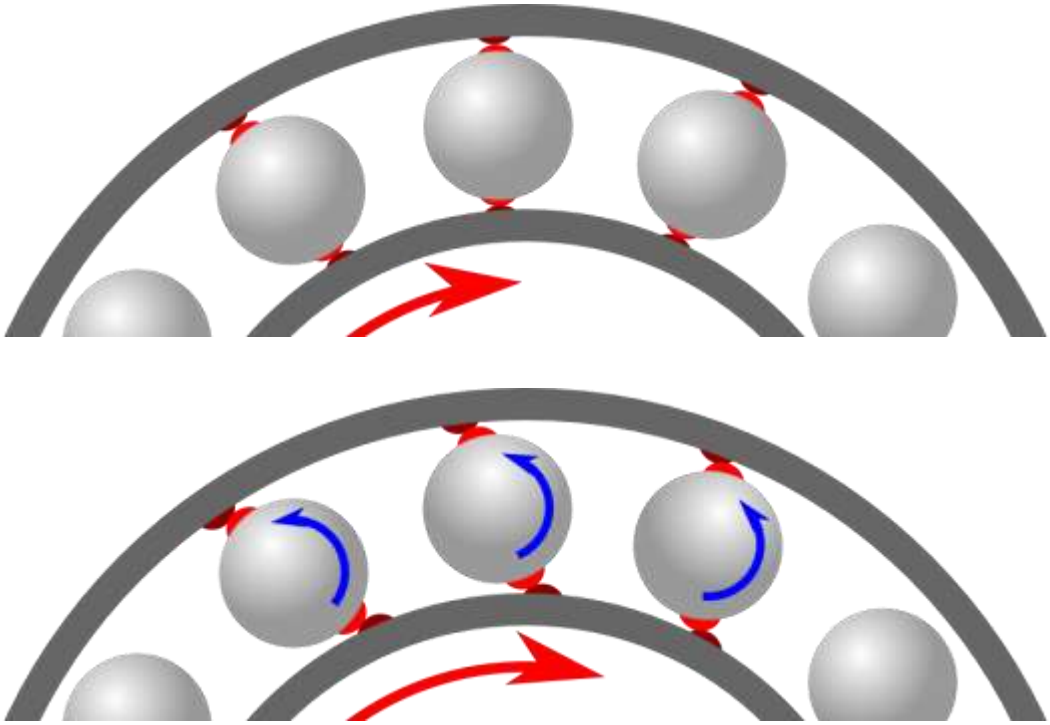
#1: Magnetic Theory



explanation of rotation: eddy currents in rollers/axle (several variations)

Kirk T. McDonald. Ball-Bearing Motor, Joseph Henry Laboratories, Princeton University, Princeton

#2: Thermal Theory

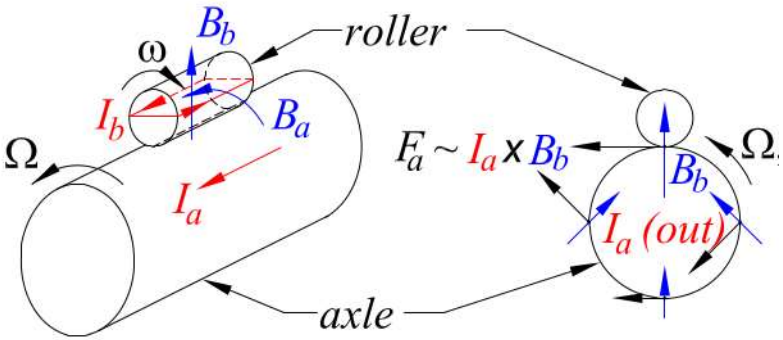


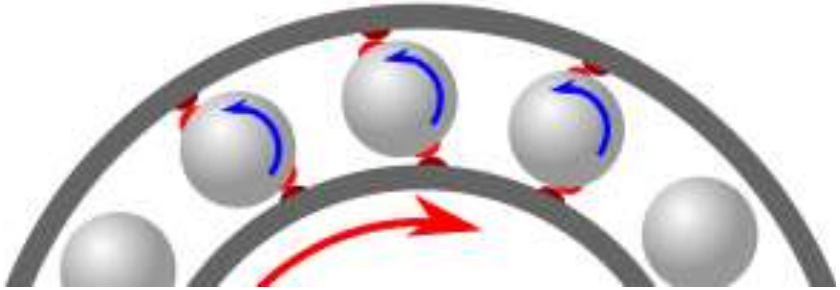
explanation of rotation: local deformations of surface caused by heating due to extreme current density

#2: Thermal Theory

Which one is valid in our case?

Experiment #1:
Cylindrical Bearings

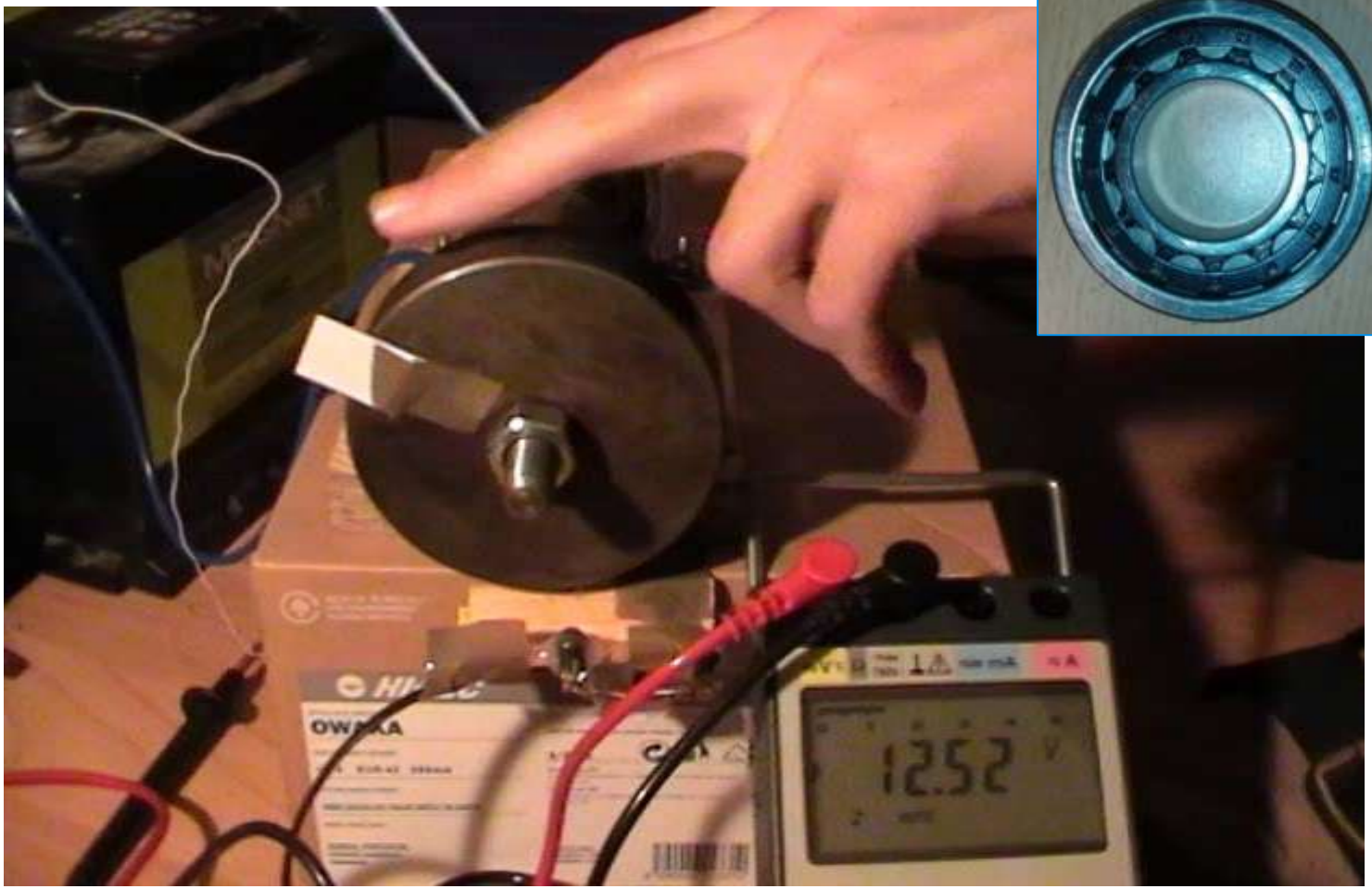




should be qualitatively the same

could be different (different shape → different deformation)

Experiment #1:
Cylindrical Bearings



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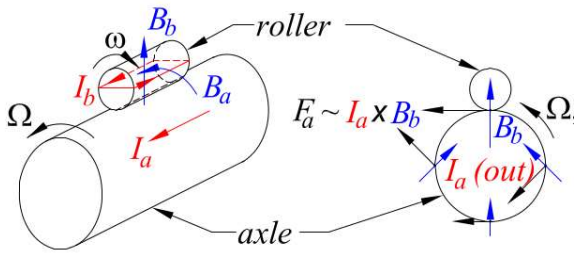
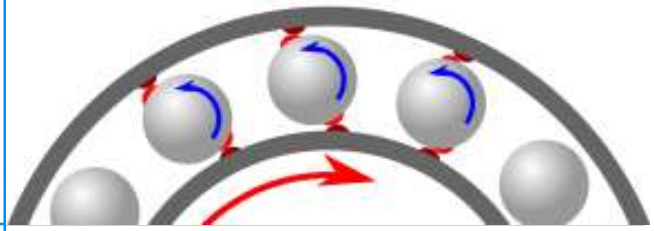
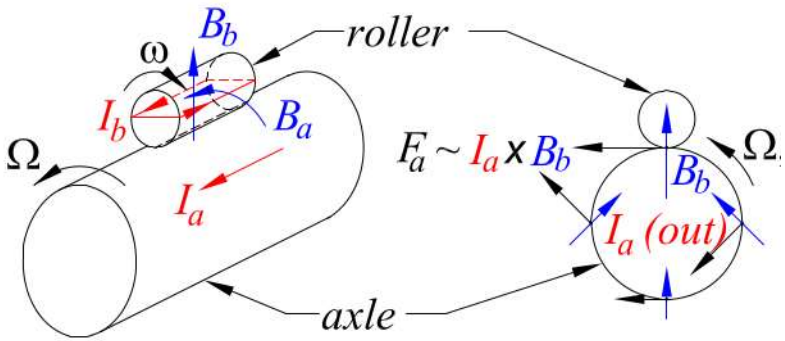
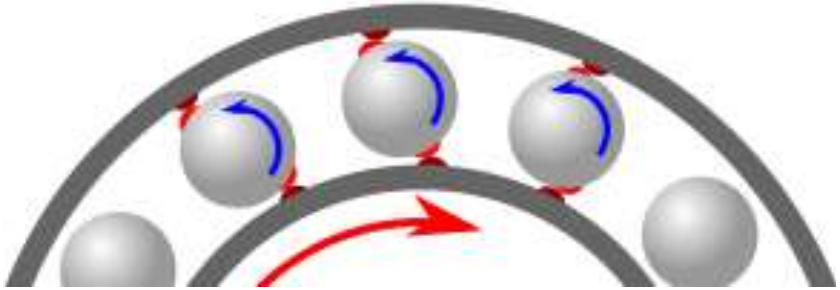
experiments:		
#1: cylindrical bearings	~~≈ the same~~	different

Experiment #2:
Strong External Magnetic Field (> 1T)

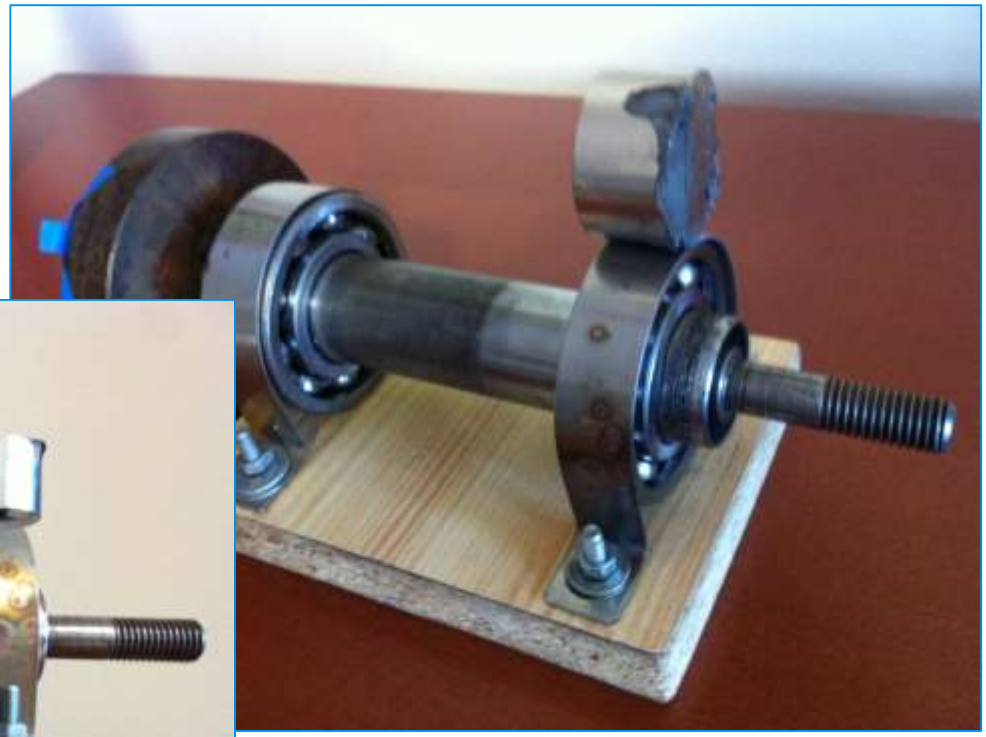




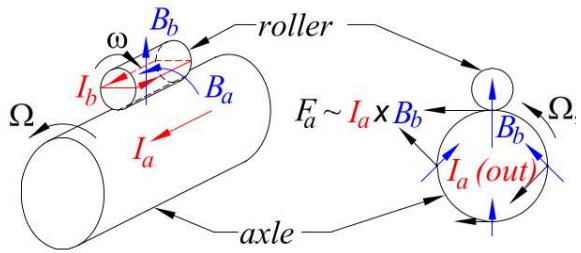
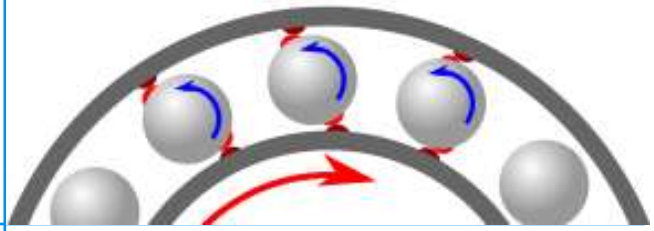
could be different

should be the same

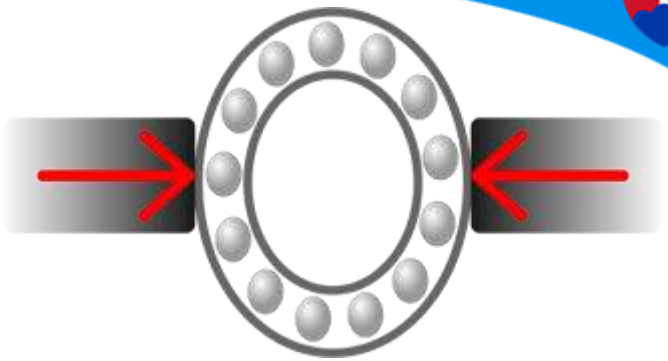
Experiment #2:
Strong External Magnetic Field (> 1T)

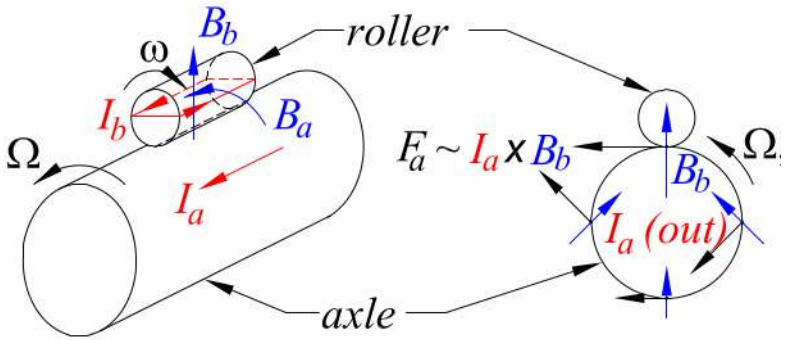


Which one is valid in our case?

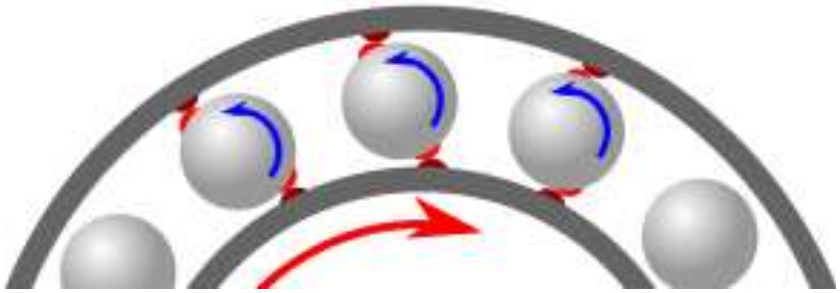
experiments:		
#1: cylindrical bearings	~~≈ the same~~	different
#2: external magnetic field	~~possibly different~~	the same

Experiment #3:
Deforming the Bearing





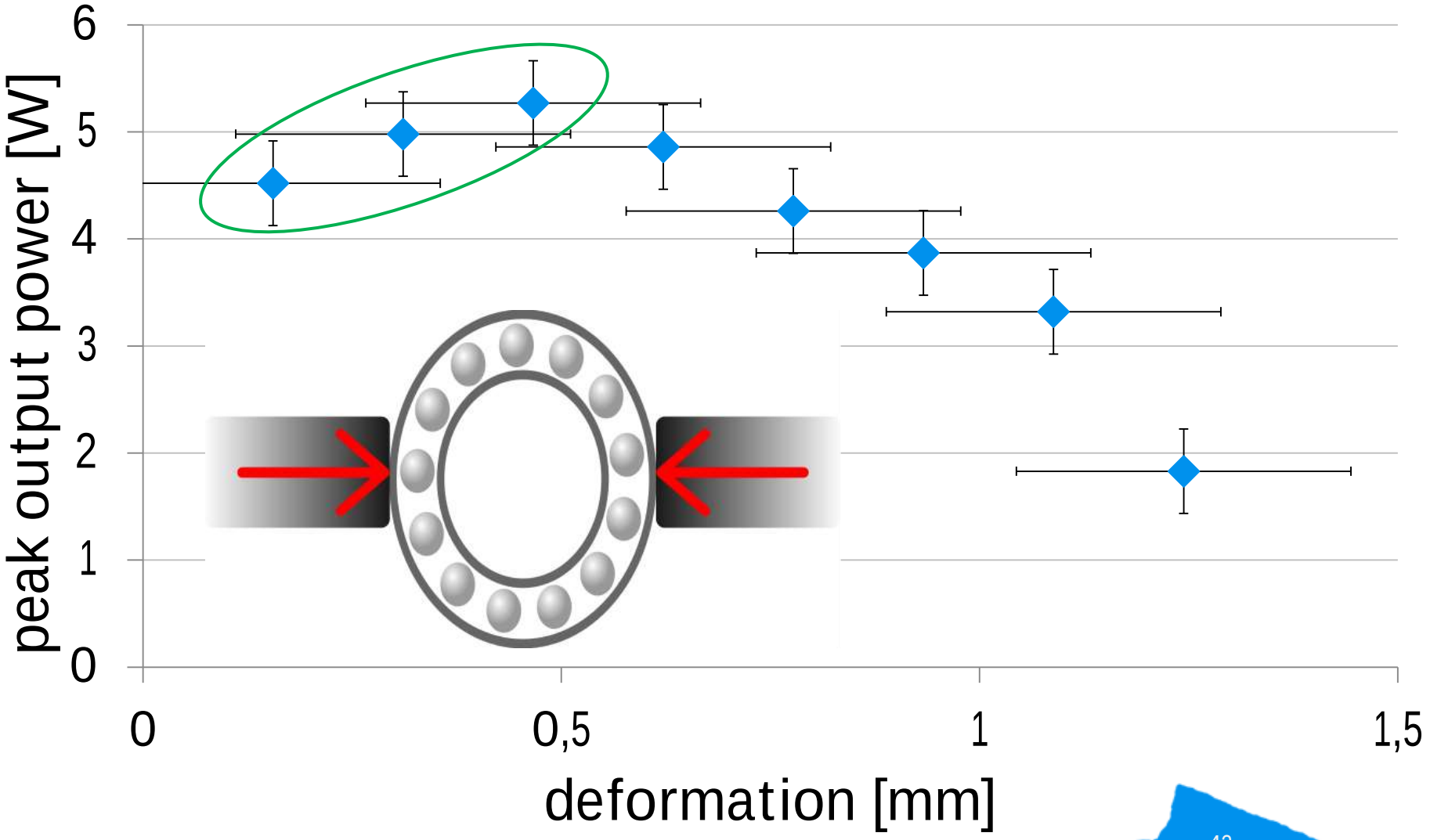
power decrease
(greater friction)



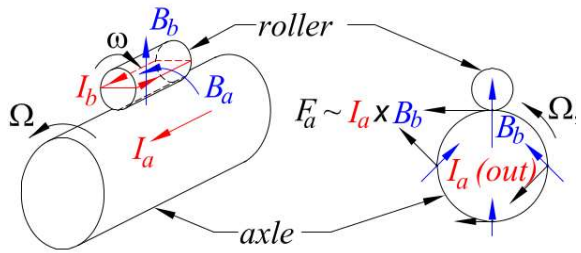
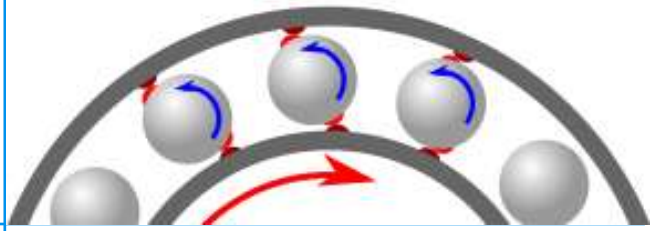
power might increase
(greater normal forces)

Experiment #3:

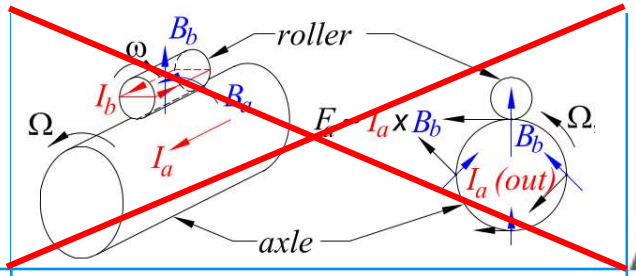
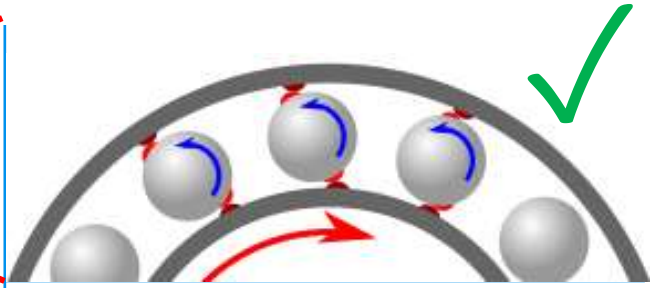
Deforming the Bearing



Which one is valid in our case?

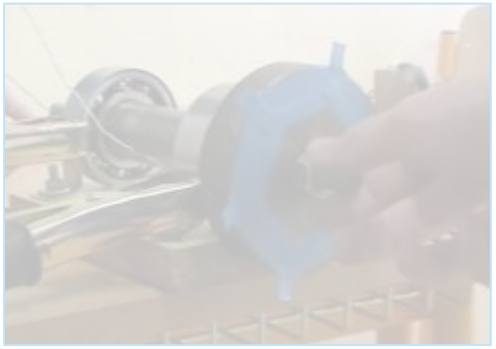
experiments:		
#1: cylindrical bearings	~~≈ the same~~	different
#2: external magnetic field	~~possibly different~~	the same
#3: deforming the bearing	~~power decrease~~	power increase

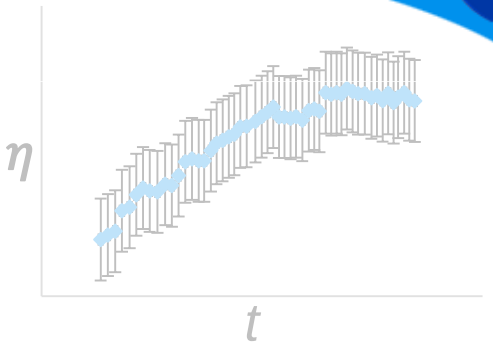
Which one is valid in our case?

experiments:		
#1: cylindrical bearings	~~≈ the same~~	different
#2: external magnetic field	~~possibly different~~	the same
#3: deforming the bearing	~~power decrease~~	power increase

Thank you for your attention!

ILLUSTRATED CONSTRUCTION & BUILT APPARATUS

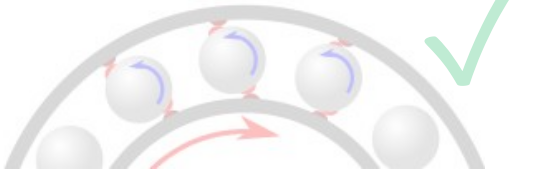


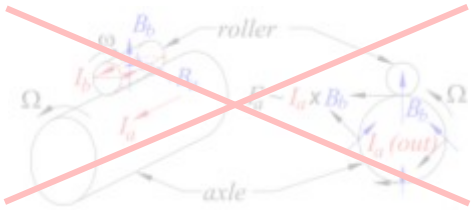


MEASURED EFFICIENCY

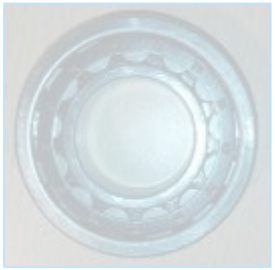
DETERMINED RELEVANT PARAMETERS

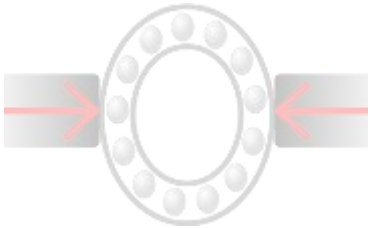
EXPLORED EXISTING THEORIES (THERMAL, MAGNETIC)





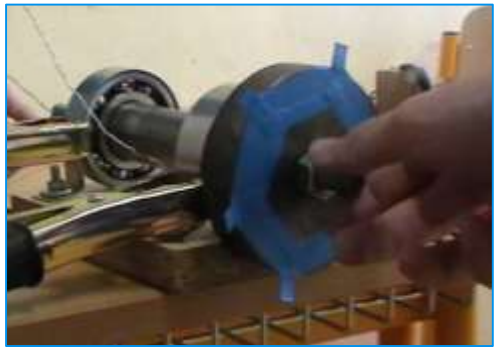
+ SHOWED VALIDITY OF THERMAL FOR OUR CASE

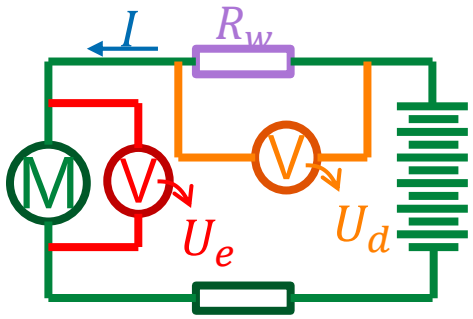


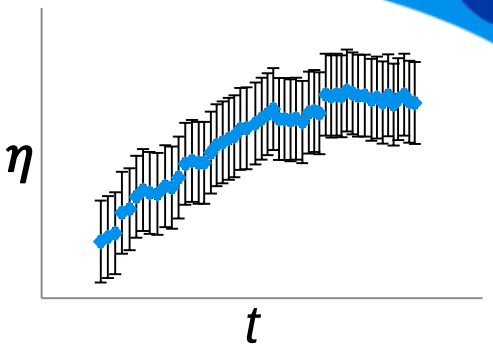


Thank you for your attention!

ILLUSTRATED CONSTRUCTION & BUILT APPARATUS

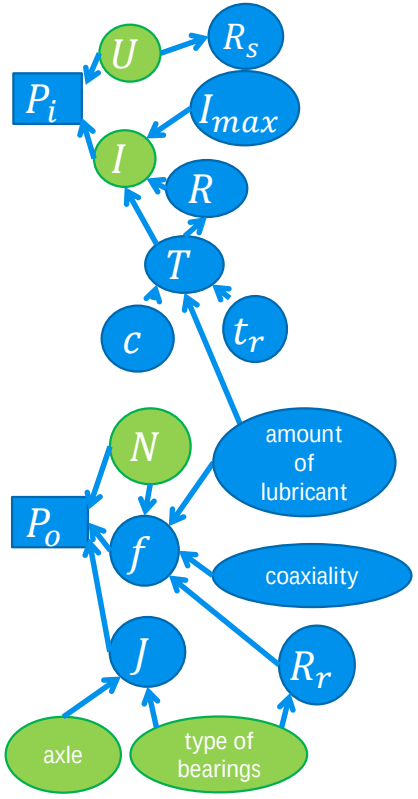




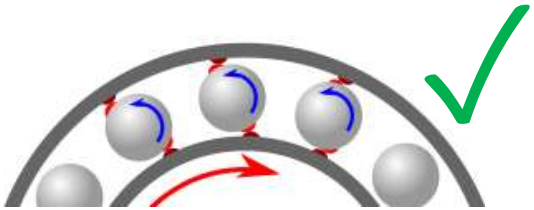


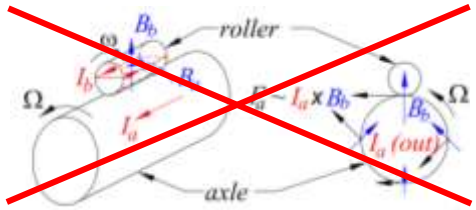
MEASURED EFFICIENCY

DETERMINED RELEVANT PARAMETERS

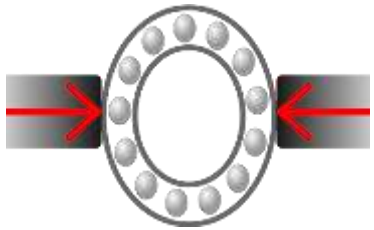


EXPLORED EXISTING THEORIES (THERMAL, MAGNETIC)





+ SHOWED VALIDITY OF THERMAL FOR OUR CASE



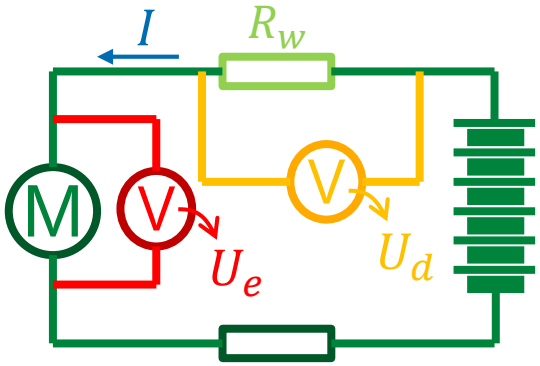
Appendices

Measuring Current

- current very large (> 100 A) – cannot measure directly

→ solution: voltage drop on wire → $I = \frac{U_d}{R_W}$

1.25 V drop on thick copper wire!



but: wire resistance R unknown

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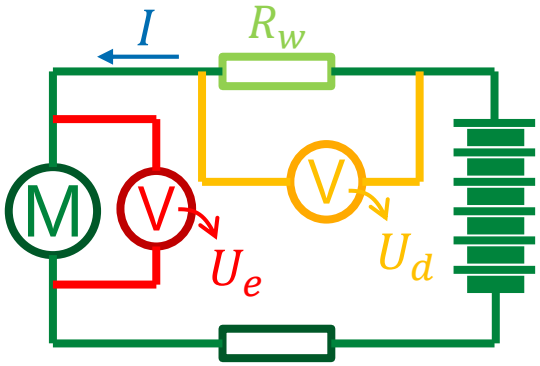

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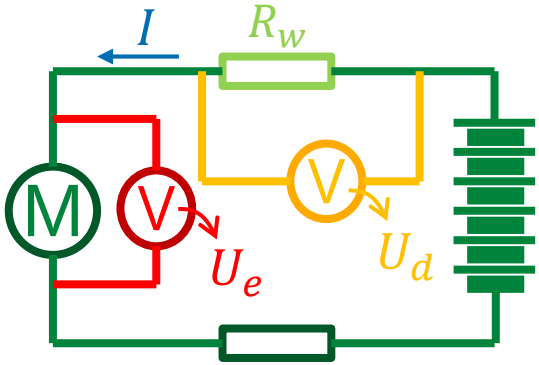
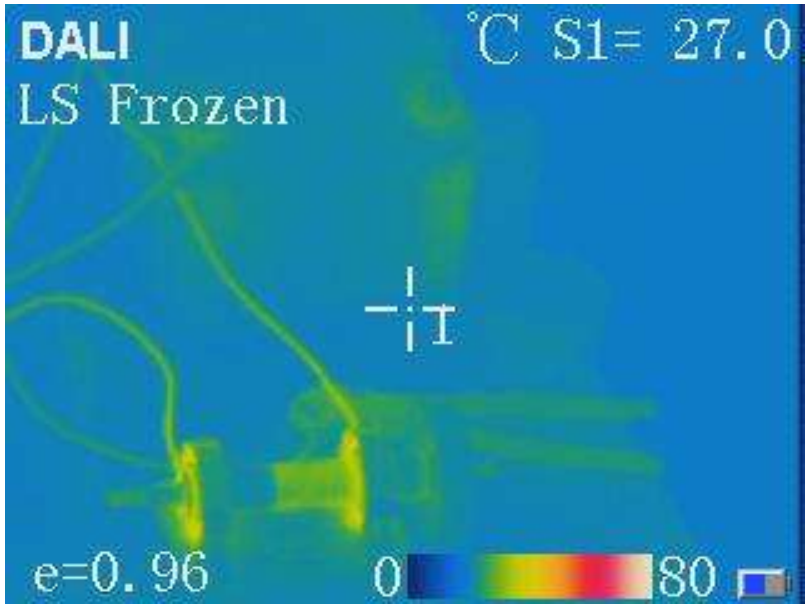


→ finding wire resistance R:

1. discharge the battery so it sources measurable current (≈100A)
2. measure current & voltage drop simultaneously
3. calculate the resistance $R_w = \frac{U_d}{I} =$ **$0.0041\ \Omega$**

Importance of temperature change



$$\Delta T = \frac{\int UI\, dt}{mc}$$

$$\Delta T \approx 80°\mathrm{C}$$

but it is also cooled by air

from $R_w = R_0(1 + \alpha\Delta T)$:

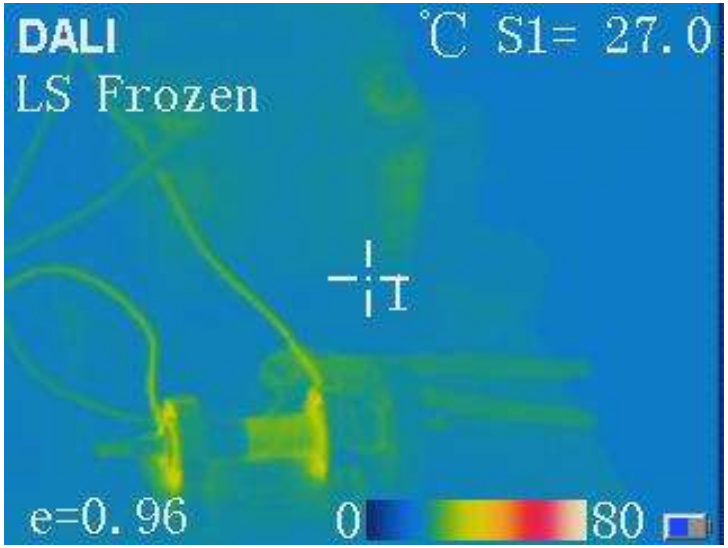
$\alpha_{Cu} = 4 \cdot 10^{-3}\mathrm{K}^{-1} \Rightarrow$ 20% resistance change

Determining Wire Temperature

$$R_w = R_0(1 + \alpha\Delta T)$$

$$Q = mc\Delta T = \int P_w(t)\mathrm{d}t$$

$$P_w = \frac{U_d^2}{R}$$



$$R_w(t) = R_0\left(1 + \alpha\frac{{U_d}^2\Delta t}{R_{prev}mc}\right)$$

Our Bearings

Type:
6206

d	D	B
30	62	16
mm	mm	mm

Type:
6303

d	D	B
17	47	14
mm	mm	mm

Type:
NJ206EC

d	D	B
30	62	16
mm	mm	mm

Calculation of moment of inertia

- Inner race
  - 1 - Main inner race
  - 2 - Bearing holder
  - 3 - Flyback wheel holder
- 4 - Outer race
- 5 - Flyback wheel

$$J = 3.2 \cdot 10^{-2}\ \mathrm{kg \cdot m^2}$$

$$J_{1,2,3} = \frac{1}{2} m r^2$$

$$J_{4,5} = \frac{1}{2} m (r_2^2 - r_1^2)$$

Small ball bearings