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Electrostatic Generator for Alternative Wind Turbine

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The thesis concerns the possibilities for a hovering wind turbine to produce electricity with electrostatic generator in near future. The research was done for University of Applied Sciences HAN research group in Arnhem, the Netherlands.

The study focuses on developing measuring methods for electrostatic generators, the improvement of the power output, using dielectric material, and exploring Rotating-Disc High Voltage Generator. The main source of information was literature, web and Arnhem's lectures interviews.

The results of this study show that it was difficult to measure electrostatic electricity, dielectric materials improved the power output and the Rotating-Disc High Voltage Generator is not suitable wind turbine generator. This study gives a good basis for developing SkyWindTurbine project in future.

Keywords	Electrostatic, Dielectric, High voltage, Wind

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Tutkinto	insinööri (AMK)
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Insinöörityössä selvitettiin leijuvan tuulivoimaturbiinin mahdollisuuksia tuottaa sähköenergiaa tulevaisuudessa sähköstaattisella generaattorilla. Tutkimus tehtiin ammattikorkeakoulu Arnhem en Nijmegenin tutkimusryhmälle Arnhemista Alankomaissa.

Työssä tutkittiin sähköstaattisen generaattorin mittausmenetelmiä, parempaa ulostulotehoa dielektrisillä materiaaleilla ja pyörivää kiekko suurjännitegeneraattoria. Työ perustuu kirjallisuuteen, internetverkkoon ja Arnhemin lehtorien haastatteluihin.

Tehdyn tutkimuksen perusteella voitiin todeta, että sähköstaattisuutta on vaikea mitata, dielektriset materiaalit parantaa tehoulostuloa ja pyörivä kiekkosuurjännitegeneraattori ei sovellu nykyasennuksien mukaan tuulivoimaturbiinin generaattoriksi. Työstä saatiin hyviä viitteitä, miten leijuvan tuulivoimaturbiinin kehitystä voidaan jatkaa tulevaisuudessa.

Avainsanat	sähköstaattinen, dielektrinen, korkeajännite, tuuli

Contents

Abbreviations

ESG	Electrostatic generator
ESVM	Electrostatic voltmeter
HV	High voltage
HVDC	High voltage direct current
RDHVG	Rotating-Disc High Voltage Generator
SWT	SkyWindTurbine
VDG	Van de Graaff

1 Introduction

This thesis concentrates on electrostatic generators (ESG) power output measurements, how to improve it with dielectric material, and on investigating Rotating-Disc High Voltage Generator (RDHVG).

Voltage measurements are performed with a new alternative voltmeter. The basic principle is that the charge affects voltmeter's weight machine, and from the weight values it is possible to calculate the effecting force, and thus, also voltage output. In order to find the power output value, current output has to be calculated first. The current output measurement is not that complicated when compared to voltage output measurement. It is necessary to know the voltage first, to calculate the current output. The Van de Graaff (VDG) generator was employed for both voltage and current measurements, due to simplicity and safety of operation.

In order to improve power output, the effects of various dielectric materials were investigated. The dielectric generator was used to investigate dielectric material's behaviour for different rotation speeds, with variable high voltage (HV) inputs. The dielectric material's relative permittivity experiments were conducted with self-made capacitors. There are many dielectric materials worth trying, unfortunately, some of them are too expensive or are presented in other fundamental states (gas, spray or liquid), which makes it much harder to work with.

RDHVG was investigated, because it could be suitable generator for producing electrical energy in alternative wind turbine project. RDHVG's activities were investigated with different couplings, rotating speeds and variable HV inputs.

The thesis is based at HAN University of Applied Sciences as part of a project named SkyWindTurbine (SWT). SWT is a school project, which is trying to develop a hovering wind turbine. The SWT will use ESG to produce electrical energy, simply because generators with permanent magnets are too heavy for hovering in the air. It will hover between 300-1000*m* above the ocean surface, given that the winds are stronger at that height. That makes for more energy production than wind turbines right on the surface. The SWT can lower offshore leverage energy costs. Without government support, offshore wind farms are not economically viable. This thesis does not concentrate on actually designing the SWT generator. The main research question is: "how to measure power output from the ESG?" and the sub research questions are: "how to improve the power output using dielectric material and how do RDHVG operates?"

Academic articles and the web are the main sources of information about electrostatic and ESG. Some of the articles are old, at least a few decades. However, good information can be found: the theory does not seem to change over the past decades. Thesis was made in the Netherlands, so there was information available in foreign languages, which requires further concentration to comprehend. The presented equations are found easily in the books or on the web. Research into different experiments and conversations with professors from various backgrounds are the applied methods to address the thesis research questions.

The choice of this subject is relevant because renewable energy sources and especially wind energy are, somewhat, familiar to me. In 2012, as an exchange student in HAN University of Applied Sciences, I concluded the minor "Wind Energy Project Management". This thesis can, hopefully, help some future project to develop a hovering wind turbine.

The thesis begins with the background information about ESG, wind turbines and the project itself. It goes on explaining the performed experiments, following with the results and calculations. Lastly, it presents the conclusion and results. In the theory and description chapter pictures of the devices and circuit diagrams are presented. Most of the results are found in Appendices. In the results chapter, detailed calculations and tables are found. The fifth chapter presents a discussion over experiment results and the sixth chapter is a summary.

SWT is a hovering wind turbine, which generates electrical energy in high altitudes. Winds are always stronger and more stable in 1000*m* heights when compared to surface height and this gives better electrical energy output, then regular offshore wind turbines generates. Wind speed is related to electrical energy output, because power output increase approximately eight times when wind speed doubles. [1]

$$P = C_p * \frac{1}{2} * \rho * S * v^3$$

explanation for formula:

C_p= power coefficient

P= electrical energy power

ρ= air density

S= turbines swept area

v= wind speed

The crucial factor for keeping SWT hovering in heights is the total weight of the SWT. Generators with permanent magnets are too heavy for operating like a SWT. ESG's advantage is that no heavy magnets or gearboxes are needed, but it has not got that good energy efficiency as regular generator. SWT is a darrieus type of wind turbine and when its blades are rotating it generates electrical energy with electrostatic principle. SWT can be remote controlled and monitored by distance. SWT or SWT's are connected with HV- cable to a floating "substation" and from there it is connected further to shore. Benefits compared to regular wind turbines are lower investments, easier maintenance and no visual contact. [2]

2 Background Information about Wind Turbines and Electrostatic Generators

2.1 History of Wind Turbines

Wind energy has existed more then a millennium. First windmills were founded in China around 200 B.C. where windmills were used to lift water at the same time persians used windmills to grind grain. Legendary four bladed Dutch windmills were produced in the year 1500. Dutch windmills were used to drain water from areas such as Rhine River. [3]

The world's first wind turbine for charging batteries was constructed by James Blyth in 1887. Later the same year, an American inventor Charles F. Brush constructed 12kW wind turbine in Ohio.

In mid 70's NASA started to develop modern wind turbines due the high oil prices. NASA made many breakthroughs with wind turbine development and some of the invented technology is still in use today. There were plenty of multi megawatts experimental wind turbines projects going on after 70's. Unfortunately all the projects came to end, when oil price was dropping radically in late 80's. [4][5]

The world's first wind farm was constructed 1980 in New Hampshire, USA. It consisted of 20 wind turbines, but the wind farm failed due to many mechanical errors. Denmark constructed the world's first offshore wind farm 1991 in Vindeby. It consisted of 11 wind turbines, each turbine of 450*kW* size. [6]

Nowadays wind turbines can be over 200*m* high with a rotor diameter of 160*m* and can produce around 7.5*MW* of electrical energy. There many ambitious wind turbine projects going on, which are trying to develop hovering wind turbines. [7]

2.2 History of Electrostatic Generator

Ancient Greek philosophers understood that when rubbing amber, it could attract small objects or create a sparks. Until the 17th century electrostatic energy effects were not fully understood. Otto van Guericke was the first to attempt simple experiments with electrostatic charge. A sulphur ball was used, which was rubbed against another person's hand, becoming electrically charged. That caused the ball to spark or to attract small objects, like straws. The electrostatic charge was used in the 18th century mostly as therapy, experiments and pleasure methods as electric kiss. Ewald Jürgen von Kleist invented, in 1745, the Leyden Jar's and it was used to store electric charge. The first experiments with Leyden Jar had multiple bottles, filled with water and connected to each other. Of course it worked, but because of the metallic cylinder in the bottles. Metal bottles were available to store electrical energy and the first capacitor was discovered. Professor Richmann, later in 1783, connected multiple Leyden Jar's together to increase the charge. Unfortunately when he tried to charge capacitors during a thunderstorm, he got an electric shock from a conductor. He was the first known HV victim. ESG based on a disc rotor was getting popular in the early 19th century and it had much better electric charge efficiency than Leyden Jar's. The latest modification in electrostatic disc generators, was made by Wimshurst ESG. Wimhurst ESG was used in x-ray tubes and is still in use in e.g. physics classes. Robert J. Van de Graaff discovered a new ESG in 1929, which could easily reach up to few megawatts it got the name Van de Graaff generator. [8]

2.3 Theory of Electrostatic Generator

The ESG's purpose is to produce electrical energy, but it has also other purposes e.g. electrostatic painting, physics class, electrostatic discharge machines etc. The basic idea is to transform mechanical energy into static electricity, which can be used like any other electricity in e.g. households.

There are different types of ESG's they can be friction or induction generators. ESG creates HV, but has very low current. The voltages can go easily up to hundred thousand voltages, but the current will only be of a few hundred microamperes. [9]

Dielectric materials can increase the breakthrough voltage and produce more electrical energy. So with high dielectric material is possible to increase the power output. Dielectric materials help increasing the electric charge in capacitors. [10]

2.4 Different Types of Electrostatic Generator

The Wimshurst's ESG, VDG generator and RDHVG give a good overview about how electrostatic electricity behaves. The VDG operates with friction, the Wimshurst and RDHVG works with induction method.

2.4.1 Wimshurst Electrostatic Generator

Wimshurst machines use electrostatic induction effect to create electrical energy. It has two dielectric plates, with multiple metal blades. A two-ended brush is connected to each plate and both plates are connected to their own conductor. When the plates are spinning in the opposite direction, Wimshurst machine starts to collect positive charge on one side of the conductor and negative charge on the other side. It continues until the conductors are enough charged and voltage will breakthrough between conductors. When the voltage breakthrough occurs, the charging process starts again, if the plates are moving. [11]

2.4.2 Van de Graaff Generator

The VDG generator as in figure 1 uses friction effect to create electrical energy. It has two different pulley materials: plastic and metal. Those two pulleys are combined together with insulating material such as a rubber belt. Both pulleys have brushes, which rubbing against the rubber belt. The metal pulley has an outer metal sphere around it, which collects positive charge. When plastic pulley is rotating with help of a direct current motor, the rubber belt got movement, which rotates over both pulleys. The rubber belt transfers positive charge to the metal sphere up and the negative charge will flow down. When voltage levels are high enough, it will try to do a voltage breakthrough to the nearest grounded conductive object and then VDG generator is discharged again. [12]

Figure 1: Van de Graaff generator from HAN University of Applied Sciences energy laboratory. [Image photographed by Mathias Nummelin (2013) JPEG file.]

2.4.3 Rotating-Disc High Voltage Generator

RDHVG as in figure 2 uses induction instead of the friction method. The electric charge will be transported from the ground potential to the HV terminal by charge carriers, which rotate in the insulators disk. Charge carriers make electrical contact through the inductors electrodes. The inductor does not move and they are located in an outer ring. [13]

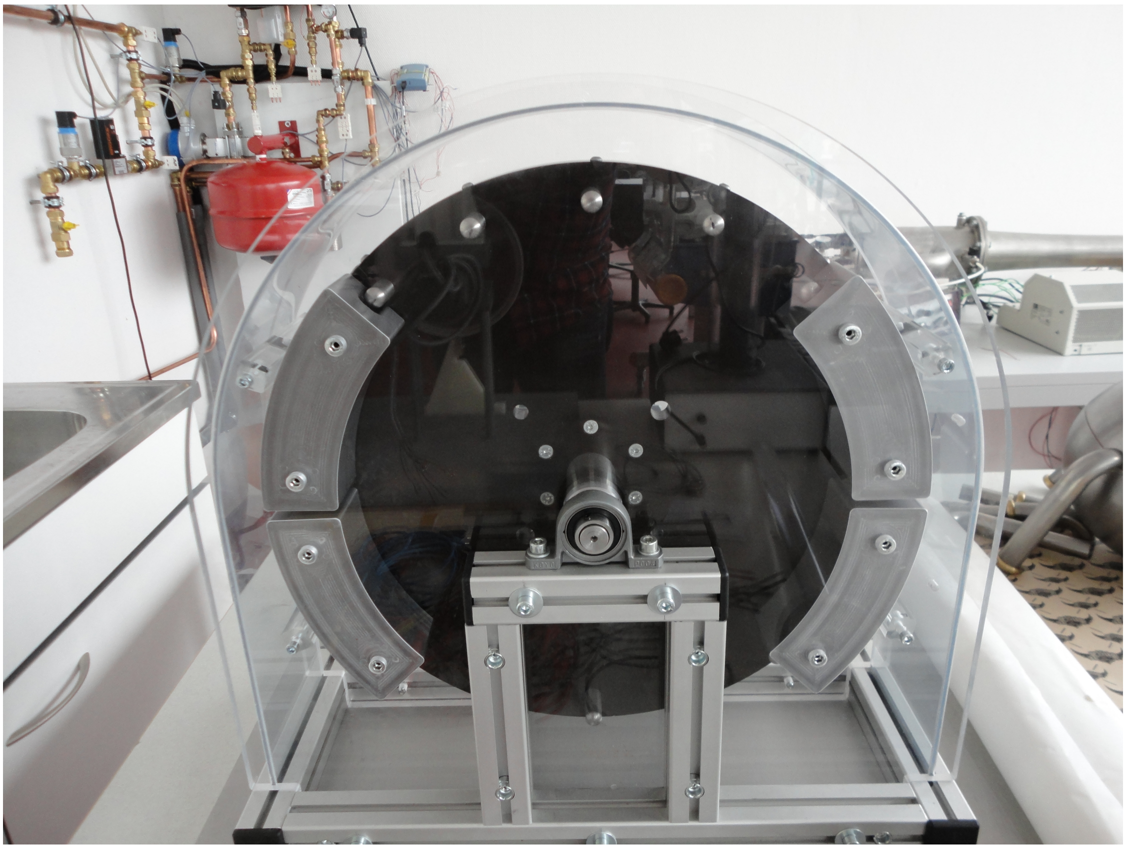


Figure 2: Rotating-Disc High Voltage Generator for HAN University of Applied Sciences energy laboratory. Connection for brushes are located on the other side. [Image photographed by Mathias Nummelin (2013) JPEG file.]

3 Theory and Description of the Experiment Methods

The third chapter explains the theory behind the experiments. Voltage, current, voltage breakthrough experiments with VDG generator, the effect of different dielectric materials and the experiments behind RDHVG are explained.

3.1 Electrostatic Voltage Output Experiment

Because of the HV and small currents that VDG generator can supply, it is not possible to use a regular voltmeter for voltage measurement. For this reason, a weight machine was used.

The ESVM has two connected metal spheres. The lower metal sphere has a "hat", which was connected directly to the weight machine. The ESVM's spheres try to repel each other, and the "hat" should repel from the sphere above when the ESVM is charged. The effecting force can be calculated from the weight machines weight values. The ESVM is charged up with the VDG generator as in figure 3. The VDG generator was connected to the ESVM's higher sphere. The VDG ground is connected to a ground sphere, which is used to discharge both ESVM and VDG generator. The weight machine is KERN and it can measure weight up to 0.35*kg* within 0.0000001*kg* accuracy.

Figure 3: Electrostatic voltmeter connected to Van de Graaff generator in HAN University of Applied Sciences energy laboratory. [Image photographed by Mathias Nummelin (2013) JPEG file.]

The ESVM did not work correctly. The ESVM's lower sphere's "hat", directly connected to weight machine, showed negative values, which means that the "hat" repels from the lower sphere. Something interfered with the voltage experiment, perhaps the higher sphere and the connecting pieces to the lower sphere. The higher sphere and the connecting pieces were removed, which gave more stable values, but the "hat" still pulls the weight machine, which means negative values. The most problematic issue was to calculate the capacitance between the lower sphere and the top part "hat", because the sphere is not anymore an identical round object. For identical round object or two identical round objects a capacitance formula can be found in literature or in web.

Another option was to do frequency drop experiment, connecting open sphere and the "hat" to a resistor and an alternative current voltage power supply as figure 4 shows. Different frequencies were tested through and the voltage changes over the capacitor (in this case open sphere with the "hat"). Then decibel drops from $0dB$ to more negative values. The value -$3dB$ is the resonance frequency. The resonance frequencies were calculated with formula 1:

$$fr = 20 * \log{(Uc/Uin)} \tag{1}$$

explanation for formula 1:

fr= resonance frequency

Uc= capacitors voltage

Uin= voltage power supply

In the experiment $1k\Omega$ and $10k\Omega$ resistors were used. For frequency and voltage measurements, an oscilloscope Tektronix TDS 2014 which could measure frequencies up to $100MHz$ was used. For alternative current power supply, a Thurlby Thander Instrument TG120, which could provide up to $20MHz$ and peak-to-peak voltage was around $20V$, was used. In this case two different resonance frequency values are obtained, because of the two different resistors two different experiments also. The capacitance value is almost the same, due to both experiments with $1k\Omega$ and $10k\Omega$ resistors. The frequency values obtained from Thurbly Thunder Instrument TG120 presents many variations making it difficult to get a precise value from the oscilloscope. For both capacitance values, the average capacitance value was calculated. [14] See Appendix 1 for ESVM's capacity results.

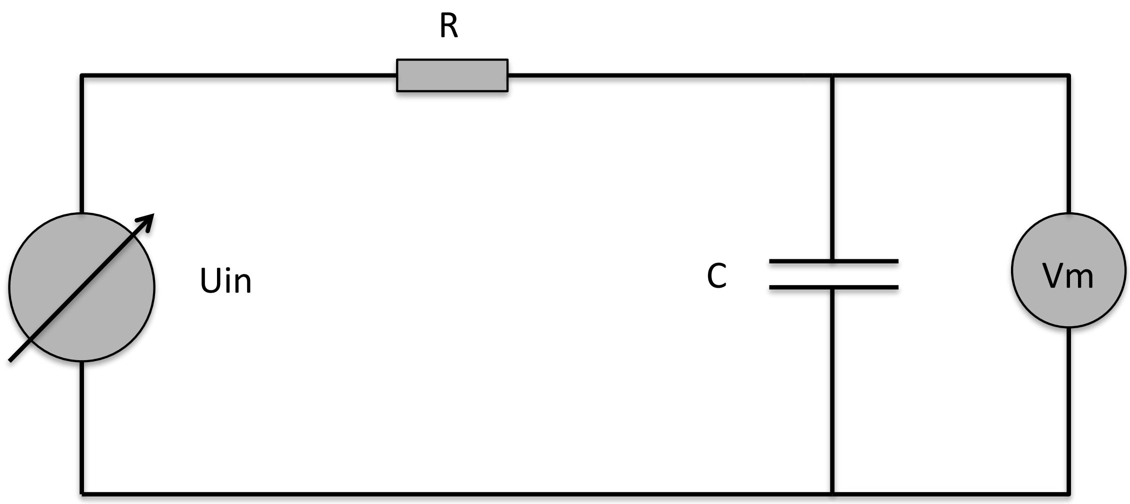


Figure 4: ESVM's capacity experiments circuit diagram.

With the resonance frequencies the capacitance was calculated with formula 2:

$$C = \frac{1}{2\pi Rfr} \tag{2}$$

explanation for formula 2:

R= resistance

π= Pi (constant)

C= capacitance

From the weight machines values force *F* with formula 3 was calculated,

$$F = m * g \tag{3}$$

explanation for formula 3:

F= force

m= mass

g= earths gravity $9.81 m/s^2$

Charge Q was calculated with formula 4,

$$Q = \sqrt{\frac{F*d^2}{k}} \quad (4)$$

explanation for formula 4:

Q= charge

d= distance

k= Coulomb's constant $8{,}988 * 10^9 F/m$

VDG generators voltage output was calculated with formula 5,

$$U = \frac{Q}{C} \quad (5)$$

explanation for formula 5:

U= voltage

3.2 Voltage Breakthrough Experiment

Dry air's voltage breakthrough is approximately 30*kV/cm*. [15] The experiment was performed with the VDG generator and a grounded sphere.

The distance was measured from the edge of both spheres with different size three pieces. The different pieces sizes were measured with a ruler, as presented in figure 5. This is the most accurate method for measuring the distance between the VDG and the grounded sphere.

Figure 5: Different size of three pieces for measuring distance between two spheres. [Image photographed by Mathias Nummelin (2013) JPEG file.]

The grounded sphere has to be on an isolated holder. Voltage breakthrough as in figure 6 was definitely not the correct way for voltage measurement, but it gives the right direction about VDG generator's voltage output.

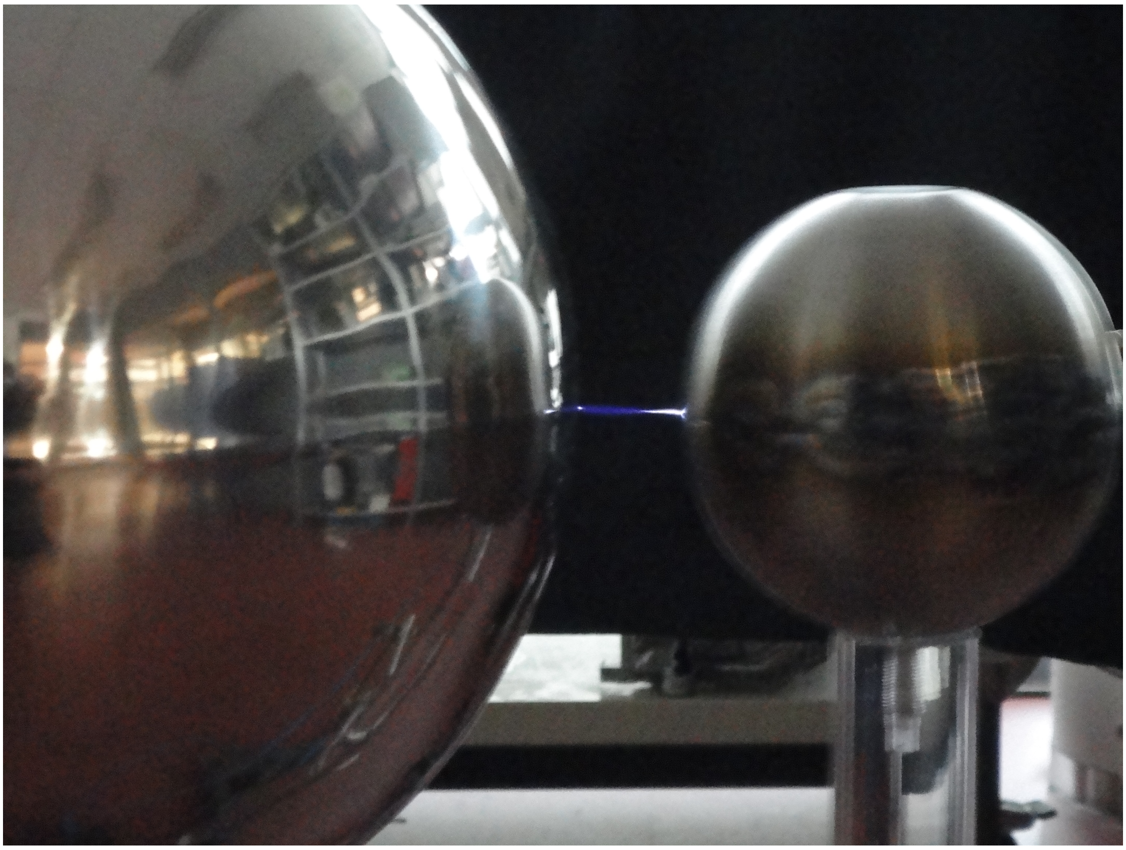


Figure 6: VDG generator voltage breakthrough to grounded sphere. [Image photographed by Mathias Nummelin (2013) JPEG file.]

3.3 Electrostatic Current Experiment

The VDG generator was used to demonstrate current measurement because of relative high voltage output. Two different methods were used for calculating current experiment. First requires high resistance for current measurement. Two resistors with values of $2M\Omega$ and $1M\Omega$ were used, connected in series like figure 7 shows. The VDG generator's sphere was connected to the $2M\Omega$ resistor in series with the next $1M\Omega$ resistor against to ground. Over $1M\Omega$ resistor was a regular voltmeter and according to Ohm's law formula 3: [16]

$$I = \frac{U}{R} \tag{6}$$

explanation for formula 3:

I= current

Currents are same through the both resistors, because of Kirschoff's law. When knowing the VDG generators voltage output, it is easy to calculate how the voltage is dividing over the both resistors. [17]

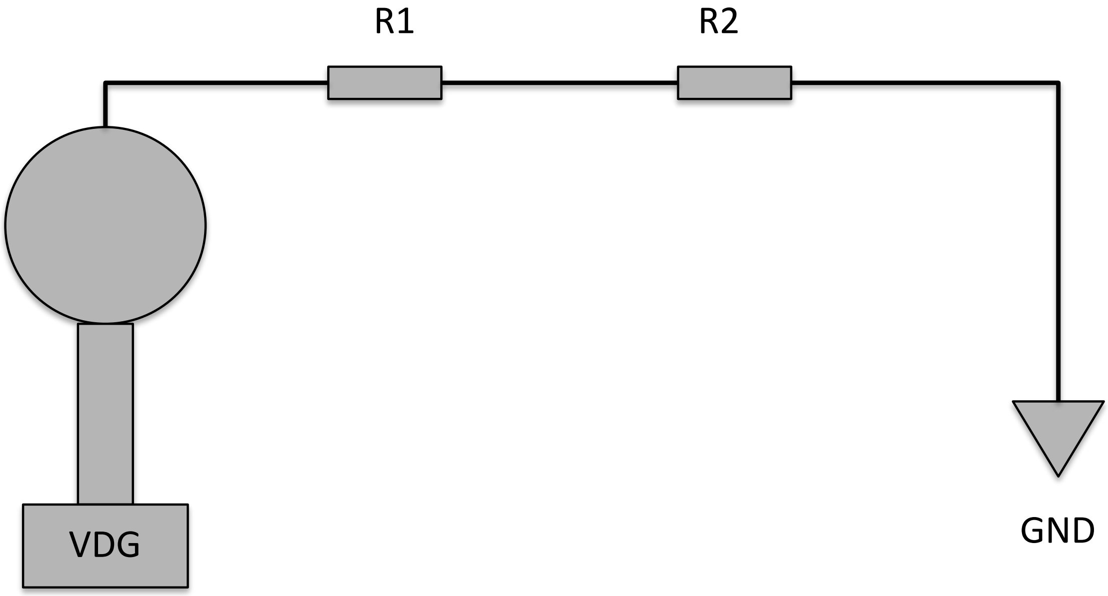


Figure 7: Circuit diagram of VDG generator first current experiment.

The second method was calculated with formula 7: [25]

$$I = \varepsilon_0 * E_{max} * W * L * n \qquad (7)$$

explanation for formula 7:

ε_0= vacuum permittivity

E_{max}= voltage breakthrough

W= belt width

L= belt length

n= belt speed (*rps*) [25]

3.4 Dielectric

Dielectric material is an electric insulator and it does not conduct electricity like e.g. copper or aluminum. The electric field is weaker in dielectric material than it would be in vacuum, because of the dielectric polarization. In other words dielectric materials allow the same amount of charge to be stored in a smaller electric field. There are many dielectric materials for commercial use. There are preponderant factors, though, for the restricted use of dielectric materials for the projects purpose. Depending on variations of temperature and/or humidity, breakthrough or resistance of the material is too low.

3.4.1. Dielectric Material

Dielectric materials (in alphabetic order):

- $BaTiO_3$ (powder)
- NCE55
- Plexiglass (Dielectric Generators rotating plate)
- PTFE (teflon)
- PVC
- PVDF (plyvinylidene fluoride)
- PVDF styrofoam
- Twaron paper (product code/from: CC121702/Teijin Aramid) [18]

These are the selected dielectric materials, as in figure 8. Available as free samples or founded at HAN University of Applied Sciences facilities.

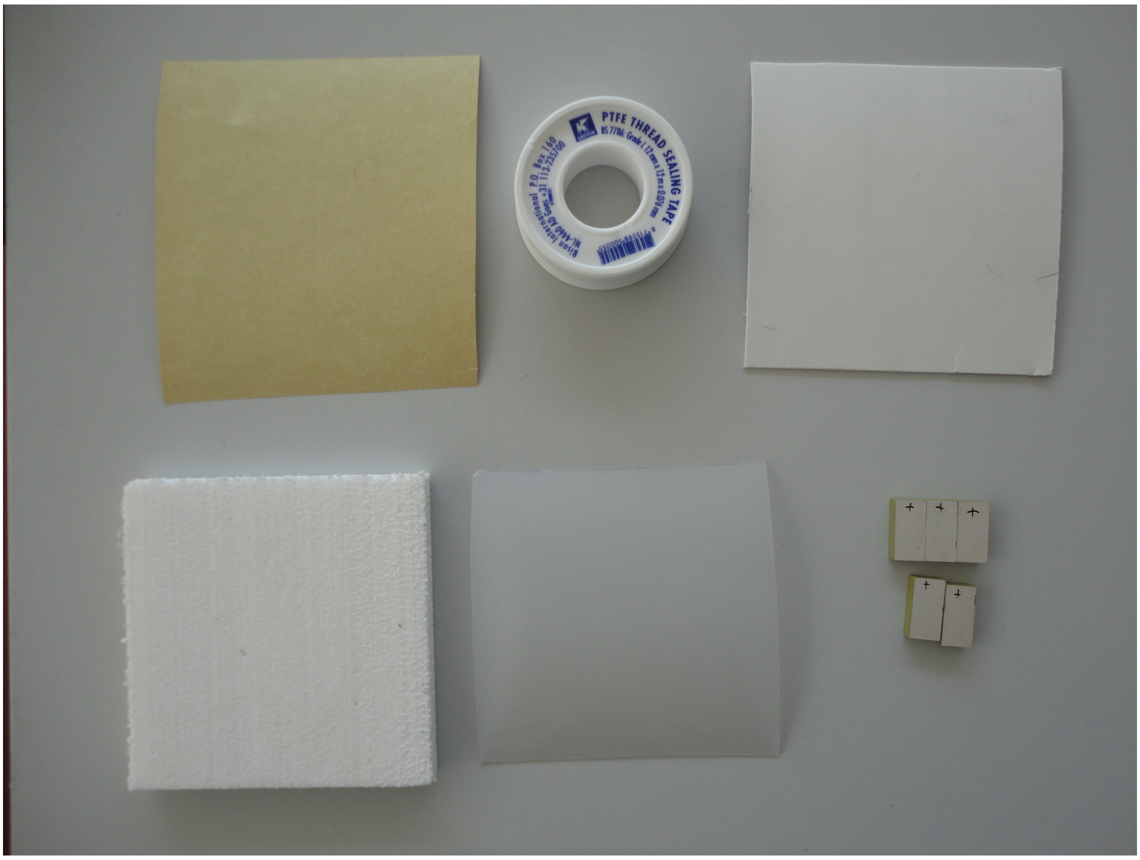


Figure 8: Different dielectric materials from left up corner to right: twaron, PTFE, PVC, PVDF Styrofoam, PVDF and NCE55 pieces. [Image photographed by Mathias Nummelin (2013) JPEG file.]

3.5 Dielectric Generator Experiment

The Dielectric Generator's purpose is to charge a metal sphere through rotating plexiglass. There are two brushes connected to the rotating plexiglass plate. First brush shots electrons at the rotating plexiglass and second brush collects the charge to a metal sphere as figure 9 shows.

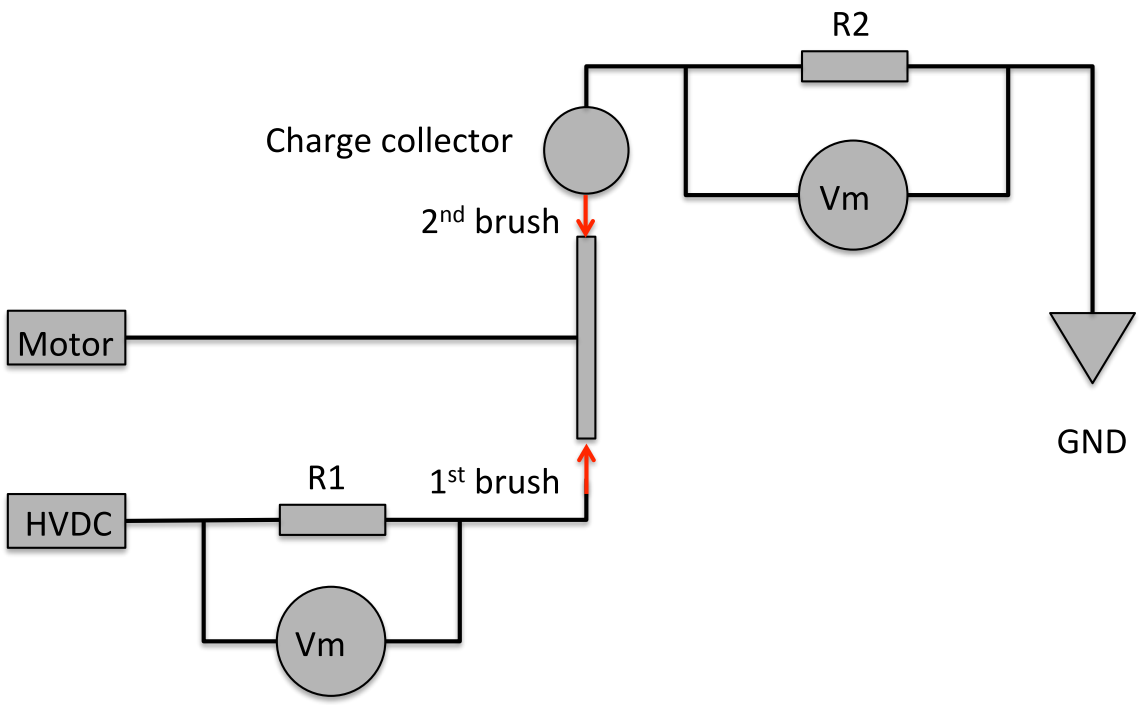


Figure 9: Dielectric Generators circuit diagram.

The current values were calculated for two points of the circuit. The current measurements were done with two $1M\Omega$ resistors and the digital Fluke multimeters. With Ohm's law formula 6, the current trough the both resistors were calculated. The plexiglass spins with a $24V$ alternative current power supply and the first brush is charged with high voltage direct current (HVDC)-power supply. [19]

Experiments with different dielectric material were performed. PTFE could not be taken into account compared to other dielectric materials. PTFE was too soft and it started to break down after 1200RPM, when break down of material happened, small PTFE pieces were flying around my lab. NCE55 pieces were too heavy and definitely not in right shape for attaching to Dielectric Generators rotating plexiglass. In the first experiment with NCE55, most of the NCE55 material was almost destroyed after 400*RPM*, when it suddenly removed for rotating plexiglass. For keeping NCE55 attached in plexiglass in high rotating speeds, NCE55 pieces had to be protected with PVC and "tapering", which helped to keep the pieces still and attached on the plexiglass as figure 10 shows.

Every time values were taken three times, for those three values the average voltage value were calculated and that experiment included with five different *RPM* and five different HV input voltage.

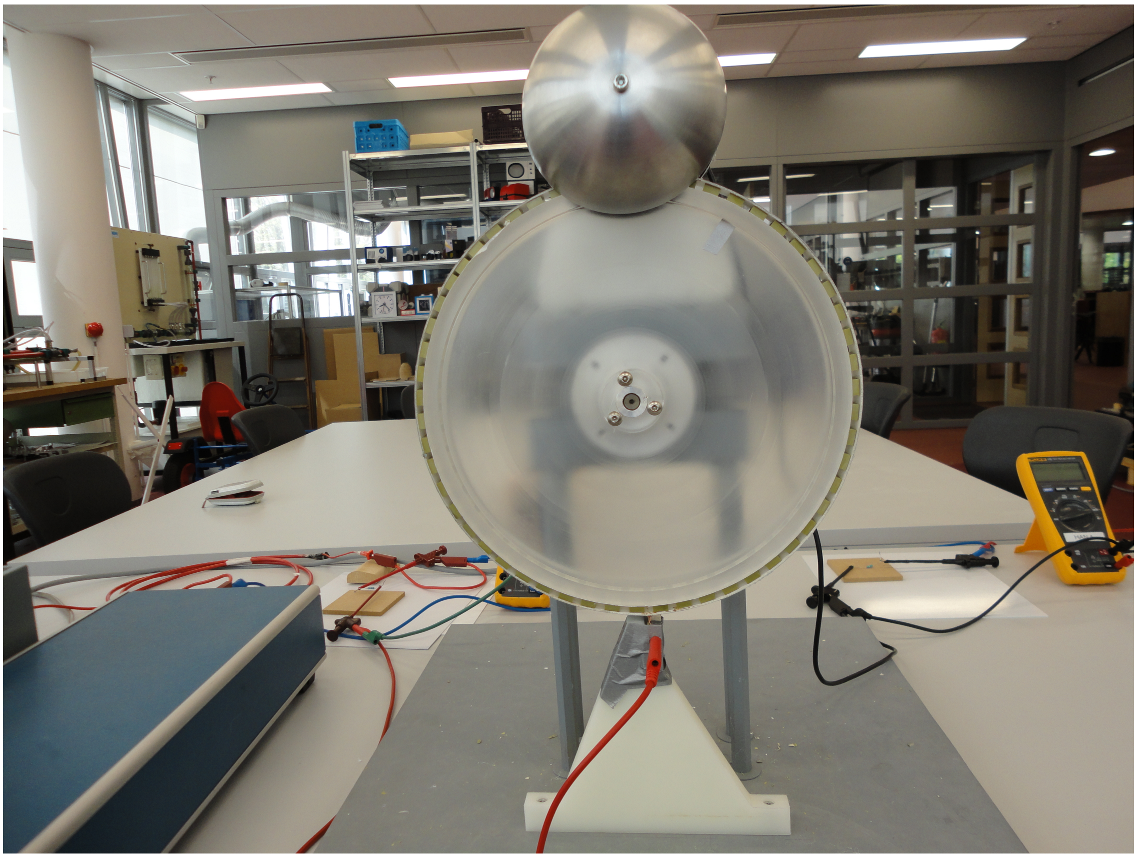


Figure 10: Dielectric Generator attached with NCE55 and PVC "tapering". [Image photographed by Mathias Nummelin (2013) JPEG file.]

3.6 Dielectric Materials Relative Permittivity Experiment

One crucial factor to increase the power output of ESG with dielectric material was to know each materials dielectric relative permittivity. The relative permittivity could be solved with a simple experiment. Each dielectric material was used between the capacitors plates. The capacitor was made from aluminium folio, which was easy to work with and has low cost. It was important to press all the air away between the capacitor plates. The capacitor was connected with Thurlby Thander Instrument TG120 alternative current power supply and different frequencies go trough the capacitor via $10k\Omega$ resistor. The basic idea was to make same size capacitors, which was not possible, because dielectric materials were in different size, thickness and shapes.

The impedance was calculated with formula 8:

$$Z = \frac{1}{2\pi f_r C} \tag{8}$$

As frequency increases, so does the current. The constant was calculated with formula 9:

$$\varepsilon = \frac{I}{U * j * \omega * \frac{A}{d}} \quad (9)$$

explanation for formula 8:

$\omega = 2\pi f$

ε= permittivity

Relative permittivity was calculated with formula 10:

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \quad (10)$$

explanation for formula 9:

ε_r= relative permittivity

ε_0= vacuum permittivity

3.7 Rotating-Disc High Voltage Generator Experiment

RDHVG in HAN University of Applied Sciences has eight inductors and four brushes, inductors are divided four on each side of RDHVG and it has two brushes on each side. Not a single brush or inductor was connected together, so connection had to be done with cables.

RDHVG experiments were done with two $1M\Omega$ resistors and HVDC- power supply. Both side's brushes were connected via $1M\Omega$ resistor to ground. Fluke multimeters were measuring volts over the resistors and with Ohm's law formula 6, current through both resistors with variable rotating speeds and HV inputs were calculated. See Appendices 2-3 for RDHVG's different coupling diagrams.

4 Results of the Experiments

In chapter four the main results are presented.

4.1 Electrostatic Voltage Output Experiment Results

VDG voltage output could not be calculated, because apparently KERN weight machine did not show trustable values. Sometimes accuracy of the values varied from each other so much, that the voltage output experiment could not taken into account. Especially with the HVDC power supply experiment. Sometimes with HVDC power supply values were positive, which means that the "hat" did not repel from lower sphere. Even if values were trustable the correct distance value, could not be calculated. The ESVM capacity was calculated with formula 2.

$$C = \frac{1}{(2\pi * 1000\Omega * 385346\text{Hz})} = 413.018 * 10^{-12}F \qquad (2)$$

From two different capacity experiments the average capacity was calculated see appendix 1.

The charge was calculated with voltage breakthrough experiments voltage value. The charge was calculated with formula 5:

$$Q = U * C = 400{,}000V * 415 * 10^{-12}F = 166 * 10^{-6}C \qquad (5)$$

Formula 5 is against formula 4, because when calculated with charge value, which have been calculated with formula 5, the distance will be with formula 4 to many kilometres. The force value is the biggest what can be found in Appendix 6.

$$d = \sqrt{\left(\frac{(166*10^{-6}C*8.988*10^{9}Nm^{2}/C^{2})}{0.102387N}\right)} = 3817.4m \qquad (4)$$

Distance result is definitely not correct, because the "hat" and spheres distance were impossible to measure and difficult to notice.

The charge was calculated with formula 4:

$$Q = \frac{(0.102387N*0.002m^2)}{8.988*10^9 Nm^2/C^2} = 4.5566 * 10^{-17}C \qquad (4)$$

Obviously this is not the correct charge value, because it would mean that VDG generator's voltage output would not even be 1V with formula 4. In formula 4 distances value was estimated to 2*mm*, because it was impossible to notice. If it would be estimated to less than 2*mm,* the charge value would be even smaller.

The "hat's" distance was changed from the sphere and it was only possible to change with 7-8*mm*. The "hat's" distance is important factor, which effected to the calculated force, because the values got more negative as with the original distance settings. There was possibility to use protection plastic tube over the ESVM, so there were settings tried with and without plastic tube protection and with both distances. See Appendix 4 for ESVM's weight values with VDG generator and Appendix 5 for ESVM's weight values inside a plastic tube with VDG generator. Only acceptable results were with formula 2 and formula 5.

4.2 Voltage Breakthrough Experiment Results

For three experiments the average value was calculated.

Average distance/[m]	Ub/[V]
0,133333333	400000

Table 1: Average voltage breakthrough values.

Average value of the three measurements was 0.13333333*m*. This is the voltage breakthrough distance between the VDG generator and the grounded sphere. When multiplied the VDG generator breakthrough distance with air's breakthrough value 30*kV/cm*, the VDG generator voltage output is exactly 400,000*V*. See Appendix 8 for all breakthrough experiment tables.

4.3 Electrostatic Current Experiment Results

The current experiment was done with resistors in series, with values of $2M\Omega$ and $1M\Omega$. Current was calculated through $1M\Omega$ resistor with formula 6:

$$I = \frac{U}{R} = \frac{10.21V}{1M\Omega} = 1.02 * 10^{-5}A \tag{6}$$

Current experiment was calculated also with formula 7:

$$I = 8.854 * 10^{-12}\, {}^{F}/_{m} * 3MV * 0.0471m * 1.21467m * \left(\frac{266rpm}{60s}\right) = 6.730059 * 10^{-6}A \tag{7}$$

Results are different from formula 6 and formula 7.

4.4 Dielectric Generator Experiment Results

Dielectric Generator experiment as figure 11 shows, was performed with different dielectric material such as twaron, twaron gap, PTFE, PVC, 2*PVC, PVDF, PVDF Styrofoam, BaTiO3 and NCE55. PTFE materials results are not presented, because it started to break to small pieces, when increased rotating speed. Dielectric Generators current in- and output was investigated with variable HV inputs and rotating speeds. Current before and after rotating plexiglass were calculated with Ohm's law formula 6.

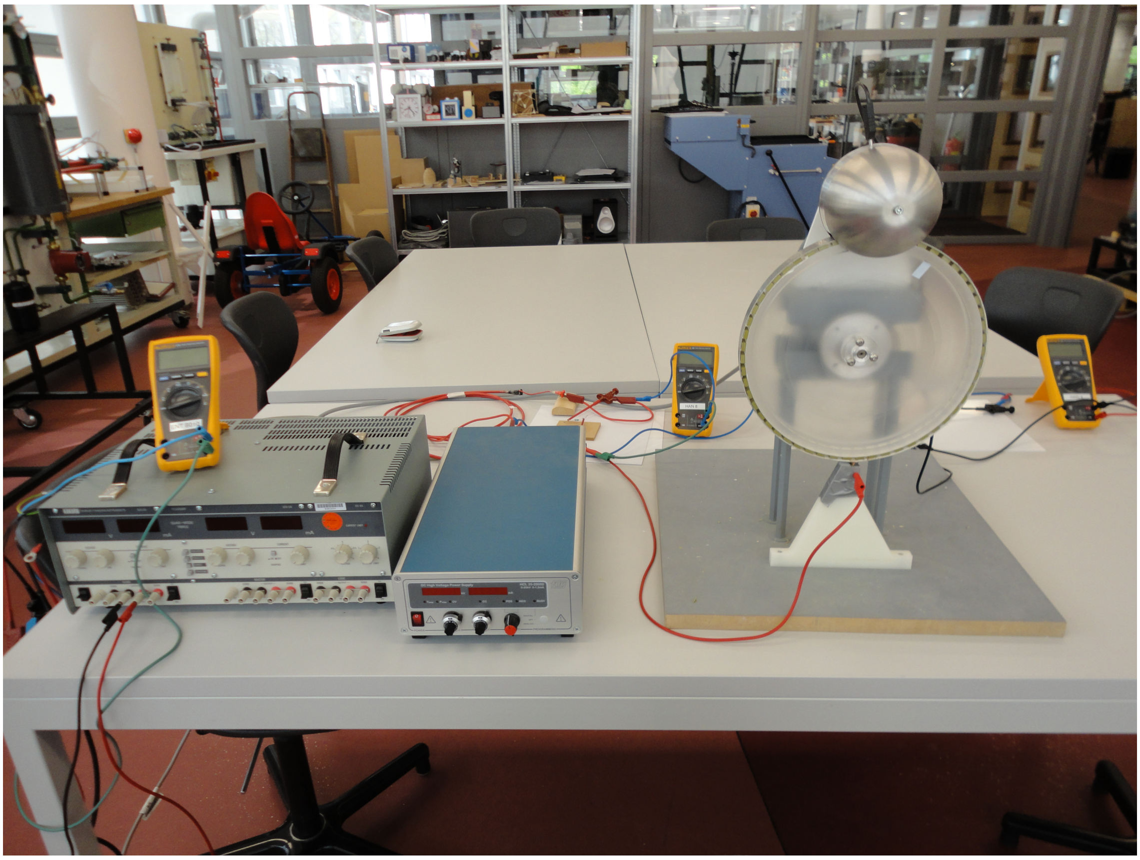


Figure 11: Dielectric Generator experiment with NCE55 and PVC "tapering". [Image photographed by Mathias Nummelin (2013) JPEG file.]

From dielectric materials average current value, tables were done, current in- and output related to HV input values. The tables are show how current is related to HV input and rotating speed. Dielectric materials current in- and output are presented in table with variable HV inputs. HV input values used in current in- and output tables were calculated average values from different rotating speeds. In Appendix 8-10 Dielectric Generators results are presented.

4.5 Dielectric Materials Relative Permittivity Experiments Results

Dielectric materials relative permittivity was investigated with self-made capacitor experiment. In relative permittivity experiment all dielectric materials' resonance frequencies were measured. In Appendix 11 all relative permittivity results are presented. Twaron papers resonance frequency was measured with formula 1:

$$f_r = 4872Hz = 20 * \log\left(\frac{6.22V}{7.23V}\right) = -3.0093826dB \quad (1)$$

Twaron papers capacitance was calculated with formula 2:

$$C = \frac{1}{(2\pi * 4872Hz * 10000\Omega)} = 3.27 * 10^{-9}F \quad (2)$$

Twaron papers impedance was calculated with formula 8:

$$Z = \frac{1}{(2\pi * 4872Hz * 3.27 * 10^{-9}F)} = 1 * 10^{4}\Omega \quad (8)$$

Current through twaron paper was calculated with formula 6:

$$I = \frac{7.23V}{1 * 10^{4}\Omega} = 7.23 * 10^{-4}A \quad (6)$$

Twaron papers permittivity was calculated with formula 9:

$$\varepsilon = \frac{7.23 * 10^{-4}A}{(2\pi * 7.23V * 4872Hz * \left(\frac{0.1^{2}m}{100 * 10^{-6}m}\right))} = 3.26838 * 10^{-11} \quad (9)$$

Twaron papers relative permittivity was calculated with formula 10:

$$\varepsilon_r = \frac{3.26838 * 10^{-11}F/m}{8.854 * 10^{-12}F/m} = 3.69142083 \quad (10)$$

Calculated values are presented in table 2.

	Epsilon R	*Epsilon R
Twaron	3,75	x
PVC	4,48	3
PVDF	5	11
PVDF Sf.	14,91	x
NCE55	3610,41	5000

Table 2: Epsilon R are measured relative permittivity and *Epsilon R are founded from web.

[20-22]

4.6 Rotating-Disc High Voltage Generator Experiment Results

5^{th} coupling was the most suitable for RDHVG settings. Coupling three, five and six made greater current output than current input. Other couplings had greater current input most of the time. In Appendix 12-15 Rotating-Disc High Voltage Generator coupling results are presented.

RDHVG did not work correctly with the original settings, because between inductors and brushes sparks occurred. It was necessary to try different couplings with RDHVG. However every coupling made sparks between inductors and brushes as figure 12 shows or only sparks between inductors. The sparks interfered RDHVG's experiment measurements, because when sparks occurred the HV input could not be increased for the RDHVG.

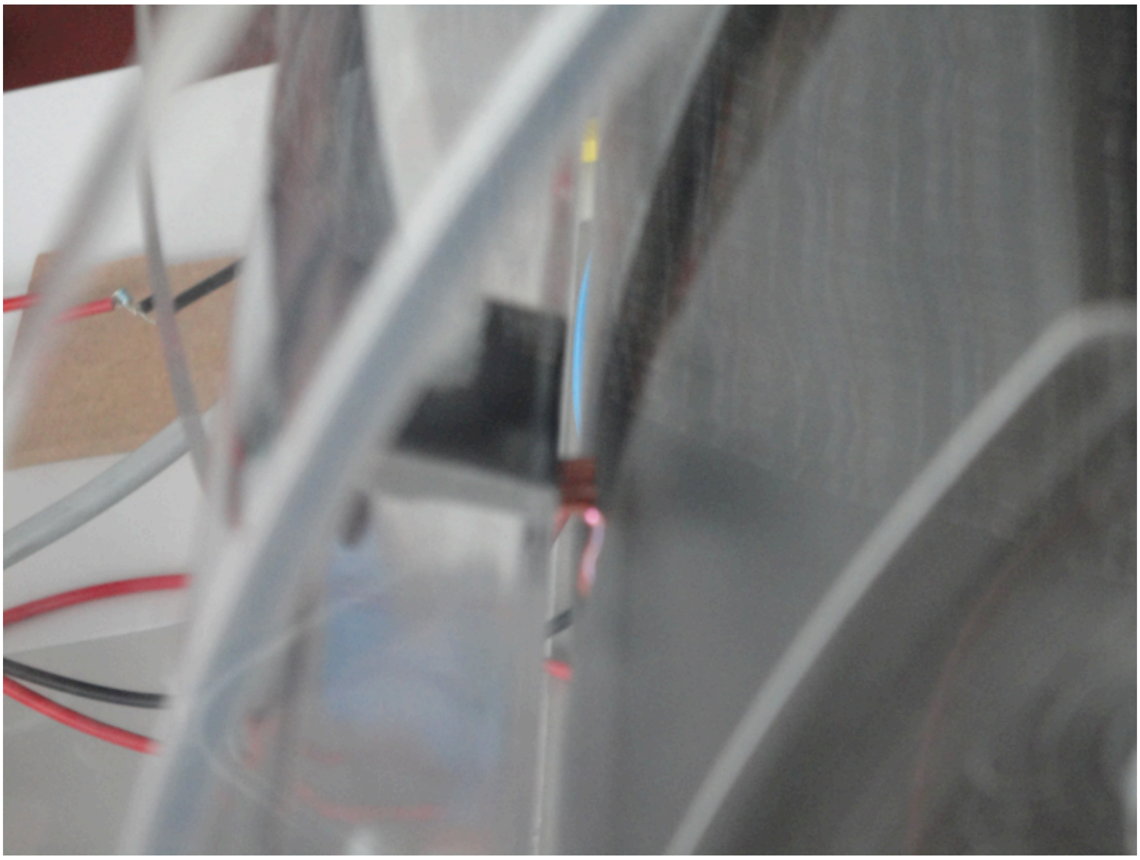


Figure 12: Red spark between brush and inductor. [Image photographed by Mathias Nummelin (2013) JPEG file.]

5 Discussion and Conclusion for the Experiments

In chapter five discussion and conclusions about performed experiments are presented.

5.1 Electrostatic Voltage and Current Outputs

Electrostatic power output was difficult to measure, because the charge was leaking always from sharp objects. If the sphere was not perfect round, the corona effect started to happen from sharp objects, like screws. Weight machine values were variable from each other, so it was almost impossible to know which values were correct. The crucial factor that affected weight machines weight values was the distance between the "hat" and the sphere. The "hat's" distance could be changed only with max. 7-8*mm*. More distance then 8*mm* interfered the "hat's" connection to the weight machine and also changed the "hat's" original weight. Plastic tube over the ESVM affected also negatively on the experiment, because plastic tube got also charged and started to attract hair straws from my hand.

ESVM could have worked better with e.g. two open hemispheres, because the distance would have been easier to measure. The idea was good for measuring voltage output with original ESVM structure. The problem was that the "hat" repelled from the sphere below and not from above with original settings. The "hat's" distance was almost impossible to notice and measuring was difficult, because it was different distances depending from which "hat's" edge measurement was performed. In this case formula 4 is not correct, because the distance can not be measured and if calculated the charge value with formula 4, it is necessary to estimate the distance. However, formula 4 is mostly used for two identical spheres and the distance is of the two spheres central origin. Formula 5 seems to be correct option for calculating one spheres charge, because the voltage and capacity is known. However, the basic idea was to calculate voltage from charge and capacitance value. Now the charge is calculated from formula 5.

The weight machine and computer was not connected together, it would have been easier, if the computer could have saved the values automatically. Values were written manually with online stopwatch. It made the values more unreliable.

Measuring electrostatic voltage and current can be performed nowadays with meters designed for surface measuring. The most common principle for measuring electrostatic charge is with two identical spheres, which are connected together. When these spheres are charged, they try repel from each other, so it could be more reliable with only two spheres and no "hat" part for operating correctly.

However, the VDG generator power output is around 5W, when the power output was calculated with formula 11:

$$P = U * I = 400{,}000V * 1.2 * 10^{-5}A = 4.8W \quad (11)$$

In formula 11 were used current value from the first current experiment, and voltage value from voltage breakthrough experiment.

Power output can be calculated also with formula 12: [25]

$$P = \varepsilon_0 * {E_{max}}^2 * r * W * L * n = 8.854 * 10^{-12}\, {}^{F}/_{m} * 3MV^2 * 0.16m * 0.0471m * 1.21467m * \left(\frac{266rpm}{60}\right) = 4.4W \quad (12)$$

It is difficult to say which formula were correct, however electrostatic energy is difficult to measure. The both values are relative near each other.

5.2 Dielectric Generator

Factor that increased current output was material's relative permittivity. BaTiO3 had the highest current output it has also very high relative permittivity compared to other experimental materials. Another factor that affected Dielectric Generator's current output was the rotating speed. BaTiO3 and PVC "tapering" had the highest current output with the rotating speed 1445*RPM*. Increased thickness of the material increased also current output. Important factor also was the HV input for the experiment. The results show how radically current is increasing with increased HV inputs.

The values were taken three times, both voltage input and voltage output, there can be noticed that usually one of the three values are different for the other values, that is why it makes sometimes so weak average sum.

Unfortunately one of two 1$M\Omega$ resistors went broken in the middle of my experiment without noticed. That is why the voltage is so high in current in (I1) compared to current out (I2). Resistor was measured again with a value of 2.8$M\Omega$. So it had to be compensated in the calculations. The resistor could have gone broken, because of sparks. Sometimes when increasing HVDC input to over 15kV, sparks occurred between resistor and table. The resistor made a post-fire to the table, if not isolated with extra isolation from the table.

Dielectric materials current outputs are presented in figure 13.

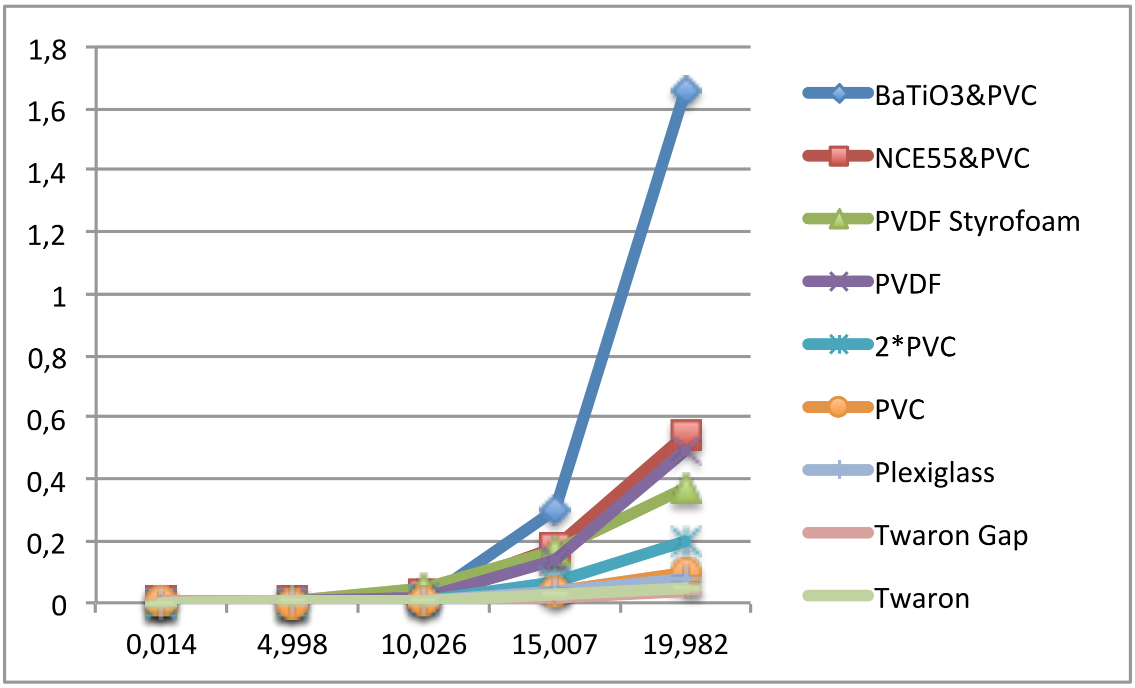


Figure 13: Different dielectric materials current output with maximum rotating speeds between 1179rpm to 1544rpm. Y-axis shows μA and X-axis shows HV input. [Graph made by Mathias Nummelin (2013) XLSX file.]

Different dielectric material had different current output results. BaTiO3 with PVC "tapering" had the greatest current output result. Maximum rotating speed did not always give the greatest current output. Some material had better current output with rotating speeds 400rpm- 800rpm compared to maximum rotating speed as figure 14 presents.

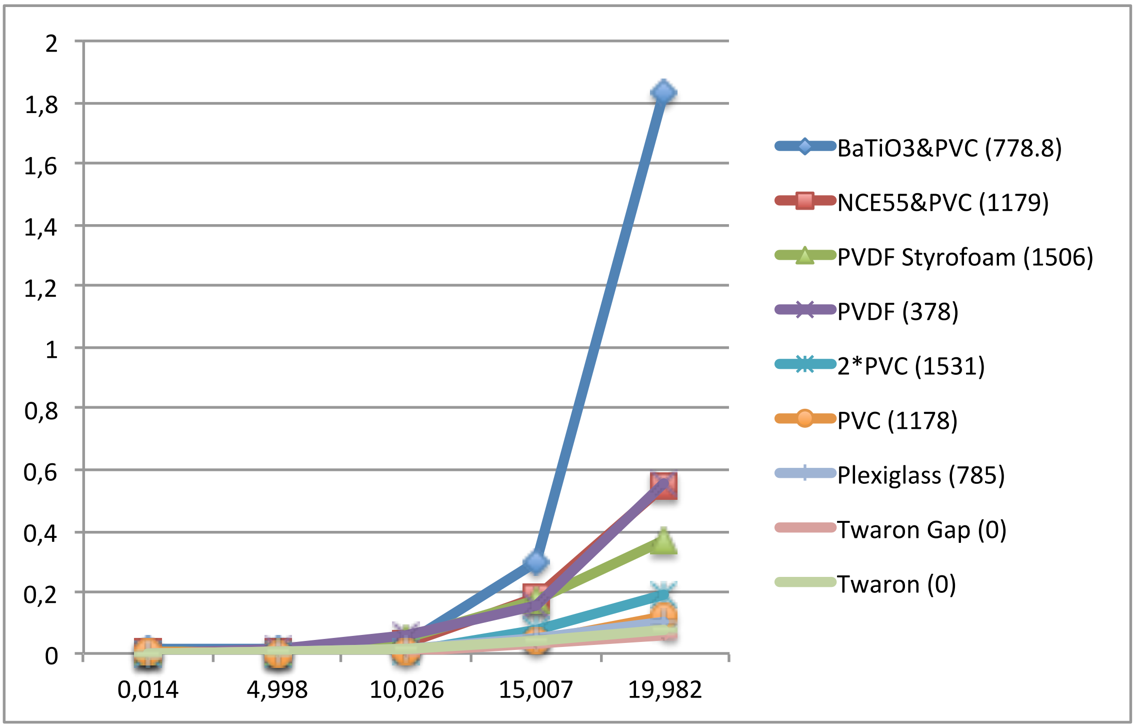


Figure 14: Different dielectric materials greatest current output. Y-axis shows μA and X-axis shows HV input. [Image made by Mathias Nummelin (2013) XLSX file.]

5.3 Dielectric Materials Relative Permittivity

Dielectric materials relative permittivity was calculated with the self-made capacitor experiment. Materials relative permittivity values are close real values, but not exactly the same. It might depend on a measuring error and frequency value was never stable.

Relative permittivity is not always constant value some material can change permittivity depending on temperature and/or frequencies. [23] In relative permittivity experiment all relative permittivity values were constant and not depending on frequency.

The formula 13 explains why it is important to have dielectric materials with strong relative permittivity and high voltage breakthrough.

$$P = E * \varepsilon \, , \qquad (13)$$

explanation for formula 13:
P= energy
E= voltage breakthrough

The formula 14 explains how the rotating speed and the size of the charge carrier surface is improving the current output. [24]

$$I_{max} = \pi * (r_{max}^2 - r_{min}^2) * f * P, \tag{14}$$

explanation for formula 14:
r_{max}= radius from the brush to the rotating disc
r_{min}= radius of the rotating disc
f= rotating speed (*RPS*)

Looks like formula 12 and 13 are correct, because what affected the current output in Dielectric Generator experiment, were rotating speed and materials relative permittivity.

5.4 Rotating-Disc High Voltage Generator Experiment Results

RDHVG experiments did not work correctly. HV input never reached acceptable values to around 20*kV*, because of the voltage breakthroughs that occurred in the system. The fifth coupling was best fitting for RDHVG. With coupling three, five and six, RDHVG was available to make a greater voltage to the ground terminal side that it was on the HV terminal side. There was a vision for using RDHVG as project SWT electrostatic generator. Unfortunately the sparks in the system, especially after some HV input, made the generator unstable for producing electrical energy. It might help, if the diameter would be greater in RDHVG, because it could diminish voltage breakthroughs (more distance between conductive parts). Of course when voltage breakthroughs does not occur anymore, it is possible to feed higher HV input to the generator. This could cause even greater current output. RDHVG could be tested with more different couplings, dielectric material and many RDHVGs in series.

Unfortunately one of two 1$M\Omega$ resistors went broken in the middle of my experiment without noticed. That is why the voltage is so high in current out (I2) compared to current in (I1). So it had to be compensated in the calculations. Same resistors were used in both Dielectric Generator experiment and RDHVG experiment.

6 Summary

Chapter six is summary and performed experiments are related to project SWT.

For improving energy efficiency in ESG it is important to use dielectric material. The best material would be something with very high relative permittivity and voltage breakthrough. It has to also be in easy form to handle, so not gas or liquids can really be taken into account.

HV inputs affect the dielectric materials positively. Rotating speeds that were used in experiments can not of course take place in nature. So, in real life the SWT's ESG can not rotate as fast as in my experiments.

Measuring ESG power output can be done with modern electrostatic voltmeters. SWT voltage and current values had to be monitored from distance, but maybe the floating substation, which is connected to SWT could have its own integrated ESVM. ESVM principle can be constructed with low investments, because needed things are two conductive objects. There can be a weight machine or it is possible also to calculate this from the angle between horizontal and the charged objects level.

RDHVG were with few couplings almost a fully operating generator. If the voltage breakthrough could have been avoided it might work as an ESG. Voltage break-throughs can be avoided with increasing the size of RDHVG. It also would affect posi-tively on the current output if the formula 14 is trustable.

Environment in 300-1000*m* over ocean surface is usually cold, humid and there is salt in the air. Humidity has higher voltage breakthrough than dry air. Temperature has also an effect on relative permittivity depending which material is used.

There are also another issues all computers and software have to be protected against electrostatic shocks or else they will be destroyed. Hopefully this thesis can help future project teams in developing a hovering wind turbine.

References

1 RenSmart [web document]. *Information > Betz' Law.* Available at: http://www.rensmart.com/Information/Betz'Law [Accessed 13.5.2013]

2 Power2nijmegen [web document]. Available at: http://power2nijmegen.com/wp-content/uploads/2012/11/Poster_REWICON2.pdf
[Accessed 13.5.2013]

3 Thinkquest [web document]. Available at: http://library.thinkquest.org/17658/wind/windhistoryht.html [Accessed 13.5.2013]

4 TheWindCoaltion [web document], *Wind Energy > History of Wind Energy.* Available at: http://windcoalition.org/wind-energy/history-of-wind-energy/ [Accessed 27.5.2013]

5 NASA [web document], Available at: http://www.nasa.gov/vision/earth/technologies/wind_turbines.html [Accessed 27.5.2013]

6 Nixon, Niki, Timeline: The History of Wind Power. *The Guardian* (2008) Available at: http://www.guardian.co.uk/environment/2008/oct/17/wind-power-renewable- energy
[Accessed 13.5.2013]

7 Airborne Wind Energy Industry Association [web document]. *Who we are.* Available at: http://aweia.org/new/ [Accessed 27.5.2013]

8 Hans-Peter's Mathematick Technick Algorithmick Linguistick Omnium Gatherum [web document]. *History > History of Electrostatic Generators*. Available at: http://www.hp-gramatke.net/history/english/page4000.htm [Accessed 6.2.2013]

9 Laboratório de Electrónica de Poténcia, *Dr.António Carlos M. de Queiroz* [web document]. *Electrostatic Machines.* Available at: http://www.coe.ufrj.br/~acmq/electrostatic.html [Accessed 6.2.2013]

10 The Pysics Hypertextbook [web document]. *Dielectrics.* Available at: http://physics.info/dielectrics/ [Accessed 7.2.2013]

11 Laboratório de Electrónica de Poténcia, *Dr.António Carlos M. de Queiroz* [web document]. *Electrostatic machines > Wimshurst Machine.* Available at: http://www.coe.ufrj.br/~acmq/wimshurst.html [Accessed 7.2.2013]

12 Virtual Amrita Laboratories Universalizing Education [web document]. *Physical Sciences > Van De Graaff Generator.* Available at: http://amrita.vlab.co.in/?sub=1&brch=192&sim=349&cnt=1 [Accessed 8.2.2013]

13 A. Isoya, K. KobaYashi, T. Nakashima and T. Maeda. *Nuclear Instrument and Methods in Physics Research* A236 (1985) p. 215-221. Rotating-Disc Type High Voltage Generator.

14 Teacher Peter van der Jagt interview. HAN University of Applied Sciences. Arnhem. 14.3.2013.

15 Paraselli Bheema Sankar, Measurement of Air Breakdown Voltage and Electric Field Using Standard Sphere Gap Method. Master of Technology. Department of Electrical Engineering, National Institute of Technology, Rourkela, India. 2011. Available at: http://ethesis.nitrkl.ac.in/2875/1/Full_Thesis_Print_04.07.2011.pdf [Accessed 7.3.2013]

16 RapidTables [web document]. *Electronic circuit laws > Ohm's Law.* Available at: http://www.rapidtables.com/electric/ohms-law.htm#formula [Accessed 7.3.2013]

17 All About Circuits [web document]. *Volume 1 > Voltage Divider Circuits.* Available at: http://www.allaboutcircuits.com/vol_1/chpt_6/1.html [Accessed 7.3.2013]

18 Visser, R., richard.visser@teijinaramid.com (2013). Twaron paper from Teijin Aramid used for student project. [email] Message to Nummelin, M. (mathias.nummelin@gmail.com). Sent 10th June.

19 Dr. Ing. Piet Sonneveld interview. HAN University of Applied Sciences. Arnhem. 13.2.2013.

20 RF Café [web document]. Available at:http://www.rfcafe.com/references/electrical/dielectric-constants-strengths.htm [Accessed 7.3.2013]

21 Noliac [web document]. *Standard products > Piezo Ceramics Specification.* Available at: http://www.noliac.com/Specification-141.aspx [Accessed 7.3.2013]

22 Noliac [web document]. Available at: http://www.noliac.com/Files/Billeder/02%20Standard/Ceramics/Noliac_CEramics_NCE_datasheet.pdf [Accessed 7.3.2013]

23 Natinal Physical Laboratory [web document]. *General Physics > Dielectric Prperties of Materials.* Available at: http://www.kayelaby.npl.co.uk/general_physics/2_6/2_6_5.html [Accessed 31.5.2013]

24 Laboratório de Electrónica de Poténcia, *Dr.António Carlos M. de Queiroz* [web document]. Available at: http://www.coe.ufrj.br/~acmq/efield.html [Accessed 30.5.2013]

25 Laboratório de Electrónica de Poténcia, *Dr.António Carlos M. de Queiroz* [web document]. Available at: http://www.coe.ufrj.br/~acmq/myvdg.html [Accessed 8.11.2013]

List of Figures

List of Tables

Appendix 1

ESVM capacity experiment values

1kΩ			
f/[Hz]	Uin/[V]	Uc/[V]	dB
9815,8	7,17	7,13	-0,1118884
20309,5	7,17	7,03	-0,394379
29492,5	7,21	7,16	-0,1391794
35052,2	7,22	7,12	-0,2789445
40916	7,2	7,17	-0,0835074
51095,7	7,18	7,11	-0,1959428
103572	7,15	6,99	-0,452636
203315	7,19	6,78	-1,1742814
305412	7,17	6,43	-2,1786223
354550	7,12	6,27	-2,5426274
370757	7,1	6,15	-2,872854
385346	7,09	6,11	-2,9751713
394796	7,1	6,09	-3,068934
397682	7,1	6,08	-3,1018018
418835	7,11	5,96	-3,5286353

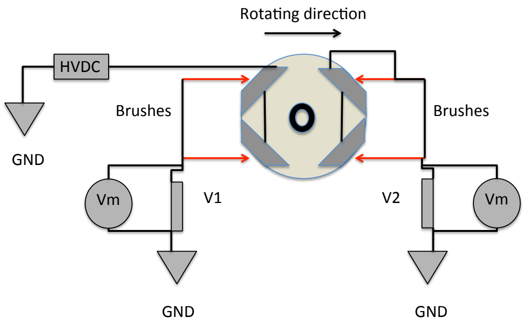
10Ω			
f/[Hz]	Uin/[V]	Uc/[V]	dB
9837,2	7,2	6,98	-0,6206422
21588,8	7,16	6,7	-1,3280491
30182,2	7,17	6,37	-2,3661237
32970	7,2	6,34	-2,5440452
33960,5	7,2	6,31	-2,638907
35472,5	7,2	6,25	-2,8299912
37985,5	7,18	6,2	-2,9350018
38027,7	7,18	6,18	-2,9996222
38826,6	7,18	6,16	-3,0644521
38905,4	7,18	6,15	-3,096946
39747,4	7,19	6,07	-3,3866513

Cap1/1kΩ	Cap2/10kΩ
413,018pF	418,524pF

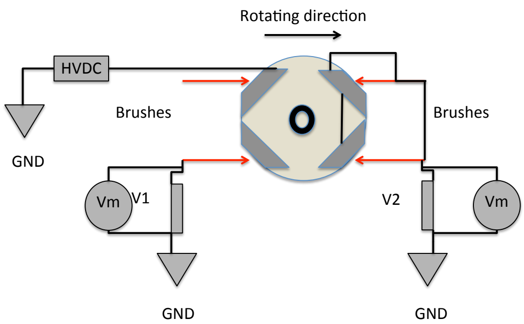
Average capcaity
415,771pF

Appendix 2

Coupling 1



Coupling 2



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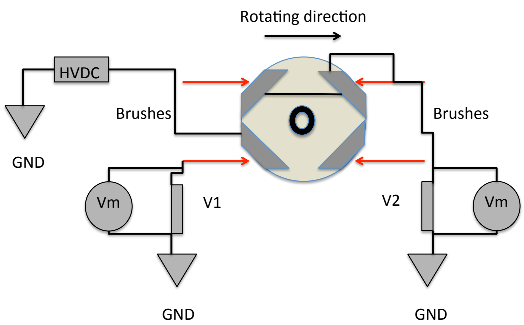

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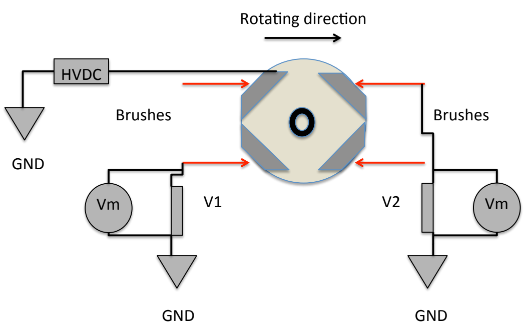
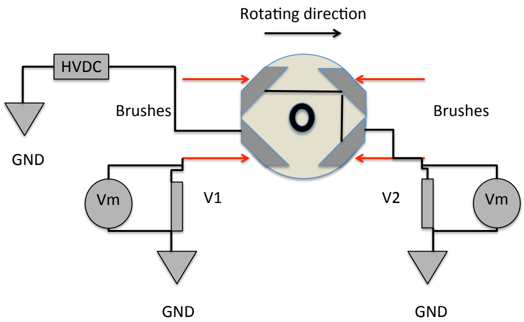


Appendix 3

Coupling 5



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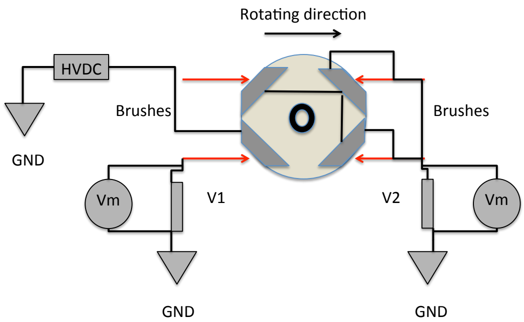

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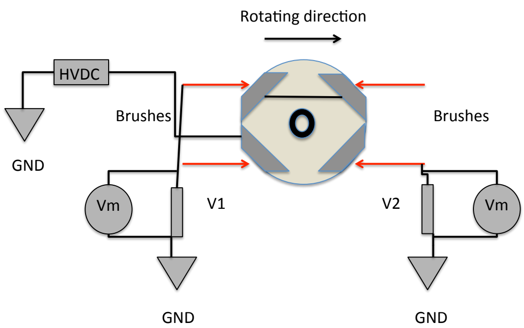

Appendix 4

Without plastic tube protection over the electrostatic voltmeter

VDG	d0	Plain
t/[s]	m/[g]	F/[N]
10	-7,218	-0,0708086
20	-7,992	-0,0784015
30	-8,483	-0,0832182
40	-8,857	-0,0868872
50	-9,014	-0,0884273
60	-9,162	-0,0898792

VDG	d1	Plain
t/[s]	m/[g]	F/[N]
10	-10,037	-0,098463
20	-12,159	-0,1192798
30	-12,712	-0,1247047
40	-12,549	-0,1231057
50	-12,415	-0,1217912
60	-12,484	-0,122468

VDG	d0	Plain
t/[s]	m/[g]	F/[N]
10	-9,645	-0,0946175
20	-9,904	-0,0971582
30	-10,056	-0,0986494
40	-10,23	-0,1003563
50	-10,293	-0,1009743
60	-10,437	-0,102387

VDG	d1	Plain
t/[s]	m/[g]	F/[N]
10	-11,22	-0,1100682
20	-11,682	-0,1146004
30	-11,667	-0,1144533
40	-11,887	-0,1166115
50	-11,556	-0,1133644
60	-11,647	-0,1142571

VDG	d0	Plain
t/[s]	m/[g]	F/[N]
10	-10,081	-0,0988946
20	-10,355	-0,1015826
30	-10,178	-0,0998462
40	-9,255	-0,0907916
50	-9,277	-0,0910074
60	-9,087	-0,0891435

VDG	d1	Plain
t/[s]	m/[g]	F/[N]
10	-11,382	-0,1116574
20	-11,501	-0,1128248
30	-11,572	-0,1135213
40	-11,47	-0,1125207
50	-11,424	-0,1120694
60	-11,758	-0,115346

Appendix 5

Plastic tube protection over the electrostatic voltmeter

VDG	d0	Plastic tube
t/[s]	m/[g]	F/[N]
10	-1,289	-0,0126451
20	-1,389	-0,0136261
30	-1,402	-0,0137536
40	-1,271	-0,0124685
50	-0,96	-0,0094176
60	-0,969	-0,0095059

VDG	d1	Plastic tube
t/[s]	m/[g]	F/[N]
10	-1,285	-0,0126059
20	-2,019	-0,0198064
30	-2,269	-0,0222589
40	-2,287	-0,0224355
50	-1,961	-0,0192374
60	-1,855	-0,0181976

VDG	d0	Plastic tube
t/[s]	m/[g]	F/[N]
10	-0,416	-0,004081
20	-0,337	-0,003306
30	-0,382	-0,0037474
40	-0,472	-0,0046303
50	-0,538	-0,0052778
60	-0,518	-0,0050816

VDG	d1	Plastic tube
t/[s]	m/[g]	F/[N]
10	-1,441	-0,0141362
20	-1,256	-0,0123214
30	-1,247	-0,0122331
40	-1,229	-0,0120565
50	-1,271	-0,0124685
60	-1,282	-0,0125764

VDG	d0	Plastic tube
t/[s]	m/[g]	F/[N]
10	-0,797	-0,0078186
20	-0,702	-0,0068866
30	-0,621	-0,006092
40	-0,558	-0,005474
50	-0,415	-0,0040712
60	-0,523	-0,0051306

VDG	d1	Plastic tube
t/[s]	m/[g]	F/[N]
10	-1,348	-0,0132239
20	-1,295	-0,012704
30	-1,254	-0,0123017
40	-1,394	-0,0136751
50	-1,412	-0,0138517
60	-1,457	-0,0142932

Appendix 6

Breakthrough experiment tables

Voltage Breaktrough	Distance/[m]	Voltage Breaktrough	Distance/[m]	Voltage Breaktrough	Distance/[m]
N	0,16	N	0,16	N	0,16
N	0,15	N	0,15	N	0,15
N	0,14	N	0,14	Y	0,14
Y	0,13	Y	0,13	Y	0,13
Y	0,12	Y	0,12	Y	0,12
Y	0,11	Y	0,11	Y	0,11
Y	0,1	Y	0,1	Y	0,1
Y	0,09	Y	0,09	Y	0,09
Y	0,08	Y	0,08	Y	0,08
Y	0,07	Y	0,07	Y	0,07
Y	0,06	Y	0,06	Y	0,06
Y	0,05	Y	0,05	Y	0,05
Y	0,04	Y	0,04	Y	0,04
Y	0,03	Y	0,03	Y	0,03
Y	0,02	Y	0,02	Y	0,02
Y	0,01	Y	0,01	Y	0,01
Y	0	Y	0	Y	0

Appendix 7

Twaron

Motor												
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0	0	0	0	0	0	0	0	0	0
		5,004	0,064	0,064	0,064	0,005	0,005	0,006	0,064	0,005333333	0,02285714	0,00533333
0	0	10,012	0,169	0,168	0,168	0,016	0,016	0,016	0,168333333	0,016	0,06011905	0,016
		15,012	1,438	1,42	1,429	0,041	0,041	0,041	1,429	0,041	0,51035714	0,041
		19,981	3,488	3,438	3,442	0,075	0,076	0,069	3,456	0,073333333	1,23428571	0,07333333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,002	0,001	0,001	0,003	0,006	0,003	0,001333333	0,004	0,00047619	0,004
		5,006	0,061	0,061	0,059	0,004	0,008	0,012	0,060333333	0,008	0,02154762	0,008
6,026	389,9	9,999	0,153	0,152	0,151	0,017	0,021	0,02	0,152	0,019333333	0,05428571	0,01933333
		15,008	1,389	1,391	1,377	0,036	0,045	0,034	1,385666667	0,038333333	0,49488095	0,03833333
		19,982	3,462	3,428	3,454	0,078	0,044	0,069	3,448	0,063666667	1,23142857	0,06366667
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,017	0,004	0,005	0,003	0,005	0,004	0,003	0,004	0,004	0,00142857	0,004
		5,013	0,054	0,054	0,053	0,003	0,009	0,009	0,053666667	0,007	0,01916667	0,007
12,03	779,5	10,009	0,153	0,148	0,146	0,009	0,012	0,014	0,149	0,011666667	0,05321429	0,01166667
		15,014	1,418	1,42	1,419	0,034	0,036	0,035	1,419	0,035	0,50678571	0,035
		19,982	3,372	3,401	3,383	0,045	0,066	0,068	3,385333333	0,059666667	1,20904762	0,05966667
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,005	0,005	0,004	0,007	0,003	0,004	0,004666667	0,004666667	0,00166667	0,00466667
		5,009	0,055	0,055	0,054	0,007	0,005	0,004	0,054666667	0,005333333	0,01952381	0,00533333
17,85	1157	9,986	0,138	0,137	0,138	0,006	0,007	0,009	0,137666667	0,007333333	0,04916667	0,00733333
		15,006	1,445	1,447	1,451	0,028	0,027	0,026	1,447666667	0,027	0,51702381	0,027
		19,984	3,362	3,363	3,359	0,044	0,053	0,048	3,361333333	0,048333333	1,20047619	0,04833333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,004	0,004	0,003	0,001	0	0	0,003666667	0,000333333	0,00130952	0,00033333
		5,016	0,049	0,049	0,049	0,004	0,003	0,003	0,049	0,003333333	0,0175	0,00333333
23,28	1511	10,007	0,128	0,126	0,127	0,008	0,007	0,008	0,127	0,007666667	0,04535714	0,00766667
		15,001	1,451	1,442	1,433	0,024	0,023	0,024	1,442	0,023666667	0,515	0,02366667
		19,984	3,33	3,303	3,321	0,047	0,048	0,046	3,318	0,047	1,185	0,047

Twaron gap

Motor												
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0	0	0	0	0	0	0	0	0	0
		5,009	0,047	0,046	0,046	0,003	0,003	0,003	0,046333333	0,003	0,01654762	0,003
0	0	9,995	0,142	0,143	0,135	0,01	0,009	0,01	0,14	0,009666667	0,05	0,00966667
		14,996	1,487	1,481	1,474	0,03	0,03	0,029	1,480666667	0,029666667	0,52880952	0,02966667
		19,982	3,382	3,425	3,392	0,058	0,058	0,057	3,399666667	0,057666667	1,21416667	0,05766667
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,001	0,001	0,002	0,003	0,003	0,002	0,001333333	0,002666667	0,00047619	0,00266667
		5,002	0,045	0,045	0,044	0,005	0,004	0,007	0,044666667	0,005333333	0,01595238	0,00533333
6,024	390,2	10,004	0,115	0,114	0,113	0,002	0,003	0,007	0,114	0,004	0,04071429	0,004
		15,004	1,429	1,425	1,424	0,023	0,024	0,024	1,426	0,023666667	0,50928571	0,02366667
		19,984	3,365	3,388	3,351	0,041	0,05	0,045	3,368	0,045333333	1,20285714	0,04533333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,016	0,003	0,003	0,003	0,004	0,001	0,002	0,003	0,002333333	0,00107143	0,00233333
		5,004	0,043	0,042	0,042	0,003	0,003	0,003	0,042333333	0,003	0,01511905	0,003
11,96	776,5	10,006	0,111	0,107	0,108	0,009	0,008	0,008	0,108666667	0,008333333	0,03880952	0,00833333
		14,994	1,431	1,439	1,429	0,023	0,024	0,02	1,433	0,022333333	0,51178571	0,02233333
		19,984	3,328	3,326	3,311	0,041	0,041	0,047	3,321666667	0,043	1,18630952	0,043
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,004	0,004	0,003	0,003	0	0,002	0,003666667	0,001666667	0,00130952	0,00166667
		5,002	0,04	0,04	0,04	0,003	0,002	0,003	0,04	0,002666667	0,01428571	0,00266667
18,06	1172	10,008	0,101	0,102	0,099	0,006	0,006	0,006	0,100666667	0,006	0,03595238	0,006
		15,022	1,432	1,425	1,423	0,019	0,02	0,019	1,426666667	0,019333333	0,50952381	0,01933333
		19,984	3,279	3,257	3,262	0,039	0,037	0,036	3,266	0,037333333	1,16642857	0,03733333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,005	0,004	0,004	0,002	0,002	0,001	0,004333333	0,001666667	0,00154762	0,00166667
		5,002	0,039	0,039	0,038	0,002	0,002	0,002	0,038666667	0,002	0,01380952	0,002
23,47	1525	10,016	0,101	0,098	0,098	0,005	0,005	0,005	0,099	0,005	0,03535714	0,005
		15,014	1,404	1,397	1,394	0,017	0,018	0,018	1,398333333	0,017666667	0,49940476	0,01766667
		19,984	3,264	3,28	3,272	0,037	0,035	0,036	3,272	0,036	1,16857143	0,036

Appendix 8

Plexiglass

Motor												
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,019	0	0	0	0		0	0	0	0	0
		4,999	0,048	0,047	0,047	0,003	0,003	0,003	0,047333333	0,003	0,01690476	0,003
0	0	9,999	0,134	0,141	0,136	0,008	0,008	0,008	0,137	0,008	0,04892857	0,008
		15,002	1,47	1,463	1,466	0,025	0,025	0,025	1,466333333	0,025	0,52369048	0,025
		19,981	3,333	3,332	3,322	0,056	0,057	0,058	3,329	0,057	1,18892857	0,057
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,002	0,001	0,005	0,003	0,006	0,004	0,002666667	0,004333333	0,00095238	0,00433333
		5,012	0,041	0,039	0,041	0,001	0,007	0,006	0,040333333	0,004666667	0,01440476	0,00466667
6,07	393	9,996	0,106	0,105	0,104	0,006	0,007	0,007	0,105	0,006666667	0,0375	0,00666667
		15,012	1,399	1,404	1,397	0,027	0,023	0,025	1,4	0,025	0,5	0,025
		19,982	3,328	3,34	3,325	0,058	0,073	0,062	3,331	0,064333333	1,18964286	0,06433333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0	0		0	0	0	0	0	0	0
		5,005	0,059	0,059	0,057	0,005	0,006	0,006	0,058333333	0,005666667	0,02083333	0,00566667
12,11	784,5	10,009	0,17	0,168	0,166	0,014	0,012	0,014	0,168	0,013333333	0,06	0,01333333
		14,998	1,641	1,67	1,647	0,054	0,052	0,051	1,652666667	0,052333333	0,5902381	0,05233333
		19,98	3,573	3,552	3,567	0,101	0,105	0,104	3,564	0,103333333	1,27285714	0,10333333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,014	0	0	0	0	0	0	0	0	0	0
		5,013	0,069	0,068	0,066	0,008	0,008	0,008	0,067666667	0,008	0,02416667	0,008
17,77	1151	10,008	0,179	0,186	0,182	0,017	0,017	0,017	0,182333333	0,017	0,06511905	0,017
		14,984	1,634	1,632	1,628	0,044	0,05	0,051	1,631333333	0,048333333	0,58261905	0,04833333
		19,98	3,488	3,472	3,454	0,102	0,095	0,093	3,471333333	0,096666667	1,2397619	0,09666667
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,016	0,005	0,005	0,004	0,001	0,001	0,001	0,004666667	0,001	0,00166667	0,001
		4,998	0,057	0,056	0,056	0,002	0,002	0,002	0,056333333	0,002	0,02011905	0,002
23,81	1544	10,02	0,203	0,196	0,194	0,008	0,008	0,008	0,197666667	0,008	0,07059524	0,008
		15,026	1,604	1,597	1,6	0,04	0,041	0,039	1,600333333	0,04	0,57154762	0,04
		19,982	3,415	3,407	3,396	0,083	0,079	0,075	3,406	0,079	1,21642857	0,079

PVC

Motor												
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,014	0	0	0	0	0	0	0	0	0	0
		4,988	0,05	0,049	0,049	0,002	0,002	0,002	0,049333333	0,002	0,01761905	0,002
0	0	9,999	0,177	0,188	0,186	0,009	0,009	0,009	0,183666667	0,009	0,06559524	0,009
		14,999	1,656	1,65	1,651	0,036	0,036	0,035	1,652333333	0,035666667	0,59011905	0,03566667
		19,982	3,528	3,514	3,524	0,07	0,07	0,071	3,522	0,070333333	1,25785714	0,07033333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,006	0,004	0,001	0,004	0,005	0,001	0,003666667	0,003333333	0,00130952	0,00333333
		5,016	0,047	0,046	0,048	0,003	0,002	0,002	0,047	0,002333333	0,01678571	0,00233333
6,04	391,4	10,02	0,143	0,138	0,143	0,008	0,004	0,006	0,141333333	0,006	0,05047619	0,006
		14,993	1,605	1,6	1,592	0,017	0,021	0,021	1,599	0,019666667	0,57107143	0,01966667
		19,984	3,588	3,63	3,6	0,089	0,089	0,086	3,606	0,088	1,28785714	0,088
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,022	0,006	0,006	0,005	0,003	0,002	0,003	0,005666667	0,002666667	0,00202381	0,00266667
		4,997	0,048	0,048	0,048	0,001	0,001	0	0,048	0,000666667	0,01714286	0,00066667
11,92	773	10,041	0,127	0,126	0,125	0,004	0,004	0,005	0,126	0,004333333	0,045	0,00433333
		15,003	1,584	1,588	1,579	0,024	0,026	0,025	1,583666667	0,025	0,56559524	0,025
		19,983	3,561	3,612	3,582	0,115	0,107	0,116	3,585	0,112666667	1,28035714	0,11266667
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,002	0,002	0,001	0,002	0,002	0,002	0,001666667	0,002	0,00059524	0,002
		5,009	0,051	0,05	0,05	0,001	0,001	0,001	0,050333333	0,001	0,01797619	0,001
18,16	1178	10,008	0,164	0,159	0,157	0,004	0,004	0,004	0,16	0,004	0,05714286	0,004
		15,014	1,677	1,677	1,68	0,037	0,039	0,038	1,678	0,038	0,59928571	0,038
		19,984	3,71	3,688	3,711	0,125	0,12	0,116	3,703	0,120333333	1,3225	0,12033333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,003	0,003	0,003	0,002	0,002	0,001	0,003	0,001666667	0,00107143	0,00166667
		5,006	0,049	0,048	0,048	0,001	0,001	0,001	0,048333333	0,001	0,0172619	0,001
23,78	1544	10,004	0,173	0,166	0,171	0,005	0,005	0,004	0,17	0,004666667	0,06071429	0,00466667
		15,018	1,664	1,668	1,662	0,033	0,032	0,033	1,664666667	0,032666667	0,59452381	0,03266667
		19,984	3,602	3,607	3,599	0,103	0,101	0,097	3,602666667	0,100333333	1,28666667	0,10033333

Appendix 9

2*PVC

Motor												
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0	0	0	0	0	0	0	0	0	0
		5,008	0,017	0,018	0,018	0,001	0,001	0,001	0,017666667	0,001	0,00630952	0,001
0	0	10,014	0,055	0,055	0,055	0,005	0,005	0,005	0,055	0,005	0,01964286	0,005
		15,004	1,364	1,363	1,371	0,077	0,076	0,076	1,366	0,076333333	0,48785714	0,07633333
		19,98	2,889	2,882	2,732	0,157	0,16	0,161	2,834333333	0,159333333	1,0122619	0,15933333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,014	0,008	0,007	0,005	0,005	0,007	0,006	0,006666667	0,006	0,00238095	0,006
		5,02	0,02	0,02	0,021	0,004	0,002	0,004	0,020333333	0,003333333	0,0072619	0,00333333
6,73	434,9	10,024	0,057	0,059	0,057	0,012	0,008	0,007	0,057666667	0,009	0,02059524	0,009
		15,002	1,359	1,36	1,353	0,078	0,075	0,077	1,357333333	0,076666667	0,4847619	0,07666667
		19,982	3,029	3,094	2,994	0,167	0,178	0,168	3,039	0,171	1,08535714	0,171
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,00035714	0,001
		5,016	0,025	0,025	0,023	0,003	0,001	0,002	0,024333333	0,002	0,00869048	0,002
12,04	779,1	10,004	0,056	0,056	0,056	0,005	0,006	0,005	0,056	0,005333333	0,02	0,00533333
		14,992	1,308	1,299	1,305	0,076	0,073	0,075	1,304	0,074666667	0,46571429	0,07466667
		19,984	3,05	3,077	3,0254	0,169	0,191	0,174	3,0508	0,178	1,08957143	0,178
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,001	0	0	0	0	0	0,000333333	0	0,00011905	0
		5,012	0,022	0,023	0,023	0	0,001	0,002	0,022666667	0,001	0,00809524	0,001
18,16	1177	9,998	0,065	0,064	0,063	0,003	0,006	0,008	0,064	0,005666667	0,02285714	0,00566667
		15,001	1,334	1,326	1,321	0,079	0,072	0,075	1,327	0,075333333	0,47392857	0,07533333
		19,984	3,002	3,035	3,048	0,18	0,188	0,207	3,028333333	0,191666667	1,08154762	0,19166667
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,013	0,001	0,001	0,001	0	0,001	0	0,001	0,000333333	0,00035714	0,00033333
		5,002	0,017	0,017	0,016	0,001	0,002	0,001	0,016666667	0,001333333	0,00595238	0,00133333
23,63	1531	10,01	0,05	0,049	0,051	0,003	0,003	0,004	0,05	0,003333333	0,01785714	0,00333333
		14,989	1,374	1,375	1,361	0,072	0,072	0,073	1,37	0,072333333	0,48928571	0,07233333
		19,984	3,052	3,066	3,041	0,207	0,187	0,191	3,053	0,195	1,09035714	0,195

PVDF

Motor												
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0	0		0	0	0	0	0	0	0
		5,003	0,048	0,048	0,048	0,002	0,002	0,002	0,048	0,002	0,01714286	0,002
0	0	10,004	0,178	0,174	0,181	0,009	0,009	0,01	0,177666667	0,009333333	0,06345238	0,00933333
		14,991	1,588	1,568	1,569	0,031	0,032	0,032	1,575	0,031666667	0,5625	0,03166667
		19,981	3,46	3,485	3,469	0,067	0,067	0,065	3,471333333	0,066333333	1,2397619	0,06633333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0	0,001	0,001	0,002	0,001	0	0,000666667	0,001	0,0002381	0,001
		5,012	0,064	0,067	0,063	0,014	0,013	0,015	0,064666667	0,014	0,02309524	0,014
5,84	378	10,003	0,198	0,201	0,196	0,054	0,056	0,056	0,198333333	0,055333333	0,07083333	0,05533333
		14,981	1,706	1,701	1,686	0,158	0,153	0,154	1,697666667	0,155	0,60630952	0,155
		19,982	3,758	3,781	3,791	0,561	0,544	0,566	3,776666667	0,557	1,34880952	0,557
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,014	0,004	0,003	0,004	0,001	0,001	0,001	0,003666667	0,001	0,00130952	0,001
		5,009	0,058	0,058	0,058	0,01	0,012	0,011	0,058	0,011	0,02071429	0,011
11,84	772,4	9,996	0,159	0,157	0,153	0,033	0,033	0,038	0,156333333	0,034666667	0,05583333	0,03466667
		15,1	1,724	1,711	1,704	0,142	0,144	0,141	1,713	0,142333333	0,61178571	0,14233333
		19,982	3,707	3,648	3,665	0,438	0,45	0,453	3,673333333	0,447	1,31190476	0,447
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,015	0,001	0	0	0,001	0	0,001	0,000333333	0,000666667	0,00011905	0,00066667
		5,012	0,058	0,056	0,055	0,008	0,008	0,007	0,056333333	0,007666667	0,02011905	0,00766667
17,98	1161	10,033	0,173	0,169	0,168	0,022	0,024	0,022	0,17	0,022666667	0,06071429	0,02266667
		15,014	1,703	1,716	1,708	0,113	0,11	0,111	1,709	0,111333333	0,61035714	0,11133333
		19,984	3,66	3,66	3,658	0,379	0,378	0,377	3,659333333	0,378	1,30690476	0,378
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0	0	0	0	0	0	0	0	0	0
		4,999	0,047	0,047	0,047	0,005	0,006	0,007	0,047	0,006	0,01678571	0,006
23,32	1514	10,008	0,185	0,173	0,176	0,018	0,019	0,019	0,178	0,018666667	0,06357143	0,01866667
		15,011	1,692	1,702	1,697	0,137	0,138	0,138	1,697	0,137666667	0,60607143	0,13766667
		19,986	3,695	3,703	3,707	0,491	0,486	0,51	3,701666667	0,495666667	1,32202381	0,49566667

Appendix 10

PVDF Styrofoam

Motor												
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,0115	0	0	0	0	0	0	0	0	0	0
		5,009	0,6	0,06	0,06	0,007	0,007	0,007	0,24	0,007	0,08571429	0,007
0	0	10,039	0,22	0,216	0,216	0,024	0,024	0,025	0,217333333	0,024333333	0,07761905	0,02433333
		15,017	1,809	1,802	1,795	0,114	0,113	0,114	1,802	0,113666667	0,64357143	0,11366667
		19,98	3,739	3,696	3,736	0,361	0,363	0,355	3,723666667	0,359666667	1,32988095	0,35966667
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,002	0,001	0,001	0	0	0	0,001333333	0	0,00047619	0
		5,005	0,059	0,06	0,063	0,007	0,007	0,007	0,060666667	0,007	0,02166667	0,007
5,94	383,4	10,011	0,168	0,171	0,168	0,023	0,024	0,024	0,169	0,023666667	0,06035714	0,02366667
		15,003	1,748	1,745	1,735	0,109	0,112	0,109	1,742666667	0,11	0,62238095	0,11
		19,982	3,757	3,737	3,748	0,363	0,352	0,362	3,747333333	0,359	1,33833333	0,359
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,019	0,003	0,004	0,004	0,001	0,001	0,002	0,003666667	0,001333333	0,00130952	0,00133333
		4,996	0,063	0,059	0,052	0,007	0,007	0,007	0,058	0,007	0,02071429	0,007
11,94	773,3	10,01	0,16	0,159	0,161	0,023	0,024	0,023	0,16	0,023333333	0,05714286	0,02333333
		15,018	1,702	1,694	1,69	0,104	0,105	0,105	1,695333333	0,104666667	0,60547619	0,10466667
		19,984	3,745	3,72	3,703	0,35	0,347	0,345	3,722666667	0,347333333	1,32952381	0,34733333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,019	0,003	0,002	0,003	0,001	0,002	0,001	0,002666667	0,001333333	0,00095238	0,00133333
		4,987	0,059	0,059	0,059	0,007	0,007	0,007	0,059	0,007	0,02107143	0,007
18,01	1172	10,03	0,161	0,162	0,16	0,023	0,023	0,023	0,161	0,023	0,0575	0,023
		15,008	1,688	1,688	1,674	0,106	0,105	0,104	1,683333333	0,105	0,60119048	0,105
		19,984	3,711	3,714	3,713	0,359	0,357	0,357	3,712666667	0,357666667	1,32595238	0,35766667
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,001	0	0	0,002	0,001	0,003	0,000333333	0,002	0,00011905	0,002
		5,008	0,016	0,018	0,018	0,005	0,003	0,009	0,017333333	0,005666667	0,00619048	0,00566667
23,19	1506	10,016	0,367	0,361	0,374	0,046	0,055	0,049	0,367333333	0,05	0,13119048	0,05
		15,006	2,005	1,909	2,021	0,168	0,177	0,172	1,978333333	0,172333333	0,70654762	0,17233333
		19,976	2,752	2,846	2,786	0,366	0,366	0,369	2,794666667	0,367	0,99809524	0,367

NCE55 & PVC

Motor												
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0	0	0	0	0	0	0	0	0	0
		4,999	0,025	0,025	0,025	0,003	0,003	0,003	0,025	0,003	0,00892857	0,003
0	0	10,003	0,081	0,082	0,085	0,01	0,01	0,01	0,082666667	0,01	0,02952381	0,01
		15,016	1,51	1,515	1,498	0,092	0,093	0,093	1,507666667	0,092666667	0,53845238	0,09266667
		19,978	4,601	4,648	4,613	0,309	0,304	0,317	4,620666667	0,31	1,6502381	0,31
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,019	0,001	0,001	0,001	0,005	0,006	0,003	0,001	0,004666667	0,00035714	0,00466667
		5,002	0,022	0,024	0,022	0,006	0,007	0,003	0,022666667	0,005333333	0,00809524	0,00533333
6	387,8	10,026	0,068	0,063	0,07	0,008	0,011	0,004	0,067	0,007666667	0,02392857	0,00766667
		14,984	1,363	1,379	1,369	0,089	0,096	0,097	1,370333333	0,094	0,48940476	0,094
		19,98	4,597	4,524	4,641	0,388	0,385	0,401	4,587333333	0,391333333	1,63833333	0,39133333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,018	0,003	0,003	0,001	0,007	0,006	0,005	0,002333333	0,006	0,00083333	0,006
		5,009	0,022	0,02	0,018	0,005	0,001	0,003	0,02	0,003	0,00714286	0,003
12,08	783,1	10,002	0,06	0,059	0,058	0,005	0,006	0,008	0,059	0,006333333	0,02107143	0,00633333
		15,012	1,501	1,506	1,489	0,096	0,095	0,094	1,498666667	0,095	0,5352381	0,095
		19,982	4,318	4,39	4,386	0,322	0,329	0,304	4,364666667	0,318333333	1,55880952	0,31833333
V	RPM	HV[kV]	U1[V]			U2[V]			Average U1[V]	Average U2[V]	I1[µA]	I2[µA]
		0,014	0,002	0,007	0,002	0,007	0,003	0,005	0,003666667	0,005	0,00130952	0,005
		4,995	0,02	0,018	0,018	0,003	0,006	0,005	0,018666667	0,004666667	0,00666667	0,00466667
18,18	1179	10,006	0,81	0,078	0,087	0,027	0,03	0,034	0,325	0,030333333	0,11607143	0,03033333
		15,002	1,408	1,401	1,398	0,183	0,188	0,18	1,402333333	0,183666667	0,50083333	0,18366667
		19,982	4,567	4,54	4,627	0,561	0,541	0,526	4,578	0,542666667	1,635	0,54266667

Appendix 11

Relative permittivity results

Twaron											
f/[Hz]	Uc/[V]	Uin/[V]	dB	U/[V]	Z/[Ω]	I/[A]	C/[F]	eps	epsR	A/[m]	d/[m]
4872	6,22	7,23	-3,0093826	7,23	9,84E+03	7,35E-04	3,32E-09	3,3215E-11	3,75144394	0,1*0,1	100*E-6
PVC											
f/[Hz]	Uc/[V]	Uin/[V]	dB	U/[V]	Z/[Ω]	I/[A]	C/[F]	eps	epsR	A/[m]	d/[m]
40840	0,82	0,952	-2,9852139	0,952	9840	9,6748E-05	3,96241E-10	3,9624E-11	4,47527788	0,1*0,1	0,001
PVDF											
f/[Hz]	Uc/[V]	Uin/[V]	dB	U/[V]	Z/[Ω]	I/[A]	C/[F]	eps	epsR	A/[m]	d/[m]
18266	5,63	6,55	-3,0271121	6,55	9,84E+03	6,66E-04	8,86E-10	4,4297E-11	5,0030206	0,1*0,1	0,005
PVDF Sf.											
f/[Hz]	Uc/[V]	Uin/[V]	dB	U/[V]	Z/[Ω]	I/[A]	C/[F]	eps	epsR	A/[m]	d/[m]
122635	0,2533	0,295	-3,048016	0,295	9840	2,998E-05	1,31957E-10	1,3196E-10	14,9036041	0,1*0,11	0,01
NCE55											
f/[Hz]	Uc/[V]	Uin/[V]	dB	U/[V]	Z/[Ω]	I/[A]	C/[F]	eps	epsR	A/[m]	d/[m]
703,1	4,665	5,415	-2,9817009	5,415	9840	0,0005503	2,30159E-08	3,1967E-08	3610,40686	0,06*0,06	0,005

Appendix 12

Coupling 1

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
0	0	0,018	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,0001	3,57143E-05
		2,497	0,3	0,2	0,2	1,4	0,3	0,6	0,233333333	0,766666667	0,00023333	0,00027381
		4,984	0,8	2,9	3,5	3,7	2,8	2,1	2,4	2,866666667	0,0024	0,00102381
		7,074	5100	5188	5053	2,1	0,6	1,5	5113,666667	1,4	5,11366667	0,0005
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
6,13	395,8	0,018	0	0	0	0,3	0,1	0,5	0	0,3	0	0,000107143
		2,507	6,2	17,8	15,8	23,5	27,4	39,8	13,26666667	30,23333333	0,01326667	0,010797619
		2,992	19,7	66,9	69,9	143,8	149,8	19,8	52,16666667	104,4666667	0,05216667	0,037309524
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
12,01	780,9	0,016	0,1	0,3	0,4	0,2	0,1	0,2	0,266666667	0,166666667	0,00026667	5,95238E-05
		2,514	19,8	9,1	17,8	57,3	92,3	73,8	15,56666667	74,46666667	0,01556667	0,026595238
		3,025	33,7	54,8	38,9	152,8	39,9	108,6	42,46666667	100,4333333	0,04246667	0,035869048
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
17,49	1149	0,018	0,2	0,4	0,3	1,3	0,1	0	0,3	0,466666667	0,0003	0,000166667
		2,506	13,2	6,3	7,4	18,8	10,3	12,9	8,966666667	14	0,00896667	0,005
		3,21	83,3	88,8	100,4	110,4	60,9	107,9	90,83333333	93,06666667	0,09083333	0,033238095
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
20,14	1351	0,018	0,7	0,3	0	0	0	0,1	0,333333333	0,033333333	0,00033333	1,19048E-05
		2,512	5,9	1	4,8	12,6	18,8	6,8	3,9	12,73333333	0,0039	0,004547619
		3,037	32,2	45,7	44,5	21,9	101,8	56,8	40,8	60,16666667	0,0408	0,021488095
		3,422	150,7	149,8	132,6	41,1	57	80,3	144,3666667	59,46666667	0,14436667	0,021238095

Coupling 2

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
0	0	0,018	0	0	0	0	0	0	0	0	0	0
		2,49	0,3	0,4	0,3	0	0	0	0,333333333	0	0,000333333	0
		5,004	0,2	0,5	8,1	5,6	3,4	1,4	2,933333333	3,466666667	0,002933333	0,0012381
		7,51	6,4	4,8	5,6	1,7	3,5	4,2	5,6	3,133333333	0,0056	0,00111905
		10,002	73,3	65,3	70,7	0,2	3,3	0,4	69,76666667	1,3	0,069766667	0,00046429
		12,49	185,6	185,9	185	0,4	0,3	2,3	185,5	1	0,1855	0,00035714
		14,992	318,9	311,6	313,3	0,1	2	1,4	314,6	1,166666667	0,3146	0,00041667
		16,941	415,8	577,8	506,7	2,5	4,6	2,8	500,1	3,3	0,5001	0,00117857
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
5,997	388,5	0,018	1,2	0,6	0,1	2,5	1,7	1,3	0,633333333	1,833333333	0,000633333	0,00065476
		2,514	1,2	0,4	0,8	1,6	0,5	2,8	0,8	1,633333333	0,0008	0,00058333
		5,002	3,5	1	0,9	2,8	2,5	3,7	1,8	3	0,0018	0,00107143
		7,503	1,1	0,9	1,3	6,9	7,1	13,9	1,1	9,3	0,0011	0,00332143
		10,004	59,2	64,7	52,1	238,6	299,9	131,8	58,66666667	223,4333333	0,058666667	0,07979762
		12,472	109,7	53,8	96,3	257,8	68,7	257,8	86,6	194,7666667	0,0866	0,06955952
		14,074	378,9	180,9	316,5	94,6	176,5	172,4	292,1	147,8333333	0,2921	0,05279762
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
11,85	775,3	0,016	0,8	0,1	0,2	2,3	1,9	1,7	0,366666667	1,966666667	0,000366667	0,00070238
		2,514	0,9	0,9	1,3	0,5	0,6	0,4	1,033333333	0,5	0,001033333	0,00017857
		5,01	0,6	0,5	1,4	1,8	2,8	1,9	0,833333333	2,166666667	0,000833333	0,00077381
		7,502	1,4	0,9	1,1	2,2	2,3	4	1,133333333	2,833333333	0,001133333	0,0010119
		10,006	4,8	5,4	6,4	1,1	2,4	5,4	5,533333333	2,966666667	0,005533333	0,00105952
		12,488	468,7	644,2	345,8	274,8	556,8	549,2	486,2333333	460,2666667	0,486233333	0,16438095
		13,996	534,8	201,8	302,5	311,8	369,5	316,5	346,3666667	332,6	0,346366667	0,11878571
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
17,6	1149	0,018	0,2	0,1	0,3	0,6	0,4	0,7	0,2	0,566666667	0,0002	0,00020238
		2,492	0,4	0,3	0,7	0,3	0,3	0,2	0,466666667	0,266666667	0,000466667	9,5238E-05
		5,016	1,4	1,5	1,7	1,1	1,2	0,7	1,533333333	1	0,001533333	0,00035714
		7,493	2	3,1	2,4	1,1	1,9	2,1	2,5	1,7	0,0025	0,00060714
		9,999	3,1	3,8	3	0,9	0,5	1,6	3,3	1	0,0033	0,00035714
		12,499	175,6	170,8	170,7	52,6	93,4	11,2	172,3666667	52,4	0,172366667	0,01871429
		14,514	340,8	174,3	315,4	152,6	127,8	80,5	276,8333333	120,3	0,276833333	0,04296429
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
20,15	1318	0,014	0	0	0,1	0,1	1	0,3	0,033333333	0,466666667	3,33333E-05	0,00016667
		2,515	0,4	0,5	0,3	0,6	0,8	0,2	0,4	0,533333333	0,0004	0,00019048
		5,025	1,2	1,4	1,1	5,2	1,6	1	1,233333333	2,6	0,001233333	0,00092857
		7,497	53,9	33,5	82,6	46,6	16,2	41,9	56,66666667	34,9	0,056666667	0,01246429
		10,062	2,9	2,8	4,8	2,8	0,1	2,2	3,5	1,7	0,0035	0,00060714
		12,512	143,7	151,8	204,8	49,8	99,8	93,6	166,7666667	81,06666667	0,166766667	0,02895238
		14,508	163,7	165,8	154,8	180,9	59	107,8	161,4333333	115,9	0,161433333	0,04139286

Appendix 13

Coupling 3

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
0	0	0,015	0	0	0	0	0	0	0	0	0	0
		2,501	0	0	0	0,1	0,1	0,1	0	0,1	0	3,57143E-05
		4,99	0,5	1,8	0,7	31,8	33,2	19,2	1	28,06666667	0,001	0,01002381
		7,51	69100	69200	69500	18,8	16,7	19,8	69266,66667	18,43333333	69,2666667	0,006583333
		8,54	190400	186500	197800	264,7	239,8	190,8	191566,6667	231,7666667	191,566667	0,08277381
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
5,91	388,6	0,015	0	0	0	0,3	1,2	0,2	0	0,566666667	0	0,000202381
		2,503	0,8	0,2	0,4	130,6	83,9	104,7	0,466666667	106,4	0,00046667	0,038
		3,011	0,6	1	0,5	54,6	40,5	54,1	0,7	49,73333333	0,0007	0,017761905
		3,483	65,2	87,9	79,7	317,7	453,1	291,9	77,6	354,2333333	0,0776	0,126511905
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
12,2	797,8	0,015	0	0	0	0,1	0	0	0	0,033333333	0	1,19048E-05
		2,492	0,1	0,1	0	2,7	2,1	2,4	0,066666667	2,4	6,6667E-05	0,000857143
		3,024	14,3	15,4	18	304,5	105,3	151,8	15,9	187,2	0,0159	0,066857143
		3,555	53,9	95,8	104,2	635	391	568	84,63333333	531,3333333	0,08463333	0,189761905
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
16,42	1074	0,018	0	0	0	0,1	0	0	0	0,033333333	0	1,19048E-05
		2,526	0,2	0,4	0,2	0,5	2,8	1,7	0,266666667	1,666666667	0,00026667	0,000595238
		3,004	4,8	12,9	10,4	104,8	188,9	231,6	9,366666667	175,1	0,00936667	0,062535714
		3,525	124,8	155,1	165,7	915	511	657	148,5333333	694,3333333	0,14853333	0,24797619
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
19,9	1308	0,018	0	0	0	0	0	0	0	0	0	0
		2,533	0,1	0,1	0	0,3	0,6	0,5	0,066666667	0,466666667	6,6667E-05	0,000166667
		2,966	3,4	4,8	10,3	77,8	153,8	145,8	6,166666667	125,8	0,00616667	0,044928571
		3,454	84,9	73,6	60,5	536,7	654,7	598,3	73	596,5666667	0,073	0,213059524
		3,864	215,4	199,8	235,6	822,3	777,4	805	216,9333333	801,5666667	0,21693333	0,28627381

Coupling 4

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
0	0	0,014	0	0	0	0	0	0	0	0	0	0
		2,53	0,1	0,2	0,3	0	0	0	0,2	0	0,0002	0
		5,044	6,1	5,6	7,5	1,6	1,9	0,7	6,4	1,4	0,0064	0,0005
		7,5	10,6	11	12,4	0,3	0,8	0,5	11,33333333	0,533333333	0,01133333	0,000190476
		10,016	15,5	13,4	14,8	2,3	3,1	0,5	14,56666667	1,966666667	0,01456667	0,000702381
		12,516	81,6	78,9	82,1	0,5	0,3	0,2	80,86666667	0,333333333	0,08086667	0,000119048
		14,992	183,7	186,5	193,7	0,2	0,5	0,3	187,9666667	0,333333333	0,18796667	0,000119048
		17,5	348,6	356,8	347,4	43,1	42,4	41,8	350,9333333	42,43333333	0,35093333	0,015154762
		19,982	536,7	538,4	528,7	72,8	70,5	69,8	534,6	71,03333333	0,5346	0,025369048
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
6,03	388,7	0,017	2,8	1,6	2,4	0,7	0,2	0,6	2,266666667	0,5	0,00226667	0,000178571
		2,499	2,7	2,3	0,9	0,5	0,3	0,5	1,966666667	0,433333333	0,00196667	0,000154762
		5,026	4,8	4,3	2,4	2	1,1	1,8	3,833333333	1,633333333	0,00383333	0,000583333
		7,477	5,1	4,2	0,9	1,4	2,6	3,2	3,4	2,4	0,0034	0,000857143
		10,097	4,5	6,3	3,4	28,8	8,3	20,8	4,733333333	19,3	0,00473333	0,006892857
		12,456	14,6	28,6	41,3	25,3	19,3	48,5	28,16666667	31,03333333	0,02816667	0,011083333
		15,035	3490	3020	3481	43,8	54,3	69,3	3330,333333	55,8	3,33033333	0,019928571
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
11,91	782,5	0,016	0,8	0,6	0,6	0,2	0,1	0,1	0,666666667	0,133333333	0,00066667	4,7619E-05
		2,49	0,9	0,8	0,9	0,1	0,2	0,3	0,866666667	0,2	0,00086667	7,14286E-05
		5,001	0,9	1,6	1,2	0,1	0,3	0,4	1,233333333	0,266666667	0,00123333	9,52381E-05
		7,503	0,8	1,6	1,5	0,6	0,2	0,6	1,3	0,466666667	0,0013	0,000166667
		10,005	1,3	0,6	3	0,6	0,8	0,7	1,633333333	0,7	0,00163333	0,00025
		12,508	8,7	6,8	5,8	18,6	13,2	24,2	7,1	18,66666667	0,0071	0,006666667
		14,54	437,8	501,8	384,1	35,9	35	20,5	441,2333333	30,46666667	0,44123333	0,010880952
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
17,53	1145	0,015	0,3	0,1	0,2	0,1	0,1	0	0,2	0,066666667	0,0002	2,38095E-05
		2,508	0,4	0,2	0,1	0,1	0,1	0,1	0,233333333	0,1	0,00023333	3,57143E-05
		5,015	0,4	0,2	0,6	0,1	0,2	0,1	0,4	0,133333333	0,0004	4,7619E-05
		7,55	0,7	0,6	0,7	0,1	0,2	0,2	0,666666667	0,166666667	0,00066667	5,95238E-05
		10,012	0,4	0,9	0,7	0,2	3,1	0,2	0,666666667	1,166666667	0,00066667	0,000416667
		12,5	83,7	110,6	89,9	9,7	14,7	16,2	94,73333333	13,53333333	0,09473333	0,004833333
		14,413	103,8	107,6	147,2	11,1	13,6	20,3	119,5333333	15	0,11953333	0,005357143
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
20,19	1327	0,018	0,4	0,2	0,2	0	0,1	0	0,266666667	0,033333333	0,00026667	1,19048E-05
		2,502	0,4	0,3	0,5	0,1	0,1	0,1	0,4	0,1	0,0004	3,57143E-05
		5,017	0,4	0,6	0,5	0,1	0	0,1	0,5	0,066666667	0,0005	2,38095E-05
		7,513	0,6	0,3	0,6	0,1	0	0,1	0,5	0,066666667	0,0005	2,38095E-05
		10,034	0,6	0,6	1,3	0,1	0,1	0,1	0,833333333	0,1	0,00083333	3,57143E-05
		12,459	2,7	5,2	4,5	10,6	11,4	2,6	4,133333333	8,2	0,00413333	0,002928571
		14,792	3627	109,2	3126	14,7	36,8	19,9	2287,4	23,8	2,2874	0,0085

Appendix 14

Coupling 5

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
0	0	0,018	0	0	0	0,1	0,1	0,1	0	0,1	0	3,57143E-05
		2,498	0	0	0	1,8	1,7	1,7	0	1,733333333	0	0,000619048
		5,006	2,1	2,4	3,6	38,2	19,4	37,8	2,7	31,8	0,0027	0,011357143
		7,49	43210	43050	43180	10,1	9,9	22	43146,66667	14	43,14666667	0,005
		7,814	65900	65800	65900	65,9	160,2	92,8	65866,66667	106,3	65,86666667	0,037964286

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
6,1	399,3	0,011	0,1	0	0	0	0,4	0,2	0,033333333	0,2	3,33333E-05	7,14286E-05
		2,515	0,3	0,1	0,6	19,2	3,1	11,5	0,333333333	11,26666667	0,000333333	0,00402381
		3,03	11,7	1,8	2,4	85,5	69,8	23,9	5,3	59,73333333	0,0053	0,021333333
		3,338	20,2	13,9	21,1	40,1	183,9	181,9	18,4	135,3	0,0184	0,048321429

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
11,65	758,2	0,018	0	0	0	0	0	0,1	0	0,033333333	0	1,19048E-05
		2,518	0,1	0	0,1	22,7	0,7	1,8	0,066666667	8,4	6,66667E-05	0,003
		2,994	0,3	0,2	0,7	0,8	38,9	120,2	0,4	53,3	0,0004	0,019035714
		3,512	31,2	29,2	38,5	525,6	411,8	394,8	32,96666667	444,0666667	0,032966667	0,158595238

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
17,4	1134	0,015	0	0	0	0	0	0	0	0	0	0
		2,502	0,1	0,1	0,1	0,5	0,1	1,1	0,1	0,566666667	0,0001	0,000202381
		2,982	0,3	11,9	3,1	11,7	48,6	99,4	5,1	53,23333333	0,0051	0,019011905
		3,473	60,4	25,2	20,3	480,5	425,7	604,9	35,3	503,7	0,0353	0,179892857
		3,829	76,2	91,2	110,2	613,8	597,8	794,5	92,53333333	668,7	0,092533333	0,238821429

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
20	1310	0,019	0	0	0	0,1	0	0	0	0,033333333	0	1,19048E-05
		2,473	0,1	0,1	0,1	0,7	0,4	0,5	0,1	0,533333333	0,0001	0,000190476
		3,034	0,1	0,1	0,1	32,9	27,2	40,2	0,1	33,43333333	0,0001	0,011940476
		3,537	19,4	41,3	56,8	505,6	557,8	411,6	39,16666667	491,6666667	0,039166667	0,175595238
		3,967	179,8	261,5	156,8	1359	987,5	808,1	199,3666667	1051,533333	0,199366667	0,375547619

Coupling 6

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
0	0	0,021	0	0	0	0	0	0	0	0	0	0
		2,509	0	0	0	1,4	1,5	1,5	0	1,466666667	0	0,00052381
		2,988	0	0	0	1,9	2,1	1,9	0	1,966666667	0	0,000702381
		3,488	0,9	1,3	0,8	22,5	23	19	1	21,5	0,001	0,007678571
		3,994	1,5	2,5	2,3	12	12,5	10,9	2,1	11,8	0,0021	0,004214286
		4,513	2,6	1,7	3,4	22,5	53,2	19,4	2,566666667	31,7	0,00256667	0,011321429
		5,059	1,2	2,3	0,4	11,2	10,2	16,4	1,3	12,6	0,0013	0,0045
		7,514	45230	45610	45180	20,2	22,1	16,7	45340	19,66666667	45,34	0,00702381
		8,476	129000	130700	131700	14,6	3,2	2,3	130466,6667	6,7	130,466667	0,002392857

V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
5,99	389,4	0,016	0	0,1	0	0,2	0,4	0,2	0,033333333	0,266666667	3,3333E-05	9,52381E-05
		2,501	0,6	0,1	0,5	3,5	7,6	9,2	0,4	6,766666667	0,0004	0,002416667
		3,068	0,5	0,9	1,2	61,6	55,4	41,8	0,866666667	52,93333333	0,00086667	0,018904762
		3,408	42,6	20,5	30,1	236,8	290,1	263,4	31,06666667	263,4333333	0,03106667	0,094083333

V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
12,12	789,4	0,018	0	0	0	0,1	0	0,1	0	0,066666667	0	2,38095E-05
		2,506	0,1	0	0,1	2,5	2,4	2,3	0,066666667	2,4	6,6667E-05	0,000857143
		3,019	0,6	0,1	0,1	3,8	10,6	3,8	0,266666667	6,066666667	0,00026667	0,002166667
		3,494	81,8	47,6	72,3	398,1	447,5	470,8	67,23333333	438,8	0,06723333	0,156714286
		3,924	128,6	187,9	180,7	653,5	602,4	526,7	165,7333333	594,2	0,16573333	0,212214286

V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
16,4	1075	0,015	0	0	0	0,1	0,1	0,1	0	0,1	0	3,57143E-05
		2,539	0,1	0,1	0,2	1,3	1,3	1,4	0,133333333	1,333333333	0,00013333	0,00047619
		3,003	1,7	6,6	1,1	17,7	4,1	28,8	3,133333333	16,86666667	0,00313333	0,00602381
		3,782	100,2	85,7	102,3	615,4	1215	908,7	96,06666667	913,0333333	0,09606667	0,326083333

V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
20,15	1322	0,015	0	0	0	0	0	0,1	0	0,033333333	0	1,19048E-05
		2,491	0,1	0,1	0,1	0,6	0,1	0,4	0,1	0,366666667	0,0001	0,000130952
		3,02	17,6	10,1	1,5	1,5	122,9	17,1	9,733333333	47,16666667	0,00973333	0,016845238
		3,865	142,5	106,2	87,2	941	785	902	111,9666667	876	0,11196667	0,312857143

Appendix 15

Coupling 7

Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
		0,015	0	0	0	0	0	0	0	0	0	0
		2,505	0	0	0	0,1	0,1	0,1	0	0,1	0	3,57143E-05
		4,981	1,5	2,3	2,2	0,8	0,6	1,1	2	0,833333333	0,002	0,000297619
		7,513	1,9	2,4	2,2	0,8	1	0,8	2,166666667	0,866666667	0,00216667	0,000309524
0	0	10,006	8,6	5,7	8,5	1,1	0,9	1	7,6	1	0,0076	0,000357143
		12,52	129,9	129,8	134,7	1,1	2,1	1,5	131,4666667	1,566666667	0,13146667	0,000559524
		15,058	273,4	243,5	266,7	6,8	6,7	5,3	261,2	6,266666667	0,2612	0,002238095
		17,547	411,7	426,8	432,5	10,2	11	12,4	423,6666667	11,2	0,42366667	0,004
		19,008	506,8	507,4	492,8	18,9	12,3	16,5	502,3333333	15,9	0,50233333	0,005678571
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
		0,015	0,1	0,1	0	0	0,1	0,2	0,066666667	0,1	6,6667E-05	3,57143E-05
		2,492	1,5	0,2	2,3	0,2	0,9	0,7	1,333333333	0,6	0,00133333	0,000214286
		5,026	5,2	4,7	3,7	1,4	1,1	1,2	4,533333333	1,233333333	0,00453333	0,000440476
6,015	389,6	7,516	5,1	5	5,6	0,8	0,9	1,5	5,233333333	1,066666667	0,00523333	0,000380952
		10,601	51,5	27,9	58,8	11,1	8,5	19,3	46,06666667	12,96666667	0,04606667	0,004630952
		12,556	339,8	435,3	364,7	58,6	47,8	50,2	379,9333333	52,2	0,37993333	0,018642857
		14,522	6200	8100	6930	120,6	108,6	133,8	7076,666667	121	7,07666667	0,043214286
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
		0,018	0	0	0	0,1	0,1	0,2	0	0,133333333	0	4,7619E-05
		2,531	0,1	0,2	0,3	0,1	0,3	0,2	0,2	0,2	0,0002	7,14286E-05
		4,993	0,6	0,8	0,7	0,2	0,4	0,3	0,7	0,3	0,0007	0,000107143
11,73	766,9	7,492	0,6	1,2	0,9	0,4	0,5	0,2	0,9	0,366666667	0,0009	0,000130952
		10,049	59,8	83,6	52,5	13,2	15,4	11,2	65,3	13,26666667	0,0653	0,004738095
		12,472	93,7	81,9	88,9	29,6	16,9	18,4	88,16666667	21,63333333	0,08816667	0,00772619
		14,053	558,6	552,9	466,7	61,1	120,7	69,9	526,0666667	83,9	0,52606667	0,029964286
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
		0,014	0	0	0	0,1	0,1	0,1	0	0,1	0	3,57143E-05
		2,517	0,1	0,1	0	0,1	0,2	0,2	0,066666667	0,166666667	6,6667E-05	5,95238E-05
		4,959	0,2	0,3	0,2	0,2	0	0,1	0,233333333	0,1	0,00023333	3,57143E-05
16,48	1078	7,523	0,6	0,3	0,3	0,2	0,1	0,2	0,4	0,166666667	0,0004	5,95238E-05
		10,148	6,6	10,3	1,1	0	0,1	0,3	6	0,133333333	0,006	4,7619E-05
		12,594	115,1	123,1	141,7	20,1	31,8	17,2	126,6333333	23,03333333	0,12663333	0,00822619
		14,078	234,1	244,5	248,2	71,2	96,2	81,5	242,2666667	82,96666667	0,24226667	0,029630952
Motor												
V	RPM	HV[kV]	U1[mV]			U2[mV]			Average U1[mV]	Average U2[mV]	I1[µA]	I2[µA]
		0,015	0	0,1	0	0	0	0,1	0,033333333	0,033333333	3,3333E-05	1,19048E-05
		2,468	0,1	0	0,1	0	0,1	0,1	0,066666667	0,066666667	6,6667E-05	2,38095E-05
		5,014	0,2	0,4	0,3	0,2	0,2	0	0,3	0,133333333	0,0003	4,7619E-05
20,08	1317	7,53	0,7	0,1	0,6	0	0	0,1	0,466666667	0,033333333	0,00046667	1,19048E-05
		10,095	0,3	0,6	0,6	0,5	0,3	0,1	0,5	0,3	0,0005	0,000107143
		12,602	2,8	2,3	2,9	0,2	0,4	0,1	2,666666667	0,233333333	0,00266667	8,33333E-05
		14,091	212,6	205,3	232,4	67,7	72,1	73,6	216,7666667	71,13333333	0,21676667	0,025404762