**Experiment 2-4. Electromagnetic Induction**

- **Faraday’s Law of Electromagnetic Induction** –

<table>
<thead>
<tr>
<th>Purpose of Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Until 19C, electric and magnetic phenomena had been studied independently and considered as having different source. But in 1820, Orsted discovered that wire flowing currents makes magnetic field around. Naturally, they had interest at reverse phenomenon, Faraday discovered that 1820. In other words, he discovered that currents flow in wire when magnet is approached. Faraday’s law of electromagnetic induction says if there is change of magnetic flux to the rate of time, electromotive force is induced in around space with same rate and that electromotive force has direction to suppress the change of magnetic flux. And induced electric field affects electric force to other charges inside field, like electric field from charge. After all, electric and magnetic field can interchange and phenomenon what we called electric, or magnetic are included wider range of phenomenon, electromagnetic phenomenon. In this experiment, we will confirm the electromagnetic phenomenon by simple course, did like Faraday, and probe a voltage difference emerged when coil rotates in the magnetic field to comprehend electromagnetic force quantitatively. And will know about principles of motor.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outline of Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Check out Lenz's law using permanent bar magnets and solenoids. The direction of the current along the pole of the rod magnet and the reactivity to the approach speed are checked. ➢ Let's look at Faraday's electromagnetic induction laws in depth by using the above-mentioned Lenz's law. The experimental equipment set is a device that can test the simple principle of a generator using a magnet and a coil, and can also understand an AC generator that we commonly use.</td>
</tr>
</tbody>
</table>
➢ Understand how changes in induced electromotive force due to changes in magnetic flux.

➢ Understand the reason for the difference between the AC and DC terminals based on the principle of the commutator.

➢ Understand that both the generator and the motor are derived from Faraday's law of electromagnetic induction.

## Experiment method

![Fig.1 experimental equipment](image)

➢ The laboratory has the following equipment for this experiment.

Solenoid(n=500) 1EA, Linear magnet 1EA, DC voltage tester 1EA, Faraday experiment equipment(n=300) 1EA, Belt(rubber O-ring) 1EA, Source device(0~10V, 0~1A) 1EA, Wire with alligator forceps 6EA, Input terminal 1EA

1) **Check the electromagnetic induce phenomenon.**

1. Put into and draw magnet at solenoid and check the induced voltage from voltage tester connected solenoid.

2. Check the change of induced electromotive force varying pole of magnet,
approaching speed and polarity of voltage tester.

Ref) If magnet stops and solenoid moves, what will be happen?

✓ Precautions before use and how to use the oscilloscope

1. Connect all the devices as shown in Figure 1.

2. To perform experiment 2), connect to the DC terminal in the blue circle in Figure 1. To perform experiment 3), connect it to the AC terminal in the blue circle as shown in Figure 1.

3. In order to change the magnetic flux in each experiment, it is possible to experiment by changing a large area magnet, a small area magnet, and a circular magnet by loosening and turning the screw marked with green circle in Figure 1.

4. It is not easy to experiment because it is fast to turn on voltage and current in the power supply. (Turning speed doesn’t affect the success of experiment). So try to use around 15 W of power. If you want to increase the speed to see the effect on the subsequent rotation speed, be careful not to malfunction.


Fig.2 Hantec oscilloscope interface and channel connections and reference signal output
Before connecting the oscilloscope's BNC cable to the DC terminal at Figure 1, you must go through the current process. On the left side of Figure 2, the red circle is the I-V measurement channel input, and the purple circle is the output to which the USB cable prepared as a preparation is connected. Plug the USB cable into the computer as shown on the left side of Figure 3, and then turn on the 'Hantek' software.

![System interface connection and first screen of single channel when there is no input signal](image1)

6. When the program is turned on, output signal is 0(Fig.3), because there is no input signal at present. Sometimes, the remaining channels displayed in green circles are displayed on the panel together, but it doesn’t matter.

![Comparison before and after AUTO scaling](image2)

7. Connect the end connection of the BNC cable to the reference signal output in the gray
circle on the right side of Figure 2. When the overall connection is good, the LED signal will show a green light as shown in the red circle on the right photo. The left side of Figure 4 is the first visible connection. In this case, the scale is not correct.

8. If you press the 'AUTO' Auto Scale button at the top of the screen, it will show the appropriate size as shown in Figure 4. If you want to scale the x-axis by adjusting the sampling rate, you can turn the dial in the blue circle in Figure 4

9. Then, the preparation before measurement is done. You can do the following experiment.

2) Measuring the DC voltage induced by motor

1. Switch to the DC terminal of the experiment device, and connect the oscilloscope for DC mode voltage induction

2. Set the direction of the permanent magnet on forward direction, and observe the shape and size of the induced electromotive force output by applying the voltage to the power supply.

![Fig.5 Comparison before and after AUTO scaling](image)

3. At first, scaling is done to observe the previous ref. signal, so you have to press 'AUTO' button for each new experiment.

☞ Can the induced electromotive force be DC? What would you do to get a waveform closer to DC?

4. Observe the change in induced electromotive force by increasing the voltage of the power supply.
5. Try experimenting with different forms of permanent magnets. Or make various combinations and observe the experimental results.

☞ There will be a noticeable difference in the waveforms shown compared to those obtained earlier. Why does this unusual shape change exist?

3) Measuring the AC voltage induced by motor

1. Switch to the AC terminal of the experiment device, and connect the oscilloscope for AC mode voltage induction.

★ It is possible to measure AC and DC modes at the same time, but it is better to measure them separately to get cleaner data.

![Graph showing AC voltage](image)

Fig.6 Measured values of appropriately scaled AC terminals

2. Try experimenting with different forms of permanent magnets. Or make various combinations and observe the experimental results.

3. Observe the change in induced electromotive force by increasing the voltage of the power supply.

☞ What are the differences compared to experiment 2)? What makes such a difference?
4. Once the three experiments are completed, Capture the measured data in advance for analyzing. Take a look at the previous data and look for answers that match your experimental objectives.

5. After all experiments, turn off all electromagnetic products. In particular, it is important to note that if the power supply connected to the motor is not turned off, the motor may be burned. That is, you should not leave it if you do not turn around.

I. A principle of motor (Induction of AC electromotive force)

In figure 7.(c), magnetic flux flowing plane of loop when line is vertical with a cross section of loop makes an angle $\theta$ with magnetic field is given by;

$$\Phi = lhB\cos\theta$$  \hspace{1cm} (1)

When loop rotates at constant angular velocity $\omega$, angle $\theta$ of loop when time is $t$ is;

$$\theta = \omega t$$ \hspace{1cm} (2)

So electromotive force induced at loop is given by Faraday’s law;

$$\varepsilon = -\frac{d\Phi}{dt} = -lhB\omega\sin\omega t$$ \hspace{1cm} (3)

This is AC currents with same angular velocity $\omega$. The general electromotive force of loop when area is $A$, winding number is $N$ is given by;

$$\varepsilon = NAB\omega\sin\omega t$$ \hspace{1cm} (4)

So, you can know the change of electromotive force varying voltage induce by power supply.
II. A principle of motor (Induction of AC electromotive force)

We consider the case what use DC motor as DC generator. In figure 8, two loops are in vertically, so electromotive force induced by brush makes electromotive force when only high electromotive is made. So seeing the output voltage when using this motor;

$$V_{\text{out}} = V_o \cos \omega t \quad (0 \leq t < \frac{T}{8})$$

$$= V_o \sin \omega t \quad \left(\frac{T}{8} \leq t < \frac{3T}{8}\right)$$

$$= -V_o \cos \omega t \quad \left(\frac{3T}{8} \leq t < \frac{5T}{8}\right)$$

$$= -V_o \sin \omega t \quad \left(\frac{5T}{8} \leq t < \frac{7T}{8}\right)$$

$$= V_o \cos \omega t \quad \left(\frac{7T}{8} \leq t < T\right)$$

It has angular frequency four times than rotating number of motor. Average voltage is given by;
\[
\langle V_{\text{out}} \rangle = \frac{1}{T} \left( V_0 \int_{0}^{T} \cos \omega t \, dt + V_2 \int_{0}^{T} \sin \omega t \, dt - V_0 \int_{0}^{T} \cos \omega t \, dt - V_2 \int_{0}^{T} \sin \omega t \, dt + V_0 \int_{0}^{T} \cos \omega t \, dt \right)
\]

And, we know \( T = \frac{2\pi}{\omega} \). So we can calculate (6), and derive \( \langle V_{\text{out}} \rangle = \frac{2V_2}{\pi} V_0 \). It is 0.9 times of maximum voltage, 0.71 times of minimum voltage.

---

Fig. 8 By E. Hecht’s general physics

Fig. 9 Faraday experiment equipment

Above photo is faraday instruments used in experiment. Although it has not exactly same structure with Figure 8, it can be used as expressing result of experiment applying background theory II. Why result of DC mode evolve as absolute value of Sin function? If you look center axis carefully you can observe the difference with AC mode. To make result more DC-like, how change the axis?

References
- Oscilloscope
- Treatment of measurement data
- Analysis method based on graph
- Michael Faraday - The natural philosopher (physicist)
- Joseph Henry - Another discoverer of electromagnetic dipole phenomena as a unit of inductance
- The Exploratorium Science Snackbook - Stripped Down Motor
- Electromagnetic Induction
- Electromagnetic Induction
- Back EMFs