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作品名稱　**Analysis on a New Electric Field Measurement Method Using Ionic Propulsion Propeller**

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關鍵詞　**Field intensity、Ionic propulsion、Stroboscopy**

作者照片

ABSTRACT : Given the high sensitivity of electronic instruments, electromagnetic field intensity measuring is now becoming an essential part of the industry. Current electric field intensity meters are unfit for individual use and focus mainly on electromagnetic radiation rather than the field itself. In ionic propulsion, the propulsion force is proportional to electric field intensity but the use of this property on measurement remains largely unexplored.
Here, our team investigates ionic propulsion in electric fields generated by electro-static methods and then systematically varies the point of measurement inside the field, thereby altering the intensity of the field without focusing on electromagnetic radiation. By combining the Van de graaff generator with an adjustable ionic thrust propeller, we find that the propeller speed which is proportional to the electric field is directly determined by the electric field intensity. Furthermore, we applied stroboscopy to the system to measure RPM, and have achieved the direct interaction between field intensity and RPM, which could be a new meter for field intensity measurement.

Ⅰ. Introduction

I-1. Ion propulsion force

When a electrode is placed at a point with voltage V, if the electrode forms a current, it will constantly be using Energy of V^2/R per second. Because work in rotation is calculated as the torque integrated with the angular displacement, rotational power can be calculated as torque multiplied to angular velocity multiplied to torque. In this logic, when two forces come to a equillibrium point and angular velocity of a electrically propelled propeller becomes constant, $V^2/R = \tau\omega$ would apply.

I-2. Introduction to research

The stronger the electrical energy of the engine, the stronger the propulsion force. Not to mention, propulsion force gets stronger as electric field intensity intensifies. Because of these properties, we can backcount the field intensity from the ion propulsion force, and this is why ion propulsion becomes a possible electric field measurement method. The primarily important thing we should care about in space is safety. And electromagnetic fields in Outer space pose a severe threat to microdevices, disabling systems, and telecommunication. The same problem happens in the electronics industry involving microdevices. These industries have to get rid of charged particles periodically, but measurement of these particles can tell us when to do this. Through this research, we have found a way to use ionic propulsion besides engines and ways to help the industry and space exploration with these ideas.

I-3. Difference with prior research

Prior research of electric field measures usually focus on electromagnetic properties of a charge, making it focus on measuring the electromagnetic waves involving the field. Our research focuses on the field itself, making our methods applicable to completely static charges. In other research, the methods are only applicable to strong fields generated by large charges. Using efficient, low-current ionic propulsion. we succeeded in measuring very low intensity fields.

II. Materials & Method

II-1. Materials

II-1.1. Van de Graaff generator

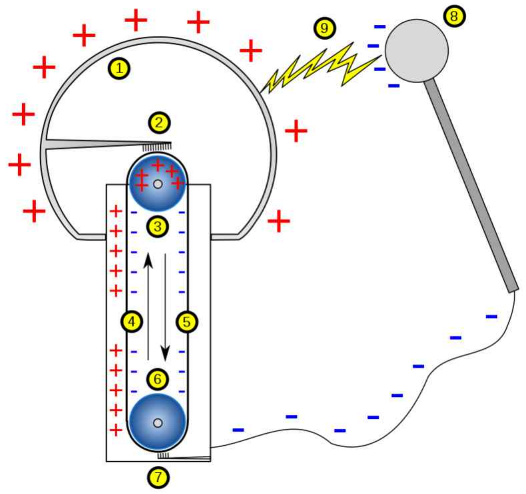

Fig. 1. Scheme of a Van de Graaff generator's mechanism

The Van de Graaff generator is an electrostatic generator that uses a moving belt to accumulate electric charges in a hollow metal sphere at the top of the insulation column, creating a very high potential electrical energy. The Van de Graaff generator structure consists of a rubber belt and a hollow metal sphere. The Van de Graaff generator is charged by triboelectricity. As the belt rotates, friction between the belt and an insulator - connected with the metal sphere causes triboelectricity. This process gives the rubber belt negative charges and the metal sphere positive charges. By repeating the process above, a large amount of charge can be accumulated on the surface of the metal sphere. Charges have the property of being drawn to sharp points. In this experiment, we intentionally created a sharp point near the Van de Graaff generator to concentrate the charge at the point.

II-1.2. Stroboscopy

As a kind of visual phenomenon, the strobe effect is caused by 'aliasing' that occurs when repetitive movements appear due to a series of temporary images. A strobe effect occurs when an object moving in a series of short scenes makes any periodic movement. The wagon wheel phenomenon is a representative example of the strobe effect. When a wheel is observed from the direction in which the wheel rotates, it may be seen as if it were rotating slower than it is. In other cases, it may appear to rotate in the opposite direction. When a stroboscope shines a periodically flashing light on a rotating body, it will show the 'flash-per-second' of the stroboscope. When bigger than the RPM (or multiple), the body seems to be rotating in reverse. If longer, the rotational speed seems to be slower, depending on the rotational and blinking time difference. Similarly, we can imagine the RPM of the body becoming equal to or multiple to the flash frequency. Then, the rotating body will be seen as stationary. Adjusting the flashing frequency of the stroboscope until the body looks stationary, we can induce the spinning body's RPM equal to that of the strobe's flash per second.

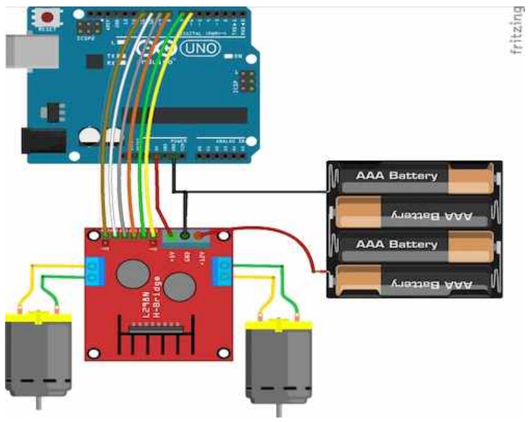

Fig. 2. Scheme of RPM altering circuit

II-1.3. Practice using Arduino motor system

The spinner's Rounds per minute (RPM) are measured by a stroboscope made with Arduino. The scope helps measure the RPM of the spinner using the stroboscopic effect, the emergence of a rapid pattern in a spinning object. To build a circuit for the Stroboscope, we connected the Mainboard and the computer to control the entire Arduino system. We also added a motor to the system to spin the scope and attached a motor driver to handle the motor's RPM. In our system, the RPM of the scope is adjustable. As the user puts the input (in this case, it is RPM of the scope), Stroboscope will spin to it, which leads to better accuracy in results. The reason for using Arduino to implement scope is simple; Easy control and Clear procedure. Arduino provides an environment for connecting hardware and software in a singular structure, showing a more intuitive program progression than other programming languages or systems.

```
// right motor pins
#define ENA 6
#define IN1 7
#define IN2 8

void setup() {
  // set up serial port
  Serial.begin(9600);

  // set motor pins OUTPUT mode
  pinMode(ENA, OUTPUT);
  pinMode(IN1, OUTPUT);
  pinMode(IN2, OUTPUT);

  // wait 2 seconds after power up
  delay(2000);

  // set motor to move forward
  digitalWrite(IN1, HIGH);
  digitalWrite(IN2, LOW);


  // set PWM of motor for a spin
  while(int pwm = 100) {
    Serial.println(pwm);
    analogWrite(ENA, pwm);
    delay(100);
  }
}

void loop() {
  // nothing to do here
}
```

Fig. 3. Code for the method and explanation

II-1.4. Propeller

Each propeller(capacitor) side will have equal charges, though different in size. The more charges there are in a smaller area, the denser the flux around it will be. Moreover, if we made that area of charges small enough to make it seem like a sharp electrode, it would exert even stronger electric fields. When the propeller is positively charged near the van de Graaf generator, the flux will collide with the air atoms, thus ripping electrons from it, creating positively charged air. Positively charged air will then be forced away from the positively charged electrodes, creating wind. The wind would blow onto our propeller, and it would spin.

II-1.5. Ground connection

In electrical engineering, ground or earth is a reference point in an electrical circuit from which voltages are measured, a common return path for electric current, or a direct physical connection to the ground. For example, exposed conductive parts of electrical equipment are connected to the ground to protect users from electrical shock hazards. If internal insulation fails, dangerous voltages may appear on the exposed conductive parts. In electric power distribution systems, a protective earth(PE) conductor is an essential part of the safety provided by the earthing system. Connection to the ground also limits the build-up of static electricity when handling flammable products or electrostatic-sensitive devices. In our experiment, the ground connection on the propeller keeps charges from being stacked on the propeller, letting it constantly have relatively negative charges compared to the generator and keep spinning.

II-1.6. 3-Crane method

To ensure that the propeller is upheld horizontally, in the middle of the generator, and at the same time able to alter the height, we have come up with a three-crane mechanism. In this way, we can place the panel anywhere and at any angle inside the three cranes. The panel was modeled and 3d-printed.

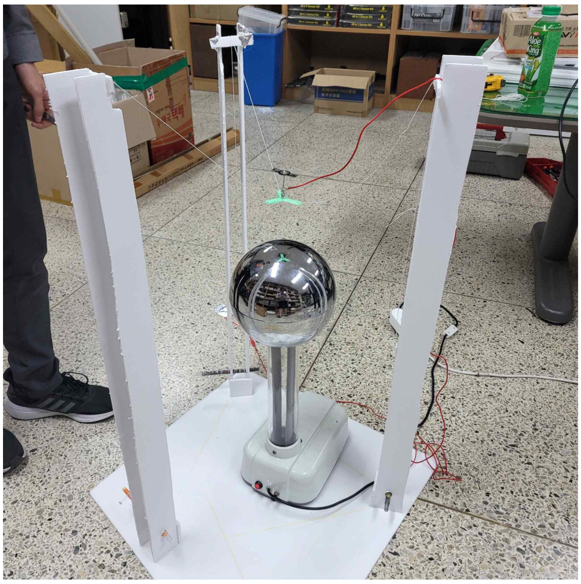

Fig. 4. Images of three cranes altering a flat panel's height and horizontal angle (3-crane mechanism)

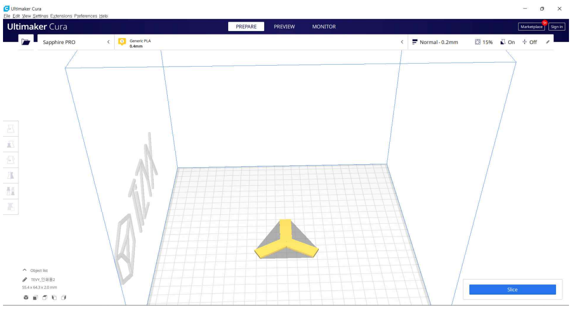

Fig. 5. Image of panel's 3d modeling

II-2. Method

II-2.1. Method① RPM measurement

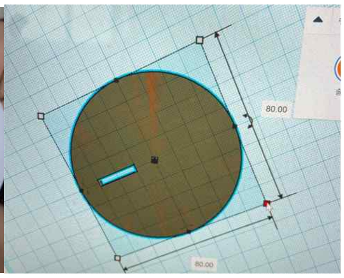

Fig. 6. Image of light added to a spinning wheel
Fig. 7. Sscheme of spinning wheel 3d model

After ground connecting the propeller and charging the generator's metal ball surface, we conduct our experiment.

Leveling the panel using the 3-crane Method, we utilize the field of a van de graff generator as our energy source, and measure RPM of the propeller generated by this energy.

II-2.2. Method② Voltage measurement

The definition of a spark gap is the minimum distance that allows an electrical spark to flow between conductors. The light generated by sparks is not caused by the current of electrons but by the collision of electrons. When electrons collide with the air between the gaps, the air raises the electrons in the orbital orbit to a higher orbital. The energy-received electrons emit light when they descend back into regular orbit.

Breakdown voltage of air is know as 30kV/cm on sea level.

Constructing a spark gap between the Van de graff generator and a metallic ball, we measured the charging time of the Van de graff generator between each spark discharge, altering distance between the generator and ground connected ball.

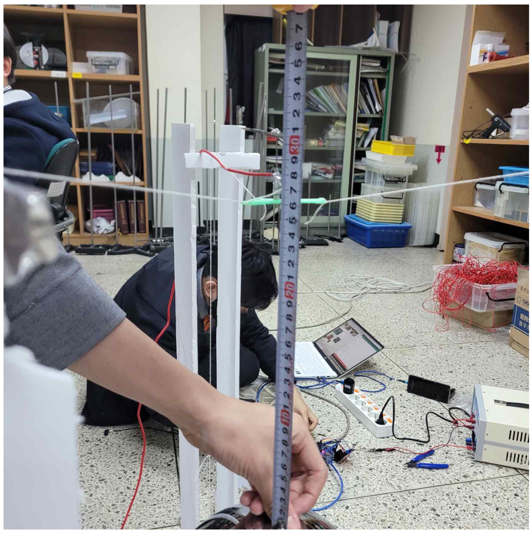

Fig. 8. picture of measuring distance of propeller and generator(**R**)

However, this distance cannot apply to calculations because it is the end of the propeller where ionic propulsion occurs. Also, the charge of the generator must be calculated as if it were in the center of the sphere rather than the surface(as seen in IV-1.1. Surface Charge: Van de graaff generator). Given this, the new value fit for our calculations can be calculated through the Pythagorean theorem, as shown in the following diagram.

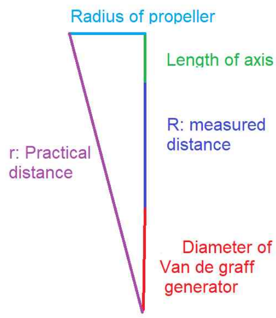

Fig. 9. diagram of practical distance between point-of-propulsion and charges

III. Results

Table 1. measured relationship between distance of propeller and generator(**R**) and propeller rotation frequency(**f**)

R(cm)	26	20.7	14.7	9
t(sec)	0.258	0.147	0.0959	0.208
RPM	288	625	409	233

Table 2. Fig. 10. chart based on the practical distance(**r**) between end of propeller and the generator's center

R(cm)	26.74	32.3	38.24	43.5
f(sec)	0.258	0.147	0.0959	0.208
RPM(/min)	288	625	409	233

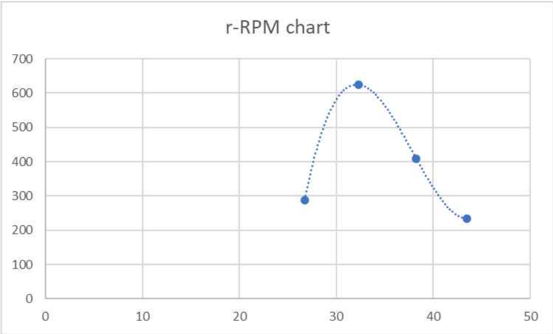

Fig. 10. r-RPM chart

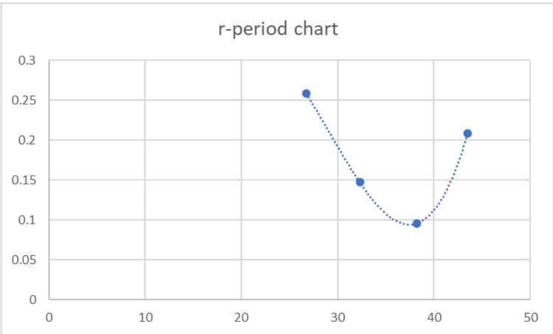

Fig. 11. r-period chart

As seen in the chart, the RPM seems to increase at a high rate as the distance shortens, but RPM appears to decrease at some point. Sounds of constant discharging and sparks occur as the distance becomes too small, implying that there is the movement of charges through the air, constantly discharging the generator.

Table. 3. measurement of discharge period of generator and spark gap distance

	0.5cm	1cm	2cm
1st	0'49	1'12	2'11
2nd	0'57	0'84	1'79
3rd	0'55	0'84	2'23
4th	0'52	0'99	2'24
5th	0'45	0'98	1'82
6th	0'45	1'01	2'17
7th	0'56	1'04	
8th	0'54	1'16	
9th	0'56	1'17	
10th	0'50	0'9	
11th	0'52	1'28	
12th	0'42	1'00	
13th	0'51	1'10	
AVG	0'51	1'03	2'06

Using the average results, we can predict that at distance of 4cm, when a spark forms 120kV will cause the spark, which means using the coulomb formula, 25.3 micro-coulombs of triboelctricity is kept in the generator at that point. This number suggests that the generator is being charged at 6 micro amperes. This number is used to calculate the field.

IV. Discussion

IV-1. Mathematical analysis

IV-1.1. Surface Charge: Van de Graaff generator

In Newton's law of gravity(1), the distance between two objects(**r** in formula (1)) is determined as the distance between each object's center of mass.

$$F = G\frac{mM}{r^2} \qquad (1)$$

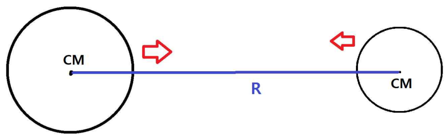

Fig. 12. distance between two celestial bodies' center of masses defined as **r**

In **Fig. 12**, universal gravity is shown between two spherical objects. However, more complex shapes can be used in this method. Regardless of the shape, the distance between objects in Newton's law of gravity is defined as the distance between their center of masses. For example, some planets (like Saturn) have rings around them. The rings' center of mass is at the center of the rings' circular shape, which is very close and held on to the planet's center of mass. Making the problem slightly more complex, the same method can be used to define the center of mass of a more 3-dimensional shape than a ring. For example, we can think of a 3-dimensional shell, similar to the shell of a nut but a bit more spherical.

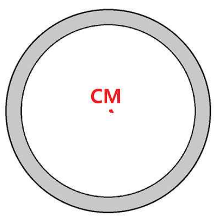

Fig. 13. CoM of rings

When calculating universal gravity in this point of view, we can put the shell's mass to be concentrated near its center of mass, when the space near it is empty, as if it were some point mass, or 0 dimensional, rather than three which is hard to think about. The forces between two electric charges electric forces can be defined as:

$$F = k\frac{q_1 q_2}{r^2} \qquad (2)$$

which is referred to as Coulomb's law.

Both Newton and Coulomb's laws have terms inverse proportional to the square of the distance; which means the force i. This means that a similar approach to that in **Fig. 13.** can be applied to electric forces. Because **q**, the electric charges replace mass, instead of thinking of a center of mass, we think of the center of charges. The center of charge in a sphere or a spherical shell will stay at its center, the same as the center of mass. This point of view lets us calculate the electric field near a charged metal sphere as if it were the field near a charged point. In a somewhat more purely mathematical way, Gauss's law for electric fields can also be applied to show how this works.

$$\varepsilon_0 \oint \boldsymbol{E} \cdot d\boldsymbol{A} = \varepsilon_0 \oint E dA = q \quad (\because \cos\Theta, \Theta = 0)$$

$$\varepsilon_0 E \oint dA = q, \qquad \varepsilon_0 E(4\pi r^2) = q$$

$$\therefore\ E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}, \quad r \rightarrow R_1, R_2, R_3 \cdot \cdot \qquad (3)$$

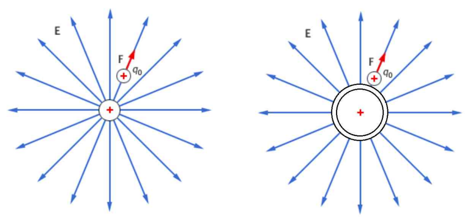

Fig. 14. Scheme of electric field intensity near shells

The van de graff generator makes an electrically charged shell itself, so the electric field near it can be approximated as a field generated by a charge at its center. So when mathematically viewing the results, the outer radius of the shell, R in **Fig. 13.** must be added to the R in the results(**Fig. 10.**). With this newly calculated distance (between the center of charges and the propeller) and Coulomb's law, we can approximately know how the electric field intensity has changed while altering the distance. Finally, this estimated field intensity will be compared to another estimated field intensity, which uses the proportion between RPM and field intensity. Electric field intensity can also be estimated from experimental methods.

IV-1.2. Experimental estimates using torque

Roughly three main forces work on a rotating propeller: friction at the axis, friction or drag from the air, and the propulsion of ions. The total torque, or net torque, much reach 0 for the propeller to get a stable RPM at each propeller wing. Velocity is proportional to RPM, and drag by air is known to be proportional to velocity. This leads to the fact that drag will be proportional to the RPM. If **f** is set as the RPM, the torque is proportional. Given that torque is force multiplied by the arm of the moment of the force, our propeller spinning on a thin needle takes very little torque from friction at the axis, which will approximate zero. In the end, the RPM will be proportional to the propulsion force. However, the electric field intensity cannot easily be calculated back from the propulsion force. To induce the approximate relationship between those two, we have to go back to how it works. Basically, the propeller is doing 'work.' In physics, work is the use of energy, which is defined as:

$$W = F \cdot S \qquad (4)$$

As the propeller rotates with constant speed and force, the power(work per time) can be defined as P=Fv. Again, since the force is proportional to the drag torque - which is proportional to speed - the propeller's power is proportional to the square of its speed. In electricity, electrical power is proportional to the current squared, proportional to how many electrons the propeller rips off from the air. This means that speed is proportional to the current on the propeller or on the wire connected to the ground. And voltage near a charge can be calculated as:

$$U_E(r) = k_e\frac{qQ}{r} \qquad (5)$$

So we project that the distance between the end of the propeller and the generator's center of charge will be inversely proportional to the propeller's speed and the RPM. And again, RPM squared will become proportional to field intensity.

$$(\text{RPM})^2 \propto (\text{field intensity})$$

Field intensity multiplied by a constant charge is the force the regular charge gets inside the field.

$$F = Eq \qquad (6)$$

As explained before, force near the generator can be approximated as a point charge, calculated with the coulomb's law. Dividing the coulomb force into a constant charge, we get the following intensity:

$$E = k_e \frac{|q|}{r^2} \qquad (7)$$

So field intensity is calculated to be inversely proportional to R, the distance squared. This means that the RPM squared is inverse proportional to the field intensity we hope to measure. Experimentally measured RPM will be analyzed with these projections compared to theoretical estimates with gaussian law.

IV-1.3. Torque of propeller

The propeller has equal mass distribution of 2g this form:

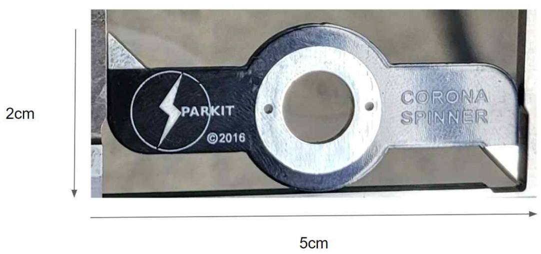

Fig. 15. Geometric width-length of the propeller

Using calculus, its moment of inertial can be calculated as about 4.3 g×cm^2. This number is used to calculate numbers in IV-1.4.

IV-1.4. Graphing and Errors

In IV-1.2, where RPM squared is proportional to field intensity, the relationship between RPM squared and practical distance appears as:

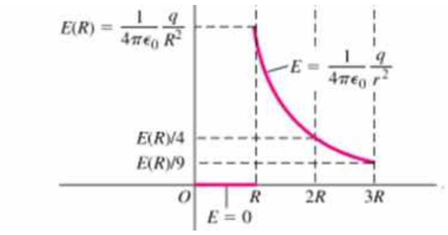

Fig. 16. Electric field near a shell by 3.1

In IV-1.2, where RPM squared is proportional to field intensity, the relationship between RPM squared and practical distance appears as:

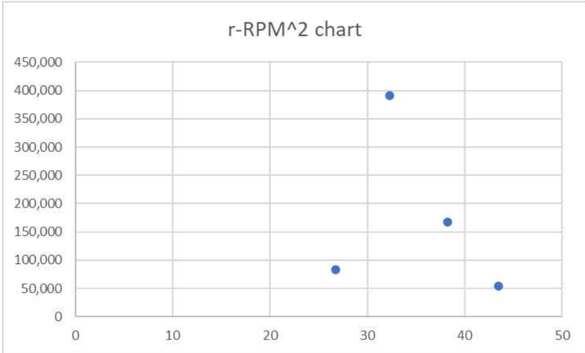

Fig. 17. r-RPM squared (field intensity) chart - experimentally induced electric field near a shell

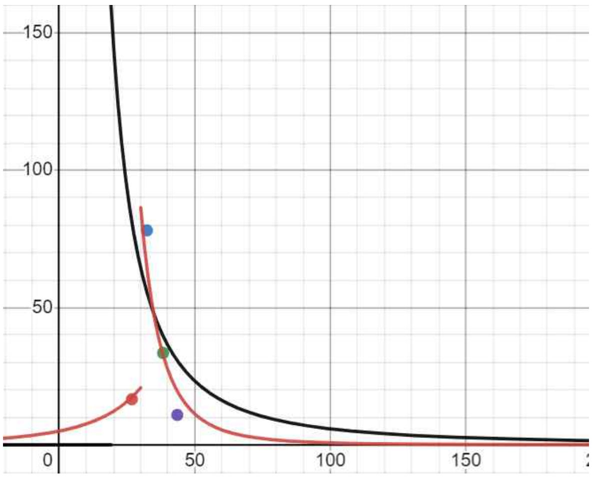

Fig. 18. Measured intensity (red lines), and theoretically predicted intensity (black lines)

As seen in **Fig. 18.** the experimental results have some errors compared to the theoretical calculations, especially since the experimental results have higher rates of difference depending on the distance. Another problem is that there is a shrinking RPM near the generator. This seems to come from 3 reasons:

1. The belt or other generator components also exert an electric field, and this may work as additional repulsion, strengthening the effect of distance on the electric field.
2. The metal sphere is not a perfect shell, and its thickness may vary, causing charges to be asymmetrically distributed. In our experimental conditions, the metal sphere's bottom was slightly flattened, causing the center of charges to move upwards. This strengthens the field than calculated.

3. There is a direct movement of charges between the propeller and the generator, causing charges on each to become weakened. This property is especially shown when the propeller is closest to the generator. Though the electric field gets stronger, the propeller doesn’t spin that well. But this usually applies to small distances. Because of this direct movement, which causes small, but some RPM, the field intensity is not measured as 0. It is predicted to get bigger as it gets closer to the generator’s shell.

IV-1.5. Application

These study results can be applied to computer science and the electronics industry, which are very vulnerable to high voltages. Supercomputers, like other computers, are more susceptible to electric fields than ordinary computers, and the fields can damage internal semiconductors in the process of Semiconductor Fabrication. In addition, quantum computers, which are considered superior to supercomputers, have performance constraints due to space and earth radiation and electric fields. Unlike ordinary computers, quantum computers have very high computational speed through quantum superposition, making qubits. Qubits are vulnerable to electric fields, magnetic fields, thermal energy, etc. Significantly, the effects of electric fields and radiation on quantum computers have come to the fore recently, as semiconductors of quantum computers can make high-sensitivity electric fields and radiation sensors. Therefore, special attention should be paid to electric fields and radiation if quantum computers are used. The use of nuclear medicine instruments involves danger caused by charged particles. A lot of nuclear medicine-related devices are considered dangerous. This is because using those instruments involves using radiation such as protons, resulting in the generation of an electric field. Frequent use of radiation leads to radiation exposure, resulting in the destruction of DNA, organelles, enzymes in biological cells, etc. Also, frequent exposure to electric fields leads to changes in our body tissues' molecular and chemical structures, resulting in fertility complications, cancer, etc. Therefore, there must be a way to ensure our safety when using nuclear medicine instruments at hospitals. That's where our study comes in. Protons or other radioactive particles work as charged particles, exerting a strong electric field. This is why our electric field measuring technology can be applied. In this case, the measurement of charged particles can be used as an alternative way of measuring radiation. We expect our measuring instruments to contribute to laboratory and medical safety related to this technology. Similarly, computers and astronauts are incredibly vulnerable to electric particles in space. Auroras are widely known examples of how much energy these particles can possess. Quite recently, the ISS also has malfunctioned due to those particles collected at its solar panels. This shows that they can also pose a threat to future space exploration infrastructures. If we are to widen our boundaries of knowledge and live in deep space, safety is our number one priority, and our systems must be protected. Fast measurement and response to electromagnetic accumulation are inevitable. Our experimental methods used to measure electric fields can ensure there isn't any accumulation of these potentially harmful particles. We used similar methods to ensure medical safety, but our methods can help humans stretch explorations further into space in critical situations.

IV-1.6. Discussion on Energy

The experiment can meet the following question: If the propeller is sped up using a static, unchanging charge, is it something similar to a perpetual motion machine? Actually, it is not because the ground connected wire shows a constant current while spinning. This current means that propeller is taking electrons from air, and on a larger viewpoint, the electrons are coming from electrons stolen from the generator by nearby gases. In this viewpoint, just by the field existing- charge is moving from the generator to the ground, and this microscopic current is taking away the generator energy, and using it to spin the propeller. However, this microscopic current is small enough to ignore it, and assume that the fully charged generators net charge does change, and of course does not dry out.

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This is a creative idea to use alternative method to measure the electric field. This study presents some successful results. It would be more complete if this research includes discussion about the accuracy of the determined field using such method. Economical cost is another issue. It could be more informative if a comparison study is performed to compare the cost and the possibility of scale-up for applications.