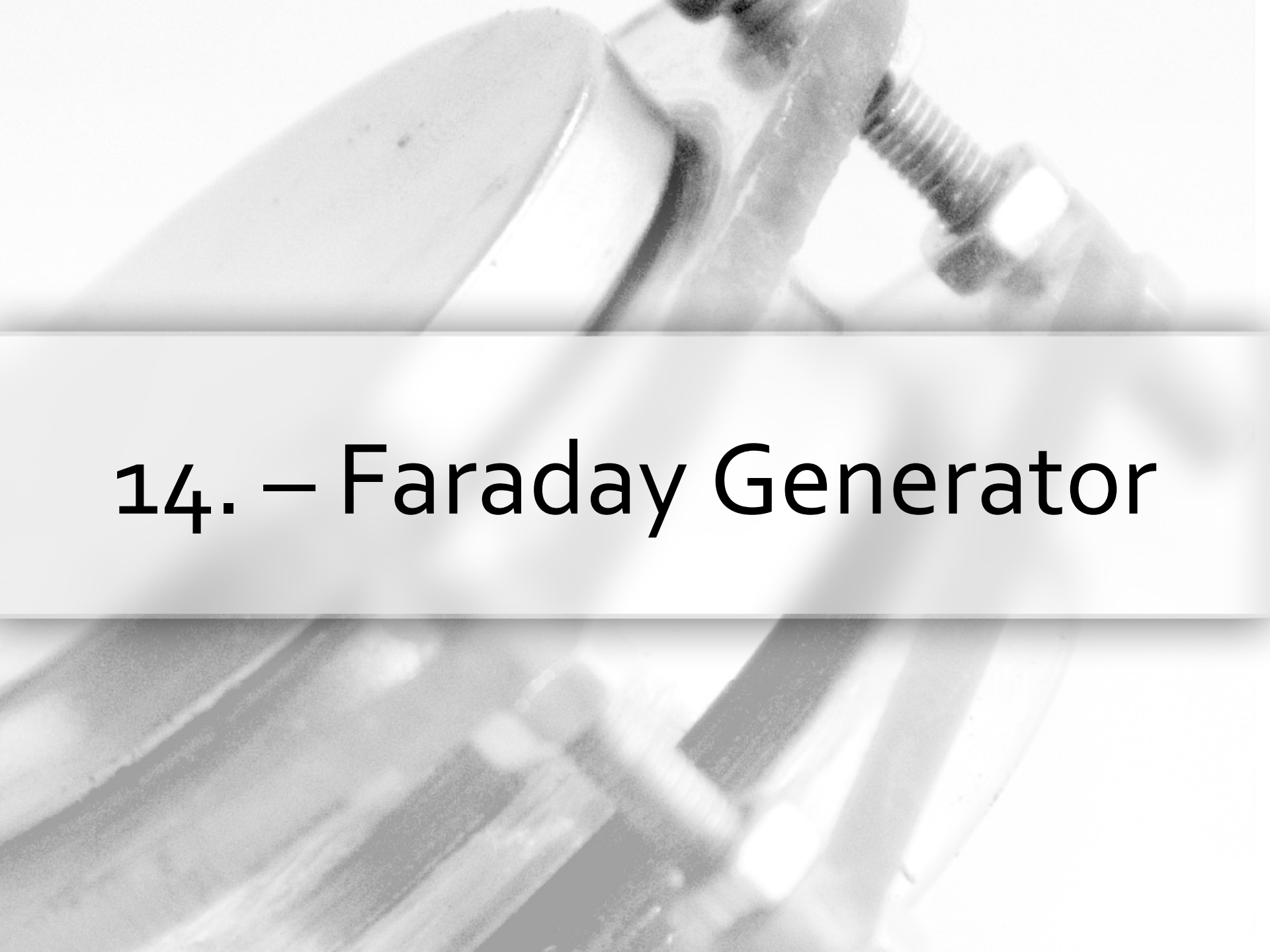


14. – Faraday Generator

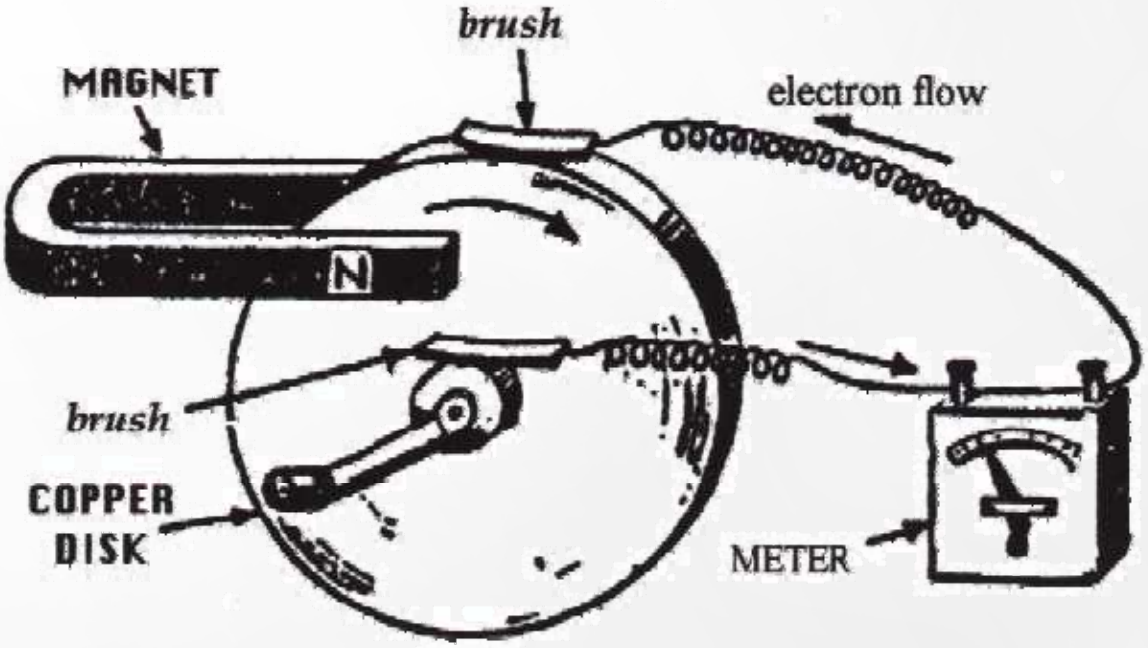
Problem

Construct a homopolar electric generator. Investigate the electrical properties of the device and find its efficiency.

Contents

- Interpretation
- Basic explanation
- Theory
  - Rotating magnets
  - Stationary magnets
- Construction
  - Rotating magnets
  - Stationary magnets
- Measurements description
- Results
- Conclusion

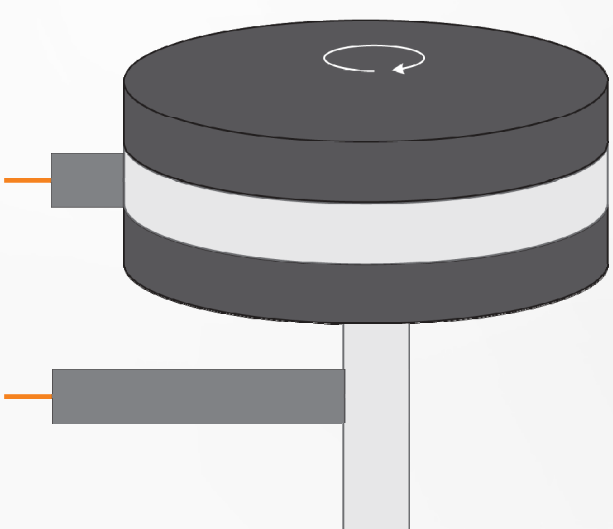
Faraday's experiment

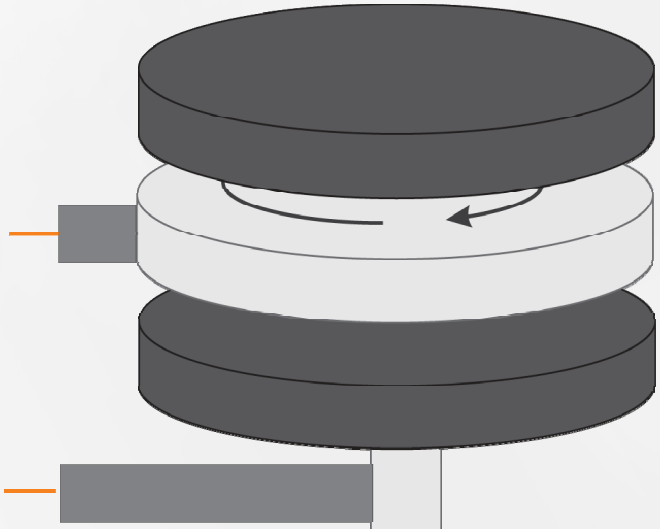


Interpretation

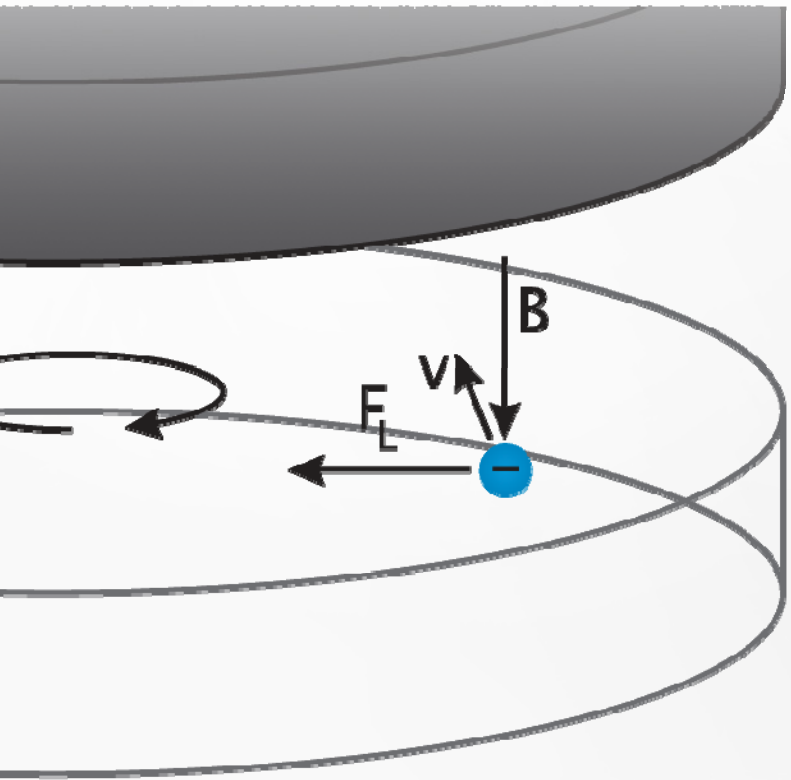
- In later experiments with cyllindrical magnets the following results were achieved:

Magnets	Disk	Voltage induced
Stationary	Rotating	Yes
Rotating	Rotating	Yes
Rotating	Stationary	No





Basic explanation



1. Stationary magnets
   - Lorentz force acting on electrons rotating inside the disk
2. Magnets rotating with the disk
   - Velocity of the disk relative to the magnets = 0

→ Explanation somewhat questionable

→ Understanding the nature of magnetism and Lorentz force

Theory
Stationary magnets

- Lorentz force

$$\vec{F}_L = q\left(\vec{v}\times\vec{B}\right) \quad \Rightarrow \quad \vec{E}_i = \frac{\vec{F}_L}{q} = \vec{v}\times\vec{B}$$

$$U_i = \int_r^R \vec{E}_i \cdot d\vec{r} = \left|\vec{B}\right|\omega\frac{R^2 - r^2}{2}$$

B – magnetic induction

v – velocity

E_i – intensity of electric field

R – outer radius

r – inner radius

ω – angular velocity

Theory
Moving magnets

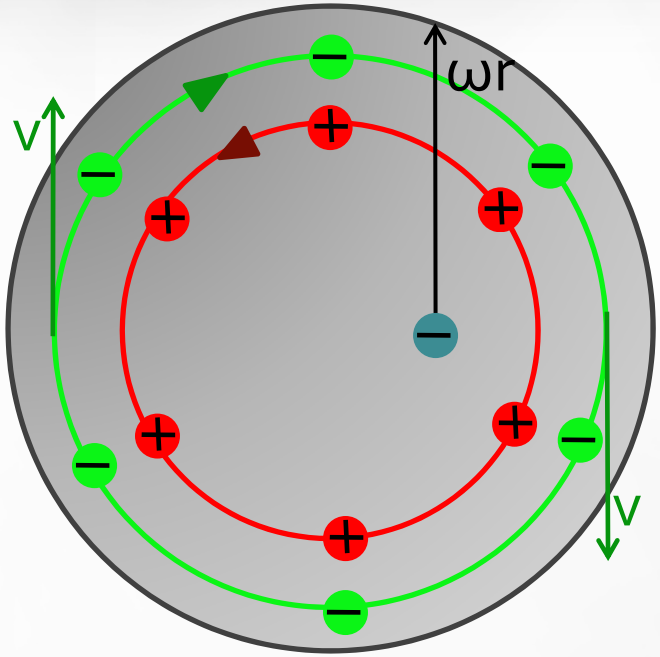
- Magnetic field is a consequence of moving charged particles

$\rightarrow$Electric and magnetic fields in different frames of refference connected by transformations

- Magnets modeled by an inductor producing a homogenous magnetic field of magnetic induction B

Theory

Moving magnets



- Currents of charged particles
- Velocity of negative particles in the reference frame of the moving electron larger on the right side then on the left side

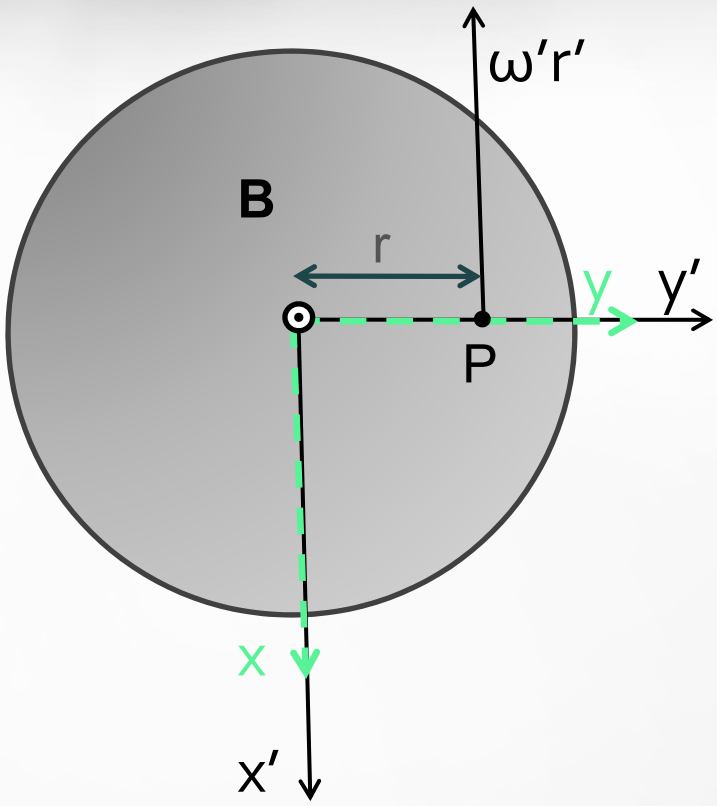
→ larger length contraction

→ larger density of positive particles

- Analogous observation → larger density of positive particles on the left side

- In the frame reference of the electron we obtain a Coulomb force acting on the left

Theory
Moving magnets



S – frame of refference of point P

S′ – laboratory frame of refference

ω' – angular velocity of rotating system

r′=r – distance of P from the center

ω′r′ – linear velocity of point P

B – magnetic field of the rotating inductor

$$\gamma = \frac{1}{\sqrt{1-\frac{(\omega' r')^2}{c^2}}}$$

$$\beta = \frac{\omega' r'}{c}$$

Theory

Moving magnets

Fields acting in point P

S		Transformations [1] →	S′
$E_x = 0$	$B_x = 0$	$E_x' = E_x$	$E_x' = 0$
$E_y = 0$	$B_y = 0$	$E_y' = \gamma(E_y + \beta c B_z)$	$E_y' = \gamma\beta c B$
$E_z = 0$	$B_z = B$	$E_z' = \gamma(E_z - \beta c B_y)$	$E_z' = 0$

$$E_y' = \frac{\omega' r'}{\sqrt{1 - \frac{(\omega' r')^2}{c^2}}} B$$

$$U_y' = \int_r^R E_y' \, dr = B\omega \frac{R^2 - r^2}{2}$$

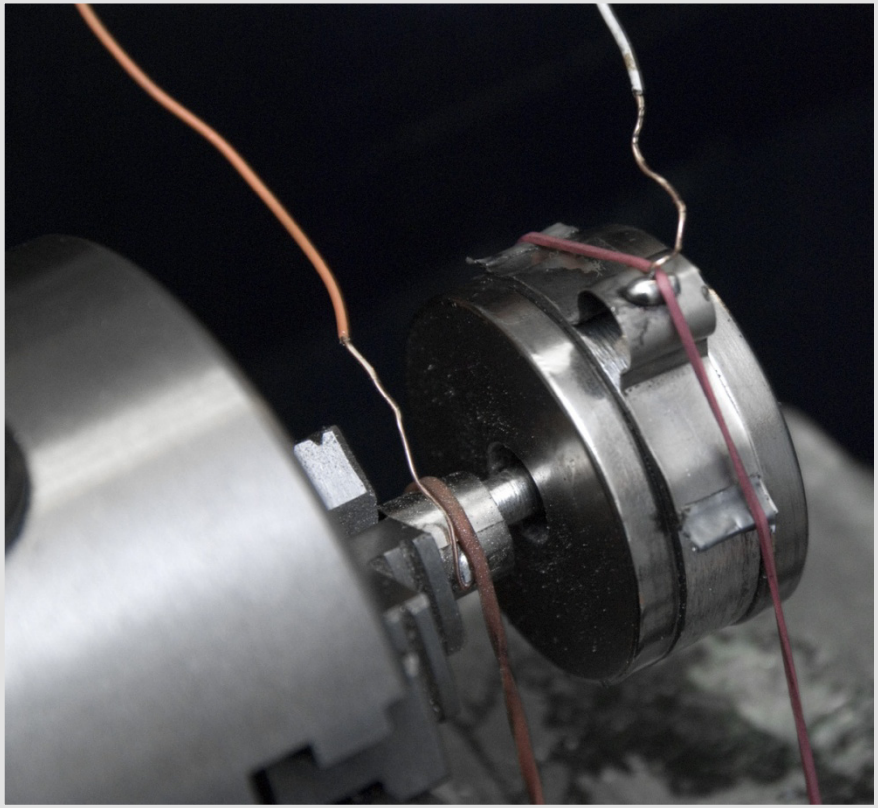
[1] Edward M. Purcell: Elecromagnetism, McGraw-Hill

Construction

- 2 variants – stationary magnets and magnets rotating with the disk
- The generator is powered by a machine lathe
  - Large range of velocities
  - Simple assembly
- In both variations the same disk and axle are used
- Diameter of disk - 40 mm, axle - 5 mm

Construction

- The disk and the axle are turned from one piece of aluminium
- The brushes are made from curved aluminium to the same curvature as the axle and the disk



Construction rotating magnets

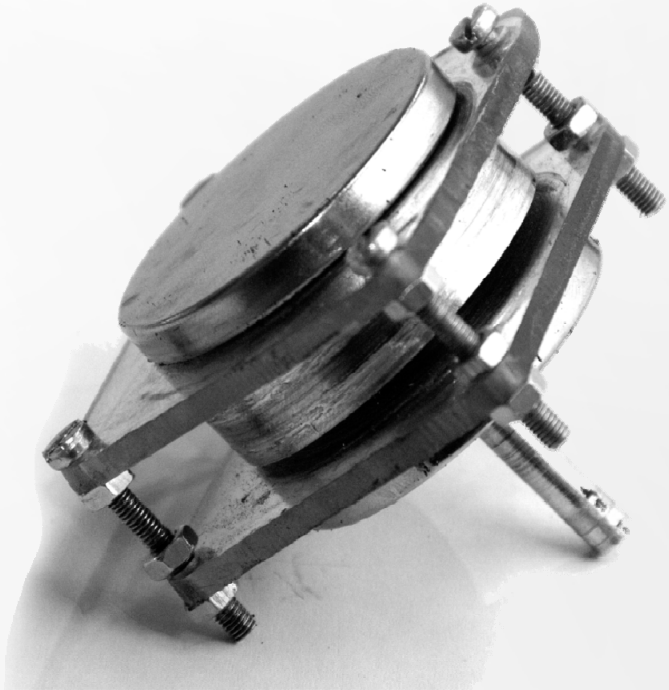
- Magnets are attached to the disk using an double sided sealing tape and are also connected by their own magnetic force



Construction

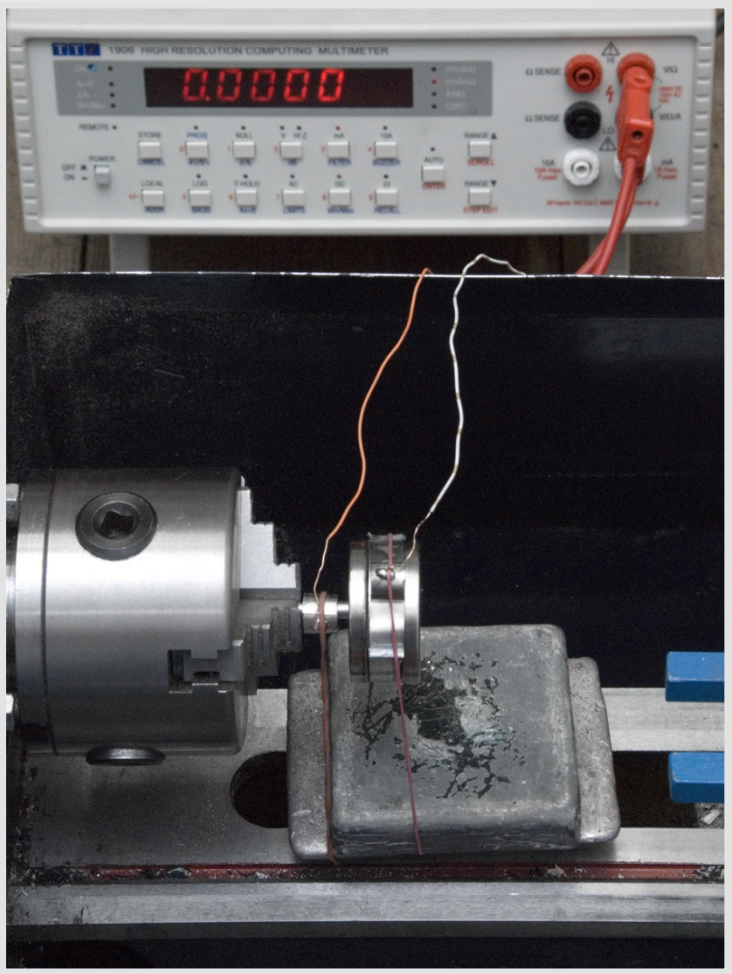
Stationary magnets

- Magnets attached with double sided sealing tape to polycarbonate housing which separates the disk and magnets. The housing is not in contact with the disk



Measurements

- Open load voltage and the short circut current are measured using a digital multimeter

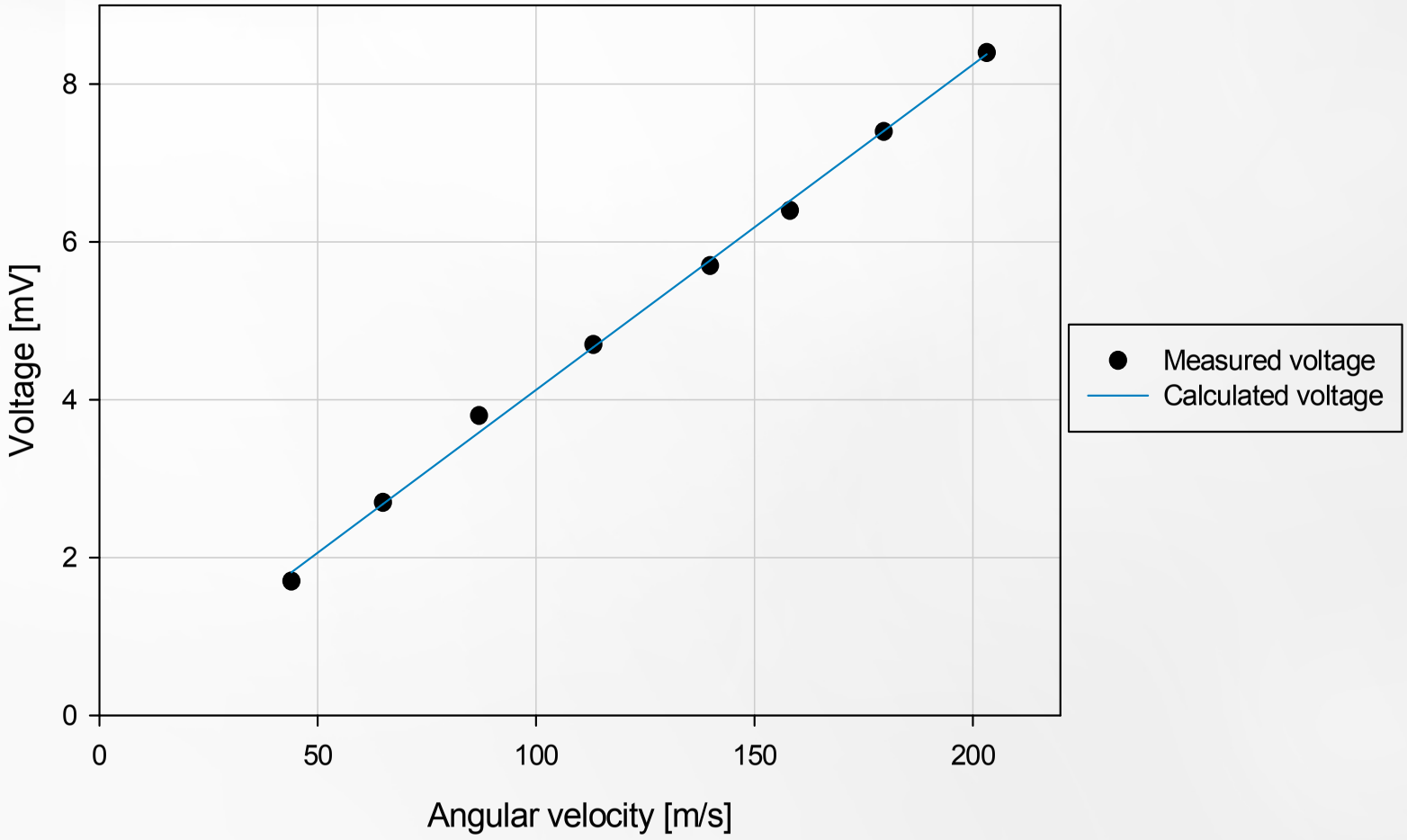


Measurements

- Rotation frequency – stroboscope
- Magnetic induction – hall probe
  - 0.22 T for the distance of the rotationg magnets
  - 0.15 T for the distance of the stationary magnets
- Moment of torque – dinamometer
  - 0.0032N for each variant (same system of brushes)

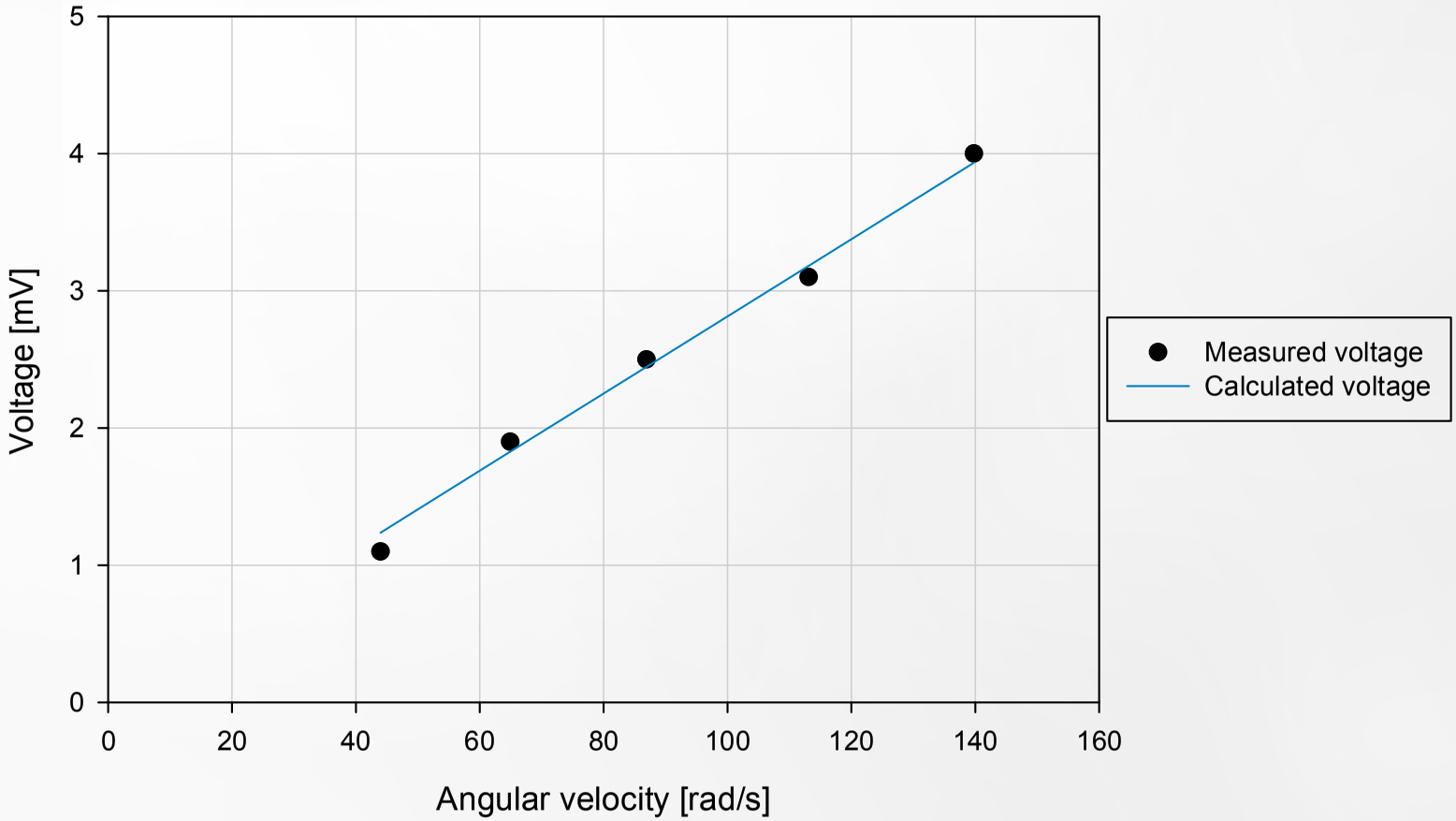
Results

Comparisson of theroetical and experimental induced voltage for rotating magnets



Results

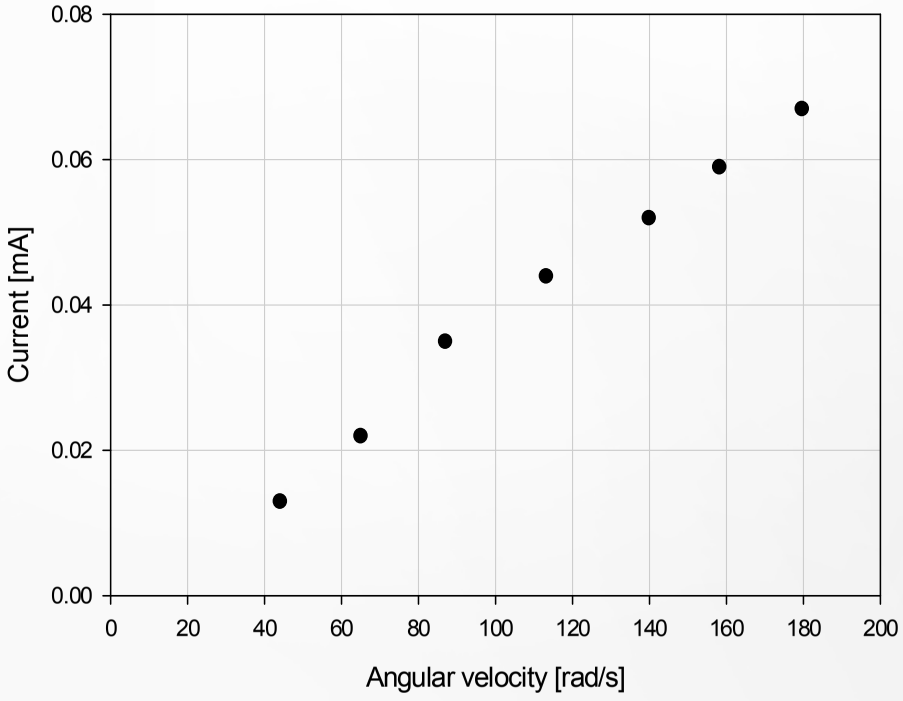
Comparisson of theroetical and experimental induced voltage for stationary magnets



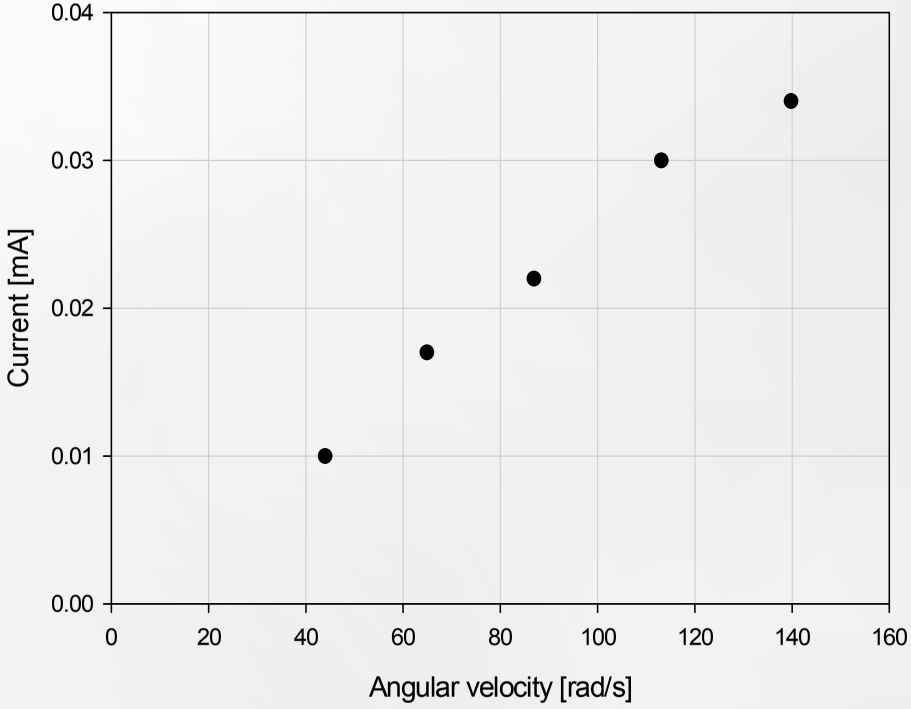
Results

- Short circut voltage

Rotating magnets



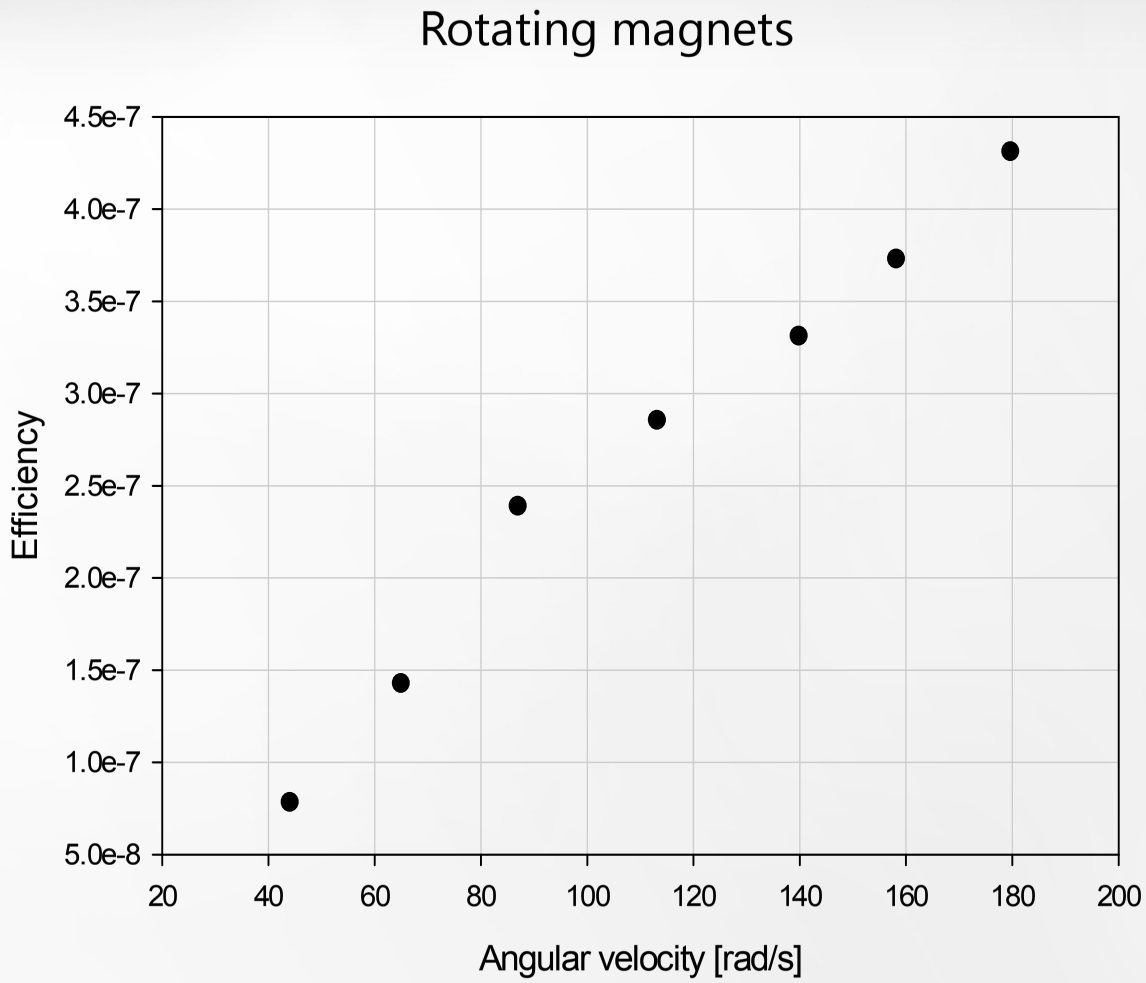
Stationary magnets



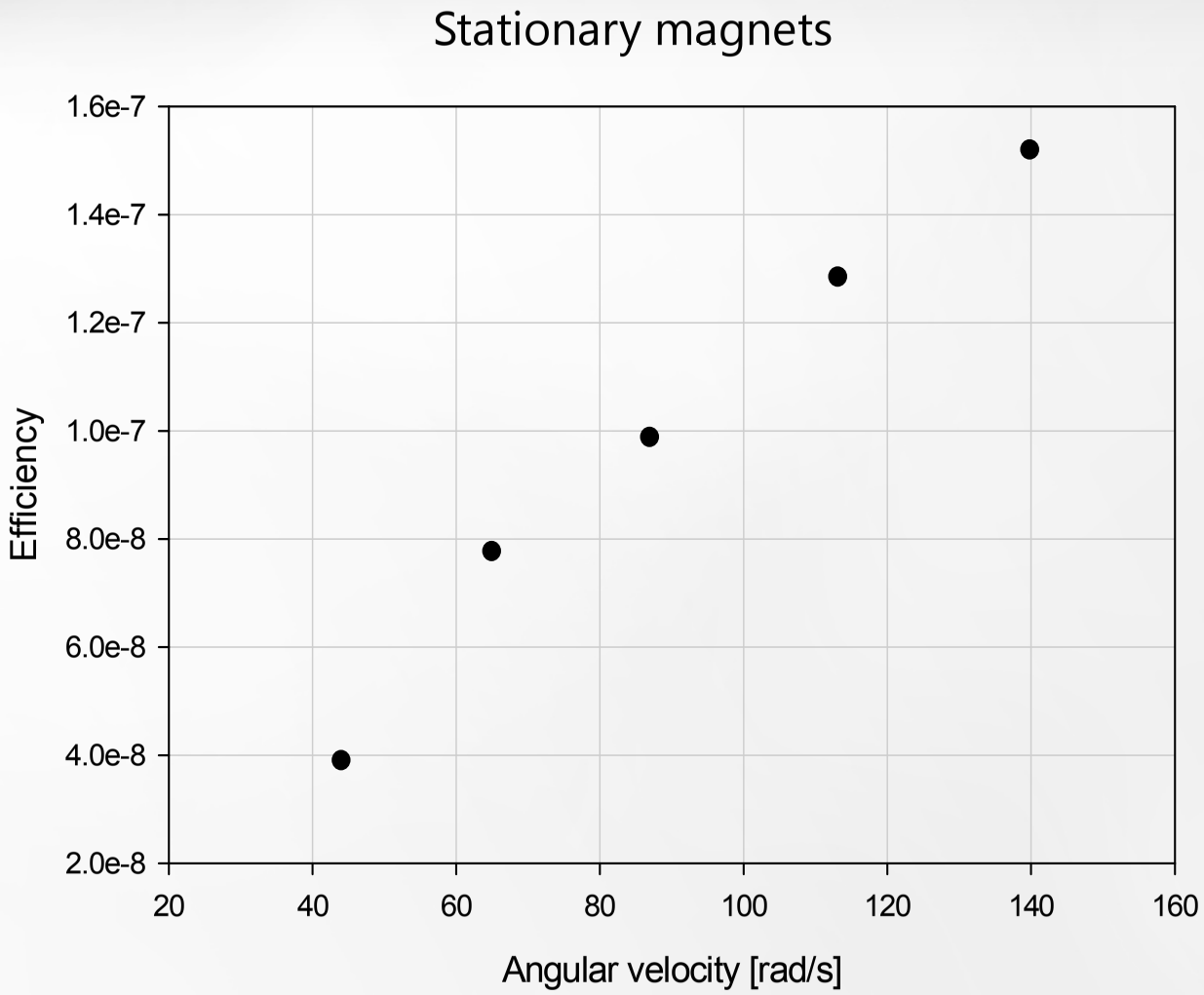
Efficiency

- Input mechanical power
  - Calculated from angular momentum of friction and angular velocity
  - $P = \omega M$
- Output power
  - Calculated from voltage on load and short circut current
  - Maximal output power: $P = UI/2$
- Efficiency – ratio of output and input power $\eta = \frac{P_t}{P_u}$

Efficiency


Rotating magnets
Efficiency
4.5e-7
4.0e-7
3.5e-7
3.0e-7
2.5e-7
2.0e-7
1.5e-7
1.0e-7
5.0e-8
20
40
60
80
100
120
140
160
180
200
Angular velocity [rad/s]

Efficiency


Stationary magnets
1.6e-7
1.4e-7
1.2e-7
1.0e-7
8.0e-8
6.0e-8
4.0e-8
2.0e-8
Efficiency
20
40
60
80
100
120
140
160
Angular velocity [rad/s]

Summary and conclusion

- Two variations of the homopolar generator were constructed
- In-depth explanation comparring two interpretations (magnetism and special relativity)
- The difference between the induced voltages between the stationary and rotating construction arises only because of different distances between the magnets

Summary and conclusion

- Measured and calculated open load voltage are in very good agreement
- The resistance in the stationary system very small, but when the disk is rotating the resistance increases dramatically because of the irregularities on the surface → very small efficiency
- The construction leaves a lot of space for improvement which would increase the effeciency by large amounts.

References

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   Jorge Guala-Valverde, Pedro Mazzoni, and Ricardo Achilles
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Thank you for your attention!

Theory

Moving magnets

Fields acting in point P

S	Transformations [1] →	S′
$E_x = 0$	$E_x' = E_x$	$E_x' = 0$
$E_y = 0$	$E_y' = \gamma(E_y + \beta c B_z)$	$E_y' = \gamma\beta c B_z$
$E_z = 0$	$E_z' = \gamma(E_z - \beta c B_y)$	$E_z' = 0$
$B_x = 0$	$B_x' = B_x$	$B_x' = 0$
$B_y = 0$	$B_y' = \gamma(B_y - \frac{\beta}{c} E_z)$	$B_y' = 0$
$B_z = B$	$B_z' = \gamma(B_z + \frac{\beta}{c} E_y)$	$B_z' = \gamma B_z$