

F18 Magnetic and Electromagnetic Experiments

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2 Introduction

2.1 Determine earth magnetism by magnetic moment

Put a horizontal magnetic needle on a place whose horizontal magnitude of earth magnetism is B . After the needle becomes still, needle's north magnetic pole will point to the north and south magnetic pole will point to the south. The perpendicular plane which passes through the earth's core and directs to the north and south direction determined by the magnetic needle is called magnetic meridian plane.

Put a magnetic bar whose length is $2l$ to a place where it is far from the center of the magnetic needle P by distance d ; moreover, its direction is perpendicular to the horizontal direction of earth magnetism. Then, the magnetic bar will produce a magnetic field B at P :

$$B_p = \frac{2Md}{(d^2 - l^2)^2}$$

where m and $-m$ are intensity of two poles, $M=2ml$ is the magnetic pole of the bar.

The magnetic needle is under earth magnetism's horizontal component B and the magnetic field B_m of the magnetic bar at the same time. Thus, it will tilt at an angle θ

$$\tan\theta = \frac{B_p}{B} = \frac{2Md}{B(d^2 - l^2)^2}$$

Rewrite the above equation, we get

$$\frac{M}{B} = \frac{(d^2 - l^2)^2 \tan\theta}{2d}$$

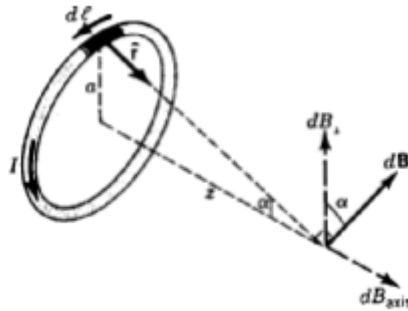
The moment of inertia of the magnetic bar is I . By Newton's second law we can derive that

$$\omega = \frac{2\pi}{T} \rightarrow T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\frac{MB}{I}}} \rightarrow MB = \frac{4\pi^2 I}{T^2}$$

2.2 Measure earth magnetism by tangent galvanometer

Suppose there is a circular coil with radius a and current I . If we want to know the magnetic field far from the center of the coil by distance z on the central axis, we can use Biot-Savart law.

$$dB = \frac{\mu_0}{4\pi} \frac{Id\vec{l} \times \hat{r}}{r^2}$$



Consider any current component (Idl) on the coil will contribute magnetic field dB , whose direction can be decided by right hand rule. Magnetic field dB can be divided into horizontal and vertical components relative to the central axis —— dB_{axis} and dB . However, vertical components of magnetic fields which current components build at two sides along the diameter in symmetrical circular coil will cancel out; moreover, dl is perpendicular to r , thus, the magnitude of magnetic field dB on central axis can be

simplified as horizontal component, namely

$$dB_{axis} = dB \sin \alpha = \frac{\mu_0 I dl}{4\pi r^2} \left(\frac{a}{r} \right)$$

After rewriting, we can get

$$B_{axis} = \frac{\mu_0 N I a^2}{2(a^2 + z^2)^{3/2}}$$

Therefore, we can use vector analysis to derive the magnitude of tangent earth magnetism.

2.3 Current balance measurement

Lorentz tell us the force that a wire is under in the magnitude field is

$$\vec{F} = i\vec{L} \times \vec{B} \quad (\text{Vector representation})$$

$$F = iLB \sin \theta \quad (\text{Scalar representation})$$

Thus, from above formulas, we can see the magnitude and the direction of the force are decided by four elements

- (1) Current's magnitude i
- (2) Wire's length L
- (3) Magnetic field's magnitude B
- (4) Angle θ between the direction of current and magnetic field

We change these parameters to measure the force acting on the wire in this experiment.

2.4 DC motor

The rotating principle of motor is according to Fleming's left hand rule or Ampere's right hand rule. If a wire placed into a magnetic field carries current, it will cut magnetic field lines and move. As the wire carries current inside a magnetic field produced by permanent magnet, it will experience a force which tends to rotate the armature. Hence, motor can transform electrical energy into kinetic energy.

2.5 Faraday's Law

The magnitude of induced electromotive force of a coil is proportional to coil's turns and the rate change of magnetic field lines passing through it.

$$e = -N \frac{\Delta \phi}{\Delta t}$$

N : Coil's turns

$\Delta \phi$: Change of number of magnetic field lines passing through the coil

Δt : Time of change of magnetic field lines

The minus sign in the formula isn't offered by Faraday but Lenz's Law. From the equation, we know when the time interval is shorter, the electromotive force will be stronger, which is able for us to measure in this experiment: If the magnet falls down from the farther spot, the larger the velocity is while passing the coil, then, the electromotive force it produces will be stronger.

2.6 Lenz's Law

Suppose that there is a permanent magnet on the left side of a circular conductor whose north-seeking pole points to the coil. If the magnet moves to the coil, magnetic flux which passes through the coil will increase. According to Lenz's Law, seen from the magnet to the coil, the induced current will flow in counterclockwise direction. This is because the counterclockwise induced current will produce a magnetic field whose direction is opposite to that of the magnet and hence resist the change of magnetic flux.

2.7 Jumping ring

The principle is the same as Lenz's Law. This experiment is just another display of Lenz's Law.

2.8 Generator

Generator is a device which can transform kinetic energy or another type of energy to electrical energy. Common generator transforms mechanical energy which is changed from primary energy by motor to electrical energy, and it will pass through transmission and distribution network to any place which needs electricity.

The fundamental principle of generator is on the contrary to motor. Motor uses coils carrying current to produce magnetic field to form electromagnet, making coils

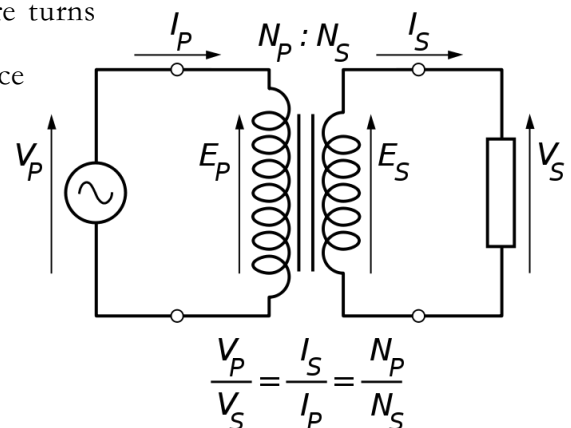
rotate by magnetic force between magnets to do work, which is a device operating "magnetic effect of current" to transform electric energy to work. On the other hand, generator uses various power (such as wind power, hydraulic power) to make coils rotate between two magnetic poles of magnet. When coils rotate, magnetic field inside coils will change, thus they will produce induced current. It is a device operating "electromagnetic induction" to transform kinetic energy to electric energy.

2.9 Transformer

A simple single phase transformer is composed of two conductors. One of which has some uncertain currents (such as alternating current or impulse directed current) to produce varying magnetic field. According to mutual inductance, this varying magnetic field will make the other conductor produce voltage difference. Suppose the second conductor is a part of a closed circuit, it will create current, therefore electricity can be delivered. In common transformer, relative conductors are made up of coils by wires (mostly copper wires) since the magnetic field created by coils are much stronger than a straight wire.

The principle of transformer is to add varying voltage to magnetic core of primary coil and generate varying magnetic field in order to incite other coils create electromotive force. Voltage of primary coil and secondary coil is V_p and V_s which is proportional to turns of coils N_p and N_s . As for the ratio of current or voltage between two sides is decided by turns. Coil having more turns own stronger voltage but lower current, vice versa. Consider no leakage, the ratio of voltage between two sides of transformer is proportional to turns. Here is the formula:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} C$$



2.10 Electromagnetic communication

When antennae receive variation of electromagnetic field, they can completely absorb signals gradually by changing capacitance or inductance of loops to make oscillating frequency equal to frequency of signals. After amplifying signals, they can drive horns to create sound. In this experiment, we let received sound under induced electromotive force between coils to form wireless transmission.

3 Equipment



3.1 Aluminum experimental platform x1

3.2 Aluminum support base with clamp and support rod 60cm x1

3.3 Tangent Galvanometer x1

3.4 Torque on a magnet dipole apparatus x1

3.5 Current balance apparatus x1

3.5.1 Variable magnetic field include six NdFeB magnet fix on inside of the movable jaws to change magnetic field.

3.5.2 Current carrying conductor set include 20 turns enameled wires to support length 30/40/50/60mm conductor.

3.5.3 Hard EVA material stand 10x10x10cm x1

3.5.4 Electric balance x1

3.5.5 Conductor holder x1

3.6 DC motor model x1

3.6.1 Magnet sets label N,S x1

3.6.2 Rotatable circle conductor made by enameled wire suspend by a U type plastic holder x1

3.7 Transformer model x1

3.7.1 Coil set : N300 x1 N900x1

3.7.2 Transformer stand x1

3.7.3 EC type Ferrite core made, size 92x45x31mm outside protected by clear acrylic.

3.8 Faraday's law tube x1

3.9 Lenz's law magnet x1

3.10 Lenz's law aluminum tube x1

3.11 Aluminum ring and iron core with adaptor ring for ring launch experiment

3.12 Holder for plastic or aluminum tube x1

3.13 Generator model x1

3.14 Radio x1

3.15 Sound pick up x1

3.16 Connecting cables x4

3.17 RCA connecting cable x1

3.18 Optional

3.18.1 AC/DC power supply x1

3.18.2 Multiple meter x1

3.18.3 Datalogger x1

3.18.4 Voltage sensor x1

3.18.5 Current sensor x1

4 Installation ,Procedure and Result

4.1 Determine earth magnetism by magnetic moment

4.1.1 Installation

4.1.1.1 Take the magnetic bar out from the plastic jar. See figure (1) and (2).

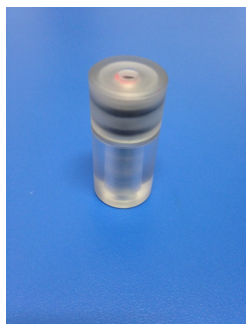


Fig.(1)



Fig.(2)

4.1.1.2 Make south seeking pole point to the direction of zero degree and place it on the center of the aluminum experimental platform whose axis is perpendicular to it. See figure (3).



Fig.(3)

4.1.1.3 After measuring the value of M/B , insert the magnetic bar in the plastic ring and hang it. See figure (4).



Fig.(4)

4.1.2 Procedure

4.1.2.1 After finishing installations, let the magnetic bar close to the south seeking pole and observe the distance when it deflect 20°, 30°, 40°, 50°, 60°, 70°. See figure (6).



Fig.(5)



Fig.(6)

4.1.2.2 Change the direction of the magnetic bar, repeat procedure 4.1.2.1 and use the formula below to calculate M/B.

$$\frac{M}{B} = \frac{(d^2 - l^2)^2 \tan \theta}{2d}$$

4.1.2.3 Measure the length (2l), radius(r), mass (m_a) to derive the moment of inertia I.

$$I_x = \frac{1}{2} m (3r^2 + (2l)^2)$$

4.1.2.4 Use a string to hang the magnetic bar and rotate it. When the rotation becomes stable, record the period T of simple harmonic oscillation in the air. Calculate the time demanded to oscillate 20, 30 and 40 times and derive MB.

$$\omega = \frac{2\pi}{T} \rightarrow T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\frac{MB}{I}}} \rightarrow MB = \frac{4\pi^2 I}{T^2}$$

4.1.2.5 Use 4.1.2.2 and 4.1.2.4 simultaneous equations to solve B and compare it with the theoretical value.

4.1.3 Result

θ	Distance d(cm)		M/B		Average M/B	Total average M/B
	Forward	Backward	Forward	Backward		
20	19.8	18.9	1412.63	1213.20	1312.99	1492.43
30	17	17	1418.25	1396.26	1407.26	
40	15.5	15	1562.34	1387.80	1475.07	

50	13.9	13.6	1600.29	1462.65	1531.47
60	12.4	12	1651.17	1450.09	1550.63
70	11	10.5	1828.43	1526.02	1677.23

Times	20	30	40
1	0.83	0.827	0.825
2	0.83	0.823	0.825
3	0.835	0.827	0.825
Average period	0.832	0.826	0.825
Total average period(T)	0.828		

By length $2l=3\text{cm}$, weight $m=4.36\text{g}$, radius $r=0.25\text{cm}$, we can get the moment of inertia (I) $=3.338125$ and derive $MB=192.4968037$. Along with average value of M/B , we solve $B=0.35914041$ Gauss.

Tangent earth magnetism(Gauss)	Referential tangent earth magnetism(Gauss)	Percentage error(%)
0.35914	0.37185	3.418

4.2 Measure earth magnetism by tangent galvanometer

4.2.1 Installation

4.2.1.1 Place the coil on the base. See figure (7).

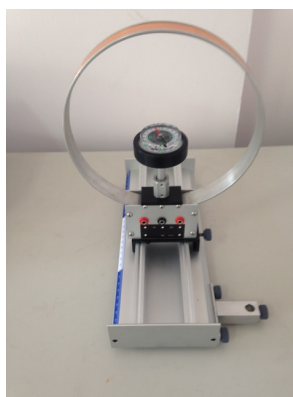


Fig.(7)



Fig.(8)

4.2.1.2 Connect the input with the power supply and turn to DC mode. See figure (8).

4.2.1.3 Insert assigned turns (N) on the output. See figure (9) to (11), separately 15, 25 and 40 turns.

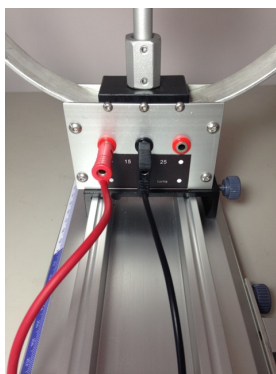


Fig.(9)

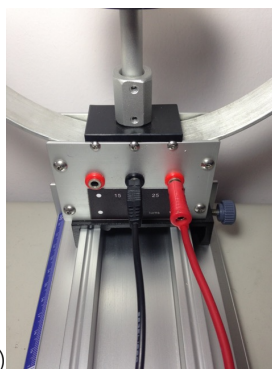


Fig.(10)

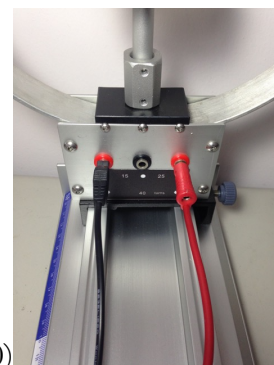


Fig.(11)

4.2.1.4 The finished installation is like figure (12).

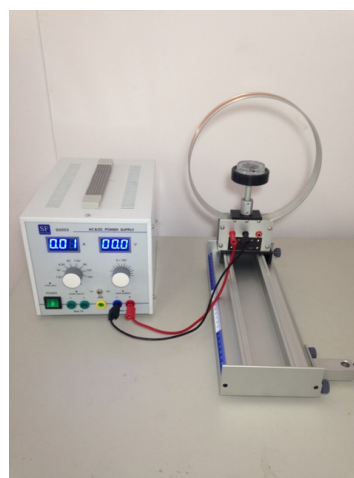


Fig.(12)

4.2.2 Procedure

4.2.2.1 After installation, don't turn on power supply instantly. Adjust north seeking pole and make it parallel to coil's radius. See figure (13).

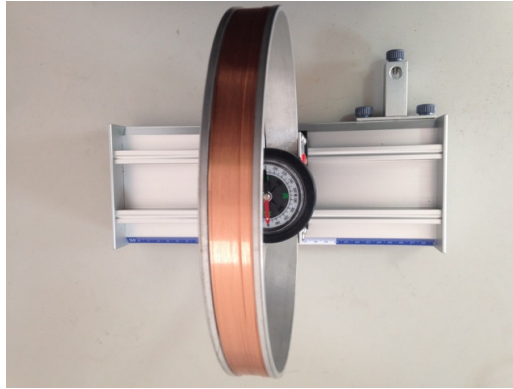


Fig.13)

4.2.2.2 Turn on power supply and increase current slowly. Observe the amount of deflection of the needle and record the deflection angle (θ).

4.2.2.3 After measuring coil's radius (a), by parameters as known and Ampere's Law, we can calculate the magnitude of external field (B) and use vector addition to calculate earth magnetism (B_G) (The unit of them is Tesla)

$$B = \frac{\mu_0 NI}{2a} \qquad B_G = \frac{\mu_0 NI}{2a \tan(\theta)}$$

a : Coil's radius N : Coil's turns I : Current

μ_0 : Vacuum permittivity

4.2.3 Result

Current(A)	Deflection angle in clockwise (°)	Current(A)	Deflection angle in counterclockwise(°)	Average current(A)	Average deflection angle(°)	Measured earth magnetism B_G (Gauss)
0.053	8	0.053	7	0.053	7.5	0.361
0.1	15	0.1	13	0.1	14	0.360
0.153	20	0.152	20	0.1525	20	0.377
0.201	26	0.2	25	0.2005	25.5	0.378
0.252	32	0.252	31	0.252	31.5	0.369
0.303	36	0.303	37	0.303	36.5	0.368
					Average earth magnetism(Gauss)	0.369

					)	
			Coil's turns(N)	15	Referential earth magnetism(Gauss)	0.37185
			Coil's radius(m)	0.105	Percentage error(%)	0.785

4.2.4 Notifications

4.2.4.1 While using power supply, you should ground it to avoid accumulating charges and getting an electric shock.

4.2.4.2 North seeking pole is affected by magnetic material. Except for the coil, you should keep distance from magnetic matters while measuring to avoid error.

4.2.4.3 Notice the unit conversion, like the relation between Tesla and Gauss.

4.3 Current balance measurement

4.3.1 Installation

4.3.1.1 Assemble the platform, supporter and coil gripper. See figure (14).

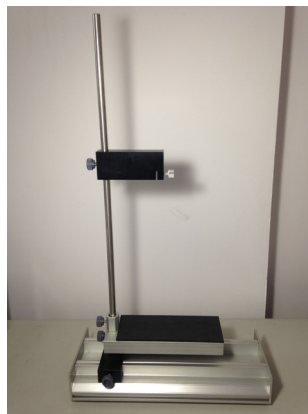


Fig.(14)

4.3.1.2 Put the digital scale, Eva foam and magnet on the platform. See figure (15).

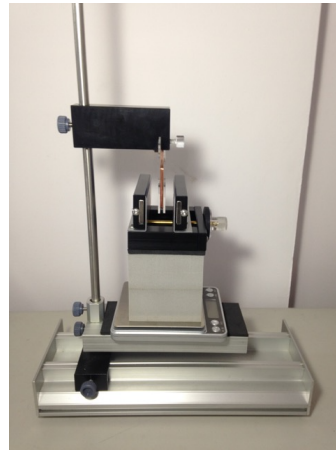


Fig.(15)

4.3.1.3 Connect the coil with the wire. You can determine the positive and negative pole, which only affects the direction of current. See figure (16).

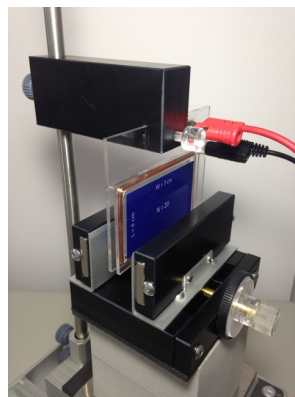


Fig.(16)

4.3.1.4 Connect the other side of the wire to the power supply and turn to DC mode.

4.3.2 Procedure

4.3.2.1 After installation, adjust the distance between magnets to the length you want. Since the width of magnets is known, you can refer to the corresponding magnitude of magnetic field.

4.3.2.2 Turn on the digital scale and set to zero.

4.3.2.3 Increase the current slowly and record the weight and the corresponding current.

4.3.2.4 Coil's length (L), magnetic field (B), turns (N), and current (i) are known, so we can use Lorentz force law to calculate theoretical force (F).

$$\vec{F} = iN\vec{L} \times \vec{B}$$

i : Current N : Turns L : Coil's length passing through magnetic field B : magnetic field

4.3.2.5 Compare with the theoretical force derived from Lorentz force law with the measured weight on the scale.

4.3.3 Result

Distance between magnets 0.027m (Attractive force)					
L=6.7cm			L=4.7cm		
Force(g)	Current(A)	Magnetic field B(T)	Force(g)	Current(A)	Magnetic field B(T)
5.32	0.5	1.588059701	4.43	0.51	1.848143513
10.28	0.98	1.565641182	8.5	1	1.808510638
15.57	1.5	1.549253731	12.67	1.5	1.797163121
20.82	2.01	1.546001337	16.87	2.01	1.785752091
25.69	2.49	1.539890907	20.98	2.5	1.785531915
30.94	3	1.539303483	25.15	3.01	1.77776207
Average magnetic field		1.554691723	Average magnetic field		1.800477224

Distance between magnets 0.027m (Repulsive force)					
L=6.7cm			L=4.7cm		
Force(g)	Current(A)	Magnetic field B(T)	Force(g)	Current(A)	Magnetic field B(T)
5.37	0.5	1.602985075	4.41	0.51	1.83979975
10.6	1.01	1.566425299	8.57	1.01	1.805350748
15.63	1.51	1.544924385	12.68	1.51	1.786670424
20.63	1.99	1.547288682	16.96	2.02	1.786391405
25.89	2.5	1.545671642	20.98	2.51	1.778418242
30.92	2.99	1.543453302	25.02	3	1.774468085
Average magnetic field		1.558458064	Average magnetic field		1.795183109

4.3.4 Notifications

4.3.4.1 Since the digital scale will be interfered with the magnets, you need to put EVA foam between them.

4.3.4.2 If the current is too strong, it will heat up the coil easily. Recommend that you

can turn off the power supply to cool down after every measurement.

4.3.4.3 Because the corresponding magnetic field of the distance between two magnets are measured from the center, the coil must be placed on the center too to avoid larger error. See figure (17).

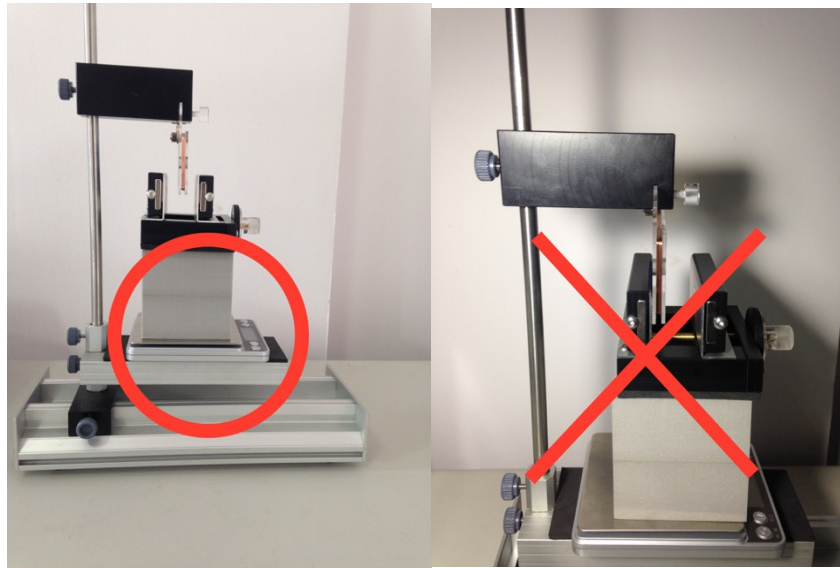


Fig.(17)

4.3.4.4 The distance between two magnets refers the perpendicular distance from one surface to the other. Thus, the width and the gap of the L-type aluminum plate must be in consideration to avoid larger error. See figure (18).

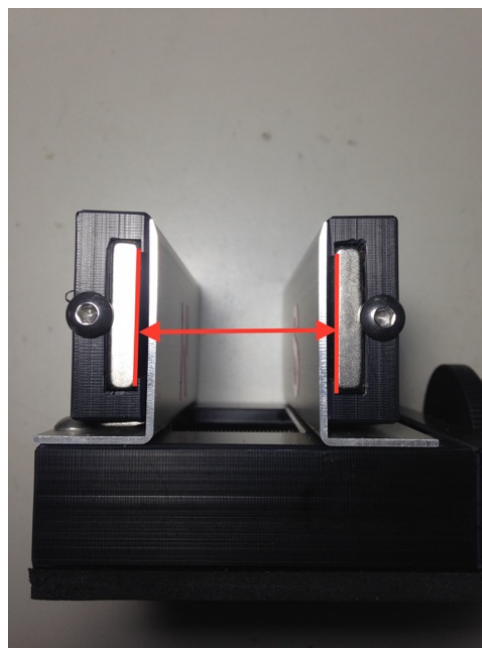


Fig.(18)

4.4 DC motor

4.4.1 Installation

4.4.1.1 Assemble the magnet, coil and platform. See figure (19).



Fig.(19)

4.4.1.2 Turn power supply to DC mode and don't turn on instantly. Connect it with the wire to the coil. See figure (20).

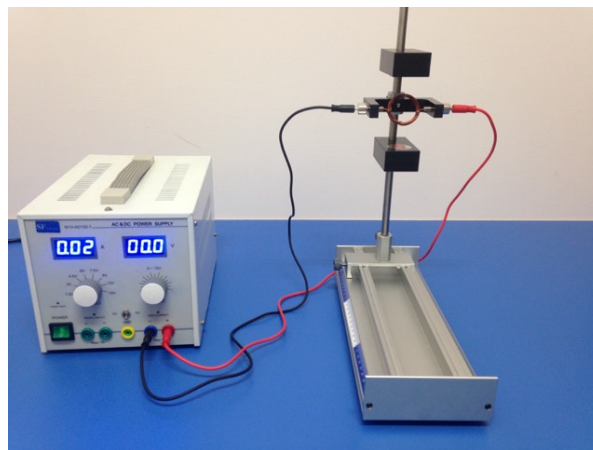


Fig.(20)

4.4.2 Procedure

4.4.2.1 After installation, turn on the power supply and increase the voltage slowly until the coil start to rotate. When the moment it rotates, stop increasing the voltage. If the coil doesn't rotate no matter how strong the voltage is, you need to check whether the screws on two sides are too tight or the circuit hasn't become a loop.

4.4.2.2 After observing the rotation phenomenon, change current's direction and magnet's pole to see the turning direction of the coil.

4.5 Faraday's Law

4.5.1 Installation

4.5.1.1 Assemble the coil, plastic tube and platform. See figure (21).

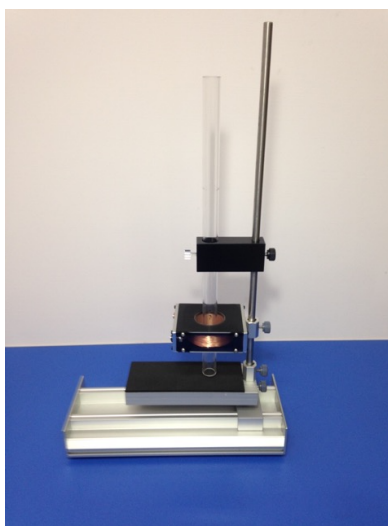


Fig.(21)

4.5.1.2 Connect the data logger and voltage sensor to the output of the coil and connect the data logger to the computer. See figure (22).

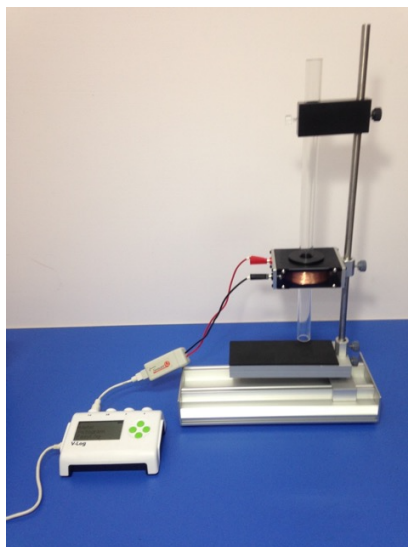


Fig.(22)

4.5.2 Procedure

4.5.2.1 Measure the distance (h) from top of the tube to the position above the coil.
See figure (23).

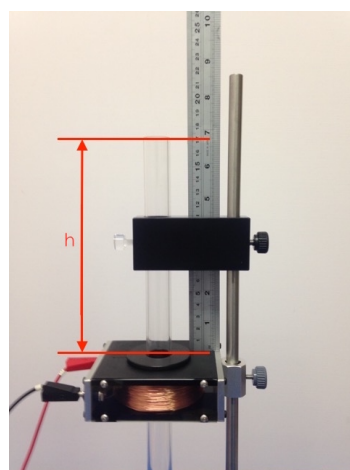


Fig.(23)

4.5.2.2 Install the data logger in the computer. After confirming the input and output are connected well, open the operating software and choose diagram mode. See figure (24).



Fig.(24)

4.5.2.3 After entering the oscilloscope mode, choose position of the sensor and press "next".

4.5.2.4 Set the total record time is 200 ms and the sampling time interval is 50 μ s and press "next". See figure (25).

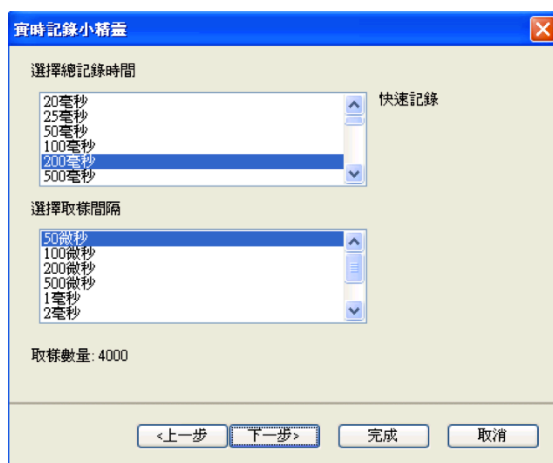


Fig.(25)

4.5.2.5 Set horizontal touching, choose voltage path higher than 100mV and touching condition 50% and press "finish". See figure (26).



Fig.(26)

4.5.2.6 Release the magnet from the upper tube and record down the peak of the data.

4.5.2.7 Change the distance between upper tube and the center of the coil and repeat procedure 4.5.2.6 until you get five different corresponding voltage peaks.

4.5.2.8 After finishing 4.5.2.7, change the voltage sensor with the current sensor and modify total record time to 200ms and sampling time interval to 200 μ s, after that, press "next".

4.5.2.9 Set horizontal touching, choose current path higher than 10mA and touching condition 50% and press "finish".

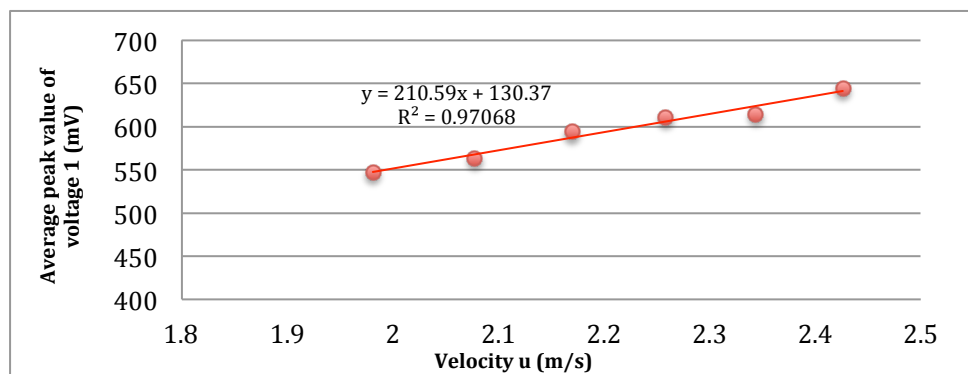
4.5.2.10 Change the distance between upper tube and the center of the coil and repeat procedure 4.5.2.6 until you get five different corresponding current peaks.

4.5.2.11 Analyze the relationship between induced voltage/current and the velocity of the magnet passing through the center of the coil. This velocity u can be derived from free fall equation $u = \sqrt{2gh}$.

4.5.3 Result

Height h(m)	Velocity u(m/s)	Peak value of voltage(mV)	Peak value of voltage (mV)	Average peak value of voltage (mV)	Difference of peak value of voltage(mV)

0.2	1.980908882	520	574	547	54
0.22	2.077594763	538	589	563.5	51
0.24	2.169976958	570	618	594	48
0.26	2.258583627	585	637	611	52
0.28	2.343842998	597	632	614.5	35
0.3	2.426107994	627	661	644	34



4.6 Lenz's Law

4.6.1 Installation

4.6.1.1 Select coil's turns and make the cover inside the center of the coil. See figure

(27).

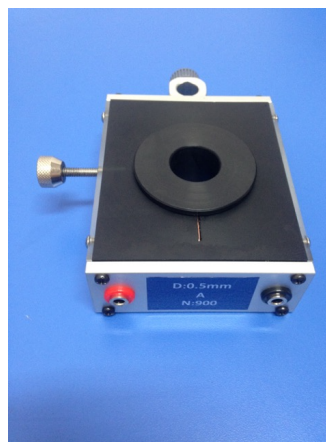


Fig.(27)

4.6.1.2 Assemble the experimental platform. The aluminum tube is only supported by

the supporter, and it can't be twisted tightly by screws. See figure (28).

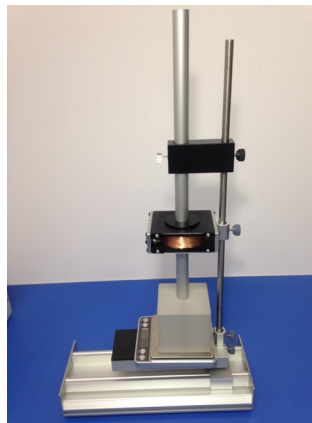


Fig.(28)

4.6.2 Procedure

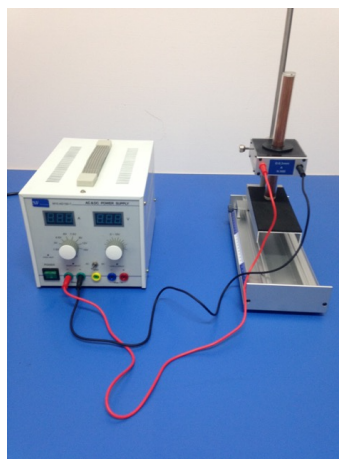
4.6.2.1 After the installation, turn on the power supply of the digital scale under the hard EVA.

4.6.2.2 Throw the magnet into the tube from above and observe the reading on the scale.

4.7 Jumping ring

4.7.1 Installation

4.7.1.1 Assemble the experimental platform. Select AC supply mode and connect the coil with the wire. See figure (29).



圖(29)

4.7.2 Procedure

4.7.2.1 After the installation, insert the metal bar in the aluminum ring and open the

power supply. Adjust input voltage and observe the height that the ring oscillates. If the ring won't jump no matter how high the voltage is, try to move the ring. See figure (30).

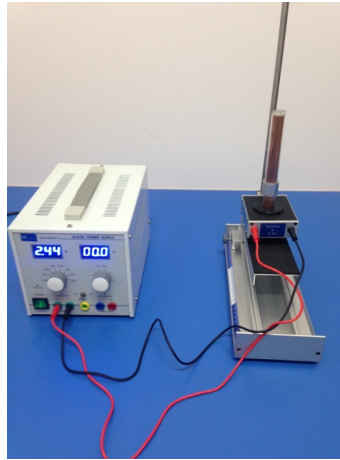


Fig.(30)

4.7.2.2 Record the oscillating height of the ring corresponding to each voltage.

4.7.3 Result

Coil	Voltage(V)	Current(A)	Height(cm)
N260	12	2.45	2.5
N260	15	2.96	4.5
N420	12	1.26	0.6
N420	15	1.51	2

4.8 Generator

4.8.1 Installation

4.8.1.1 Put the iron core into the coil and fasten it with screws to avoid loosening.
(Because of the direction of gravitational force, there is only one coil needs to be fastened) See figure (31).

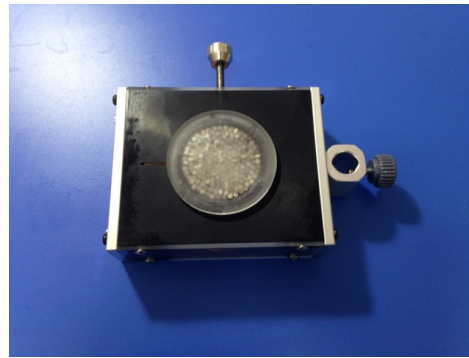


Fig.(31)

4.8.1.2 Fix the coil and the rotatable magnetic field apparatus on the platform. See figure (32).



Fig.(32)

4.8.1.3 Connect the Data logger with voltage sensor and with the output of the selected coil. See figure (33).

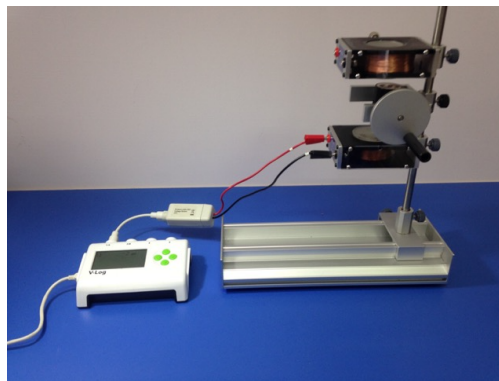


Fig.(33)

4.8.2 Procedure

4.8.2.1 After installation, install Data logger into the computer. After confirming input and output are connected well, open the operating software and choose oscilloscope mode.

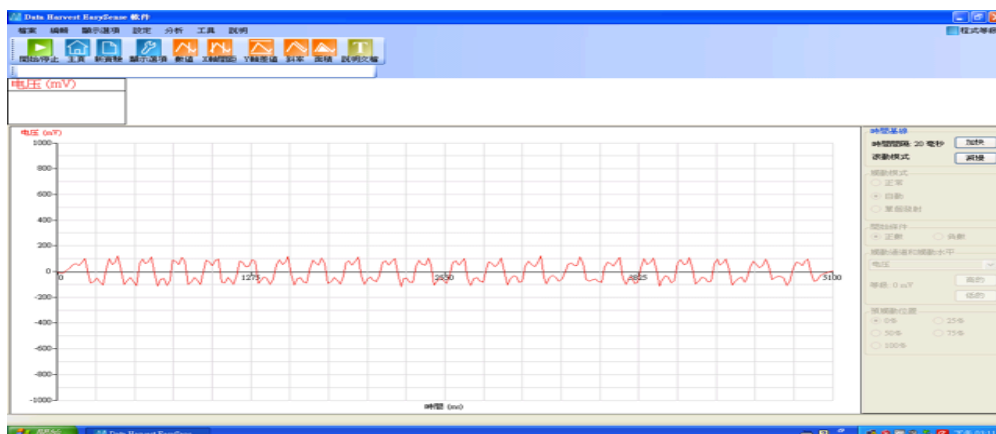
4.8.2.2 After entering oscilloscope mode, select the position of the sensor and press

"next". Press "start" at the upper left corner.

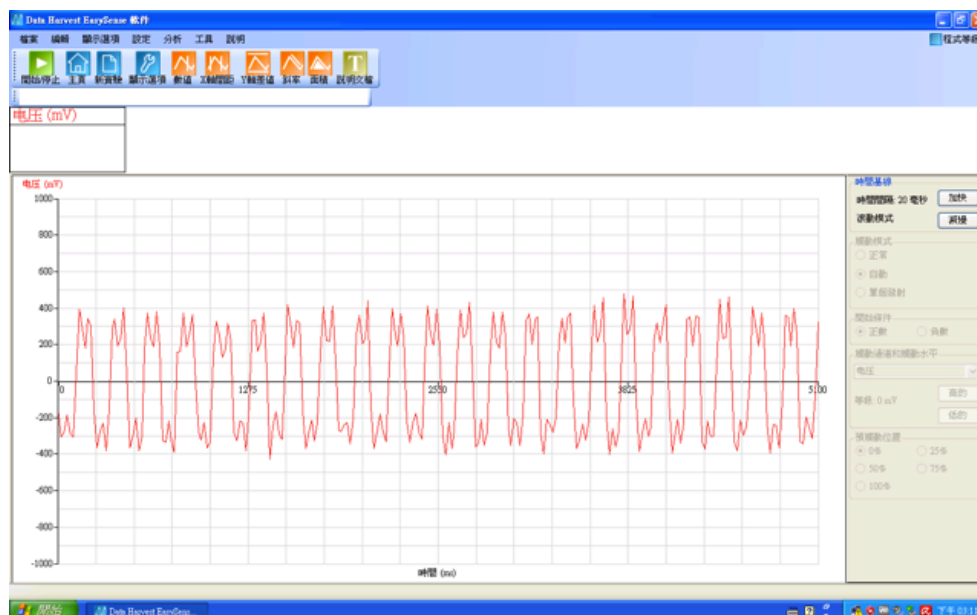
4.8.2.3 Start the rotatable magnetic field apparatus and observe the output voltage on the oscilloscope.

4.8.2.4 Change the coil with different turns as the voltage output, repeat procedure 4.8.2.3 and observe the relation between voltage and turns.

4.8.3 Result



300 turns



900 turns

4.9 Transformer

4.9.1 Installation

4.9.1.1 Loosen the screws above the supporter of aluminum transformer. See figure (34).

Fig.(34)

4.9.1.2 Put the coil on the supporter and fasten it with screws. See figure (35) and (36).

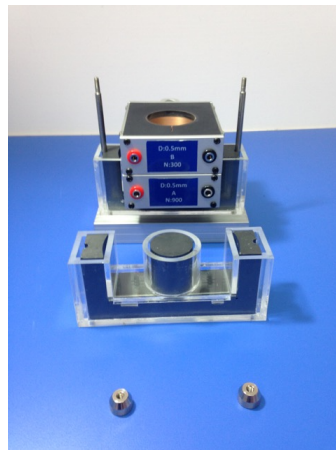
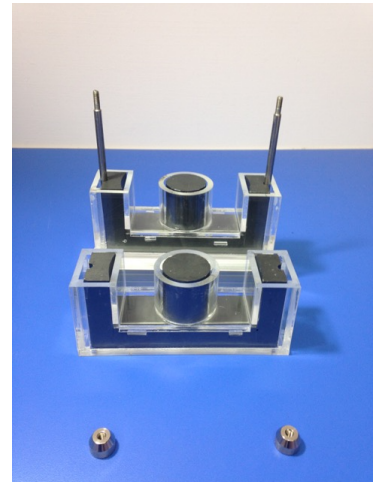


Fig.(35)

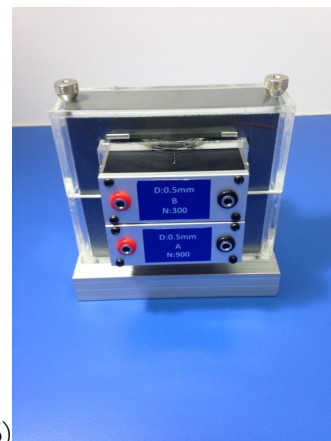


Fig.(36)

4.9.1.3 Connect Data logger with voltage sensor and with the selected output coil. Furthermore, connect AC power supply with selected input coil. See figure (37).

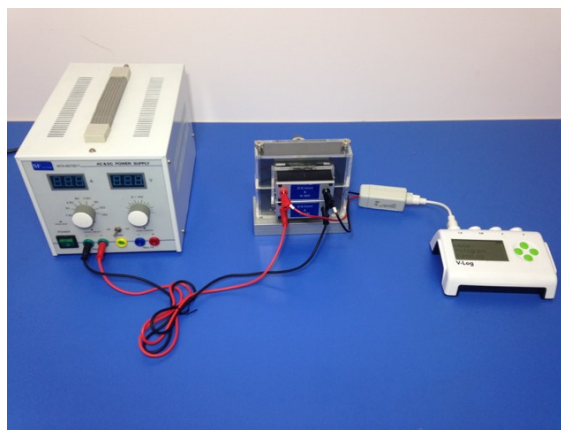


Fig.(37)

4.9.2 Procedure

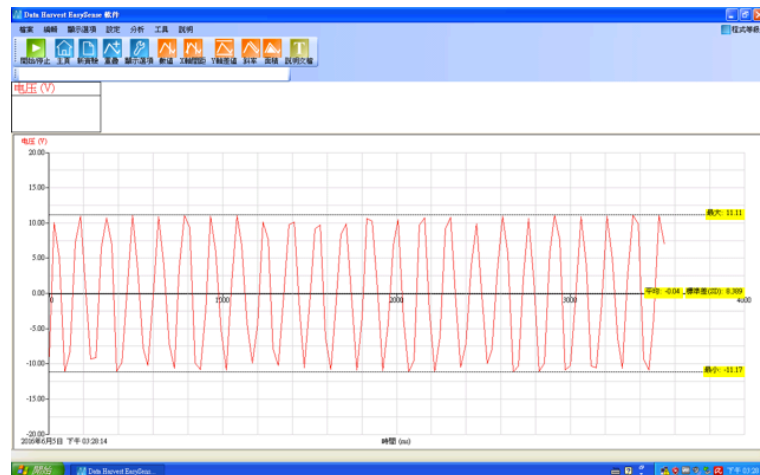
4.9.2.1 After installation, install Data logger into the computer. After confirming input and output are connected well, open the operating software and choose

oscilloscope mode.

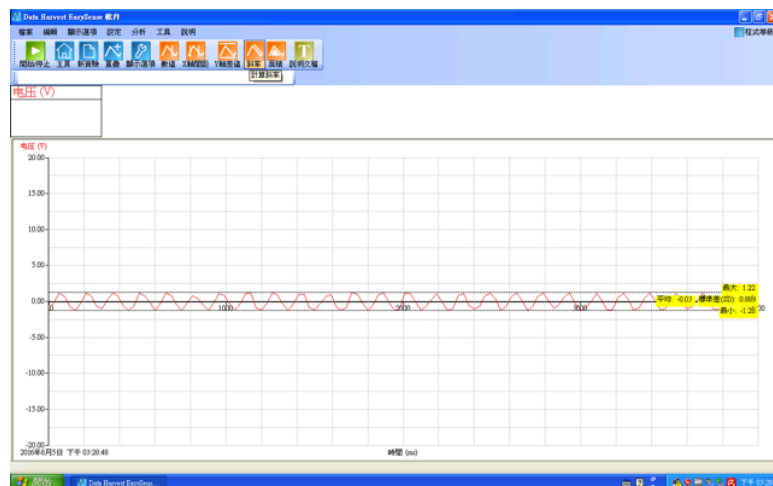
4.9.2.2 After entering oscilloscope mode, select the position of the sensor and press "next". Press "start" at the upper left corner.

4.9.2.3 Open the power supply and select input voltage. Observe the relation between output voltage and turns.

4.9.3 Result



Input turns=300, output turns=900



Input turns=900, output turns=300

4.10 Electromagnetic communication

4.10.1 Installation

4.10.1.1 Connect one side of the audio cable to the radio and connect the other side

with the input coil first. On the other hand, connect one side of the wire with the audio. See figure (38).

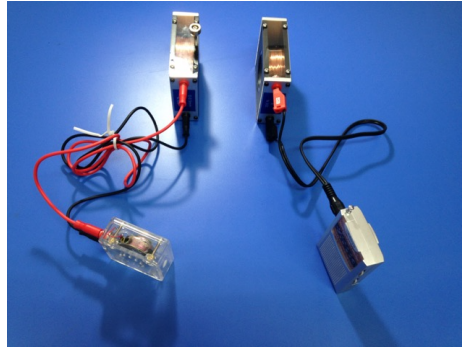


Fig.(38)

4.10.1.2 Put the iron bar into the center of two coils. See figure (39).

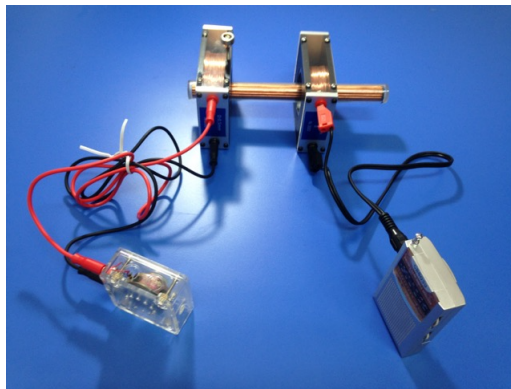


Fig.(39)

4.10.2 Procedure

4.10.2.1 After installation, turn on the power of the radio and select the channel you want.

4.10.2.2 Adjust the distance between two coils and observe whether the audio has sound, moreover, observe the relation between sound and distance, sound and the existence of the bar.