TEXTBOOK NO. 7017④

Fundamentals of Electricity

TEXTBOOK

Mitutoyo

CONTENTS

1. THEORY OF ELECTRICITY

1.1 Direct Current

1.1.1 Current and voltage

If the switch is closed in a device such as the one shown in **Fig. 1**, something flows through the lamp and the copper wire, and the lamp lights up. The force that causes the flow in the device is called electricity, and the flow is called electric current. Ampere (A) is used as a unit of electric current.

Electric current (flows) because one terminal has a higher potential than another terminal. The terminal which has higher potential is called the positive terminal, and the one with lower potential is called the negative terminal. The difference between the two is called the potential difference, which is commonly known as voltage. Volt (V) is used as its unit.

The analogy to water shown in **Fig. 2** may help you understand this relationship. The difference in height and the cock can be thought as potential difference and the switch, respectively.

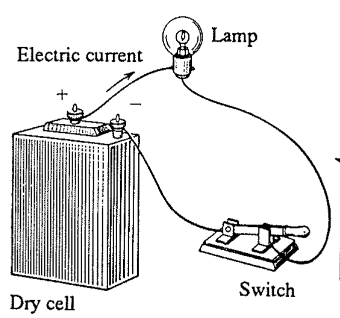


Fig. 1

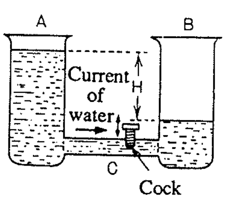


Fig. 2

1.1.2 Resistance

The degree of difficulty for electricity to flow is called resistance and ohm (Ω) is used as its unit. A material that allows electricity to flow easily is called a conductor, and a material that does not allow it to flow easily is called a nonconductor or insulator. A material which has a conductivity considerably greater than that of an insulator and yet much less than that of a conductor is called a semiconductor.

Resistance of a conductor is proportional to its length and inversely proportional to its sectional area, as shown in equation 1.1.

$$R = \frac{\ell}{A} \times P \qquad (1.1)$$

Where, R: Resistance (Ω)
A: Sectional area (m^2)
ℓ : Length (m)
P : Conductivity (Ωm)

Specific conductivities are shown in **Table 1.1**.

Table 1.1 Conductivity of metals and alloys (from Electric Engineering Handbook)

Metals and Alloys		Resistivity at 20°C (unit : 10^{-8} Ωm)
Gold	(Au)	2.40
Silver	(Ag)	1.62
Copper	(Cu)	1.69
Aluminum	(Al)	2.62
Platinum	(Pt)	10.5
Zinc	(Zn)	6.1
Nickel	(Ni)	6.9
Tungsten	(W)	5.48
Tin	(Sn)	11.4
Lead	(Pb)	21.9
Chromium	(Cr)	2.6
Iron	(Fe)	10.0
Mercury	(Hg)	95.8
Manganin	(Cu-Mu)	34~100
Brass	(Cu-Zn)	5~7
Constantan	(Cu-Ni)	47~51
Phosphor bronz	(Cu-Sn-P)	2~6
Cast iron	(Fe-C)	57~114
Steel	(Fe-C)	20.6
Silicon steel	[Fe-Si (4.5%)]	62.5
Nichrome	[Ni-Cr-(Fe)]	100~110
German silver	(Ni-Cu-Zn)	17~41

1.1.3 Power and energy

The amount of work which is done by the electric voltage per unit time is called power and watt (W) is used as its unit. The kinetic power of a machine is often referred to as horsepower. This horsepower can be converted into electric power by the equation: one metric horsepower (1 PS) equals 740 W.

The amount of work which is done by the electric power over a certain time interval is called energy and determined by multiplying power and time. The amount of work which is done by 1 kilowatt in 1 hour is used as a unit of energy, and the name of the unit is kilowatthour (kWh). 1 kwh is equivalent to 860 kcal.

1.1.4 Ohm's law

Current I (A), voltage V (V) and resistance R (Ω) have the relationship shown in the equation 1.2. This is called Ohm's law.

$$V = IR \quad (1.2)$$

1.1.5 Connection of resistors and combined resistance

When two resistors are connected together, they can be connected either in series or in parallel, as is also the case with dry cells, inductors, capacitors and other electric elements.

(1) Series connection

When resistors R_1 and R_2 are connected in series as shown in **Fig. 3**, the combined resistance is given by equation 1.3.

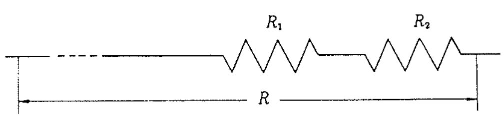


Fig. 3

$$R = R_1 + R_2 + \cdots \ (\Omega) \quad (1.3)$$

(2) Parallel connection

When resistors R_1 and R_2 are connected in parallel as shown in **Fig. 4**, the combined resistance is given by equation 1.4.

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots\cdots} \ (\Omega) \quad (1.4)$$

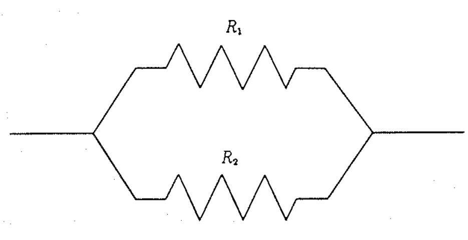


Fig. 4

1.2 Magnetism

1.2.1 Magnet

The two ends of a magnet where the magnetic force is greatest are called magnetic poles. One is called the north (N) pole or positive (+) pole, and the other is called the south (S) pole or negative (-) pole. Unlike poles attract each other and like poles repel each other. The magnetic force generated between opposite poles is proportional to the product of the magnitudes of the poles and inversely proportional to the distance between them. (Coulomb's law)

The area which is affected by the magnetic force is called the magnetic field. An imaginary line of force which shows the direction of magnetic field is called line of magnetic force.

1.2.2 Magnetic induction

If an iron bar is put in the vicinity of a permanent magnet as shown in **Fig. 5**, the bar becomes a magnet. The end of the iron bar closer to the permanent magnet has the opposite polarity and is thus attracted to the permanent magnet. The phenomenon of magnetizing an object in the magnetic field is called magnetic induction, hence the iron bar is magnetized by magnetic induction.

A material which is easily magnetized is called a magnetic material and one which is hard to magnetize is called a nonmagnetic material.

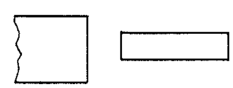


Fig. 5

Similar to electrical resistance, there can be thought to be a magnetic resistance. Magnetic material has a lower magnetic resistance and nonmagnetic material has a higher magnetic resistance. The lower the magnetic resistance, the higher the production of magnetic flux.

1.3 Electricity and Magnetism

1.3.1 Magnetic field generated by current

An electric current in a conductor creates a magnetic field in the vicinity of the conductor. The relationship between the current and the direction of the line of magnetic force is given by the Ampere's right handed screw rule, that is, if the advancing direction of the right handed screw coincides with the direction of the current, the rotation of the screw represents the line direction of magnetic force. Ampere's right handed screw rule is illustrated in **Figs. 6** and **7**.

If an iron bar is inserted into the solenoid shown in **Fig. 7**, the bar becomes a magnet. This is called an electro-magnet.

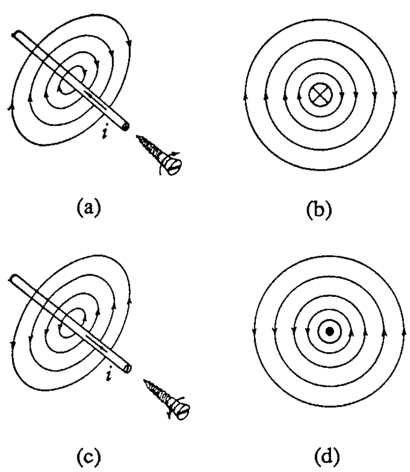


Fig. 6 Ampere's right handed screw rule

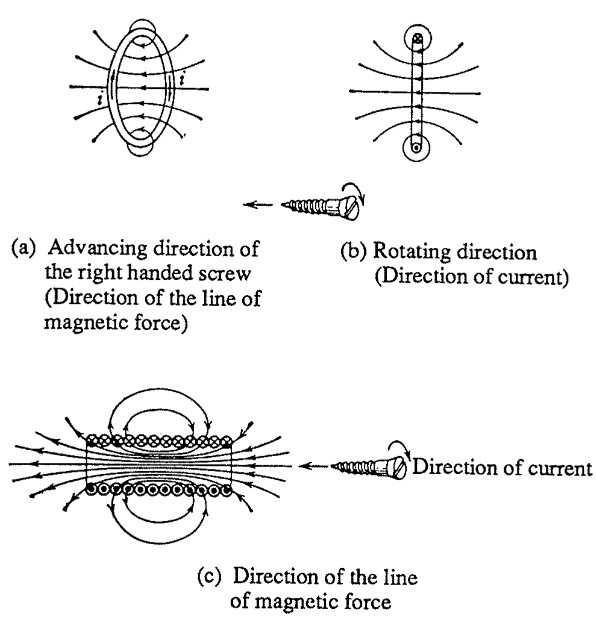


Fig. 7 Magnetic field in a coil and a solenoid

1.3.2 Electromagnetic force and electromagnetic induction

When a conductor, with its associated magnetic field is placed in a separate magnetic field, a force f on the conductor results. This force is called electromagnetic force, which is well known as the basis for motors. The relation between the current, magnetic field and the electromagnetic force is given by Fleming's rule of left hand. See **Fig. 9**. On the other hand, changes in a magnetic field around a conductor produce an electric current in the conductor. The current is maintained as long as the magnetic field moves. This phenomenon is called electromagnetic induction, which is known as the basis for electric generators and transformers. The relation between the current, the direction of magnetic field and the direction of conductor movement across the field is given by the Fleming's rule of right hand. See **Fig. 10**. By the same principle, eddy current is produced in a plate conductor placed perpendicular to the magnetic flux when the magnetic field is altered. **Fig. 11** illustrates the eddy current when the magnetic flux is increasing.

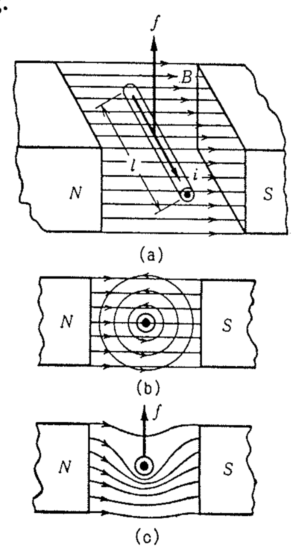


Fig. 8 Electromagnetic force

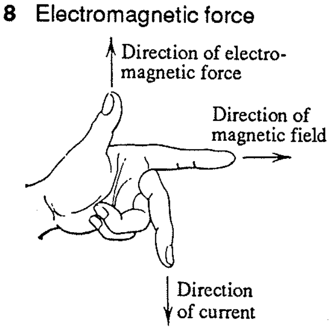


Fig. 9 Fleming's rule of left hand

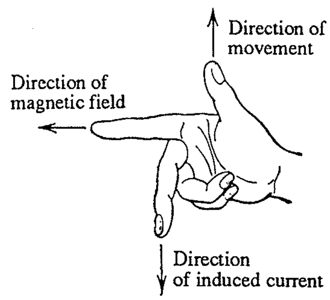


Fig. 10 Fleming's law of right hand

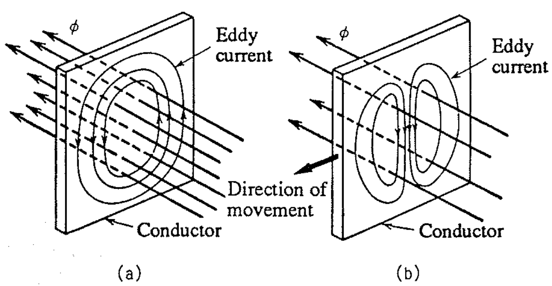


Fig. 11 Eddy current

1.4 Static Electricity

1.4.1 Static electricity

It is well known that electric charge is produced when certain materials such as rubber and silk are rubbed together. This charge is in a static state and is therefore, called static electricity.

1.4.2 Electrostatic capacity

The electric potential of a conductor increases in proportion to the quantity of charge Q (c) in the conductor just like the water level increases in proportion to the quantity of water put into a container. The relation between the potential V (V) and the quantity of charge Q (c) is given in equation 1.5 below.

$$V = \frac{Q}{C} \text{ (V)} \qquad (1.5)$$

Where C is a constant indicating electrostatic capacity, the capacity to store electric charges. Farad (F) is used as a unit of electrostatic capacity. A device to store electric charges is called a capacitor .

1.4.3 Piezoelectricity

Some crystals become electrically charged when pressure or tension is applied. Conversely, the crystals produce pressure or tension when they are put in an electrostatic field. This phenomenon is called the piezoelectric phenomenon.

Piezoelectricity is widely used in acoustic components. It is also utilized in precision measurement such as in surface roughness and other measurement machines as well as in lighters.

1.5 Alternating Current

1.5.1 Direct current and alternating current

An electric current which always flows in the same direction is called direct current, as shown in **Fig. 12**. An electric current which changes its direction periodically, as shown in **Fig. 13**, is called alternating current. Various types of alternating currents can be produced and are classified according to their wave shapes. The wave shown in **Fig. 13** is called a sinusoidal wave. Examples of other waves are given in **Figs. 14** and **15**.

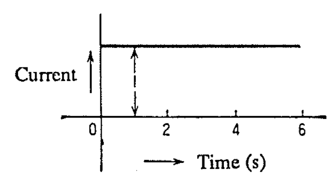


Fig. 12 Direct current

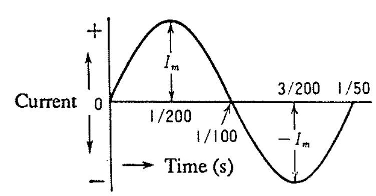


Fig. 13 Example of sinusoidal alternating current

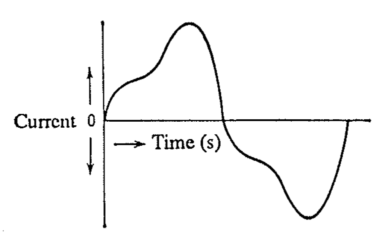


Fig. 14 Example of distorted sinusoidal current

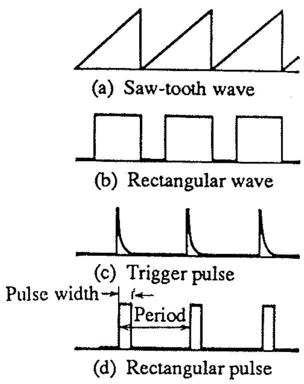


Fig. 15 Variation of pulses

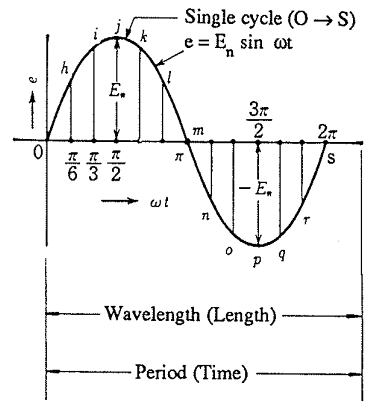


Fig. 16

Alternating current is not as simple to deal with as direct current since its values are not constant. Therefore it is often converted into the equivalent amount of direct current. The converted value is called the effective value. Usually, alternating current is referred to by this effective value and, for this reason, typical ammeters and voltmeters display this value.

If two alternating currents of the same frequency are compared, there might be a time difference in their periodic alternation. This difference is called phase difference.

If a single alternating current flows in a single wire, it is called a single phase alternating current. If three alternating currents which have 120 deg. phase differences to each other flow in three, four, six or seven wires, it is called three phase alternating current.

1.5.2 Frequency

An alternating current periodically changes its direction as already explained. A single complete alternation of direction is called a cycle. The length of one cycle is called wavelength and the time required for one cycle is called period. The number of cycles in one second is called frequency and hertz (Hz) is used as its unit. See **Fig. 16**.

The frequency of alternating current which is used for lamps, televisions, etc., is called commercial frequency. In Japan, 50 Hz commercial power is used east of the Fujigawa River in Shizuoka prefecture and 60 Hz power is used west of the river.

Waves of various frequencies are listed in **Table 2**.

Table 2 Classification of waves for wireless communication on frequency band and wavelength band

No. of frequency band	Range of frequency (Stated upperlimit is included but not lower limit)	Metric classification	Code
4	3 kHz (kc) - 30 kHz (kc)	Megameter wave	VLF
5	30 kHz (kc) - 300 kHz (kc)	Kilometer wave	LF
6	300 kHz (kc) - 3000 kHz (kc)	Hectometer wave	MF
7	3 MHz (Mc) - 30 MHz (Mc)	Decameter wave	HF
8	30 MHz (Mc) - 300 MHz (Mc)	Meter wave	VHF
9	300 MHz (Mc) - 3000 MHz (Mc)	Decimeter wave	UHF
10	3 GHz (Gc) - 30 GHz (Gc)	Centimeter wave	SHF
11	30 GHz (Gc) - 300 GHz (Gc)	Millimeter wave	EHF
12	300 GHz (Gc) - 3000 GHz (Gc)	Decimillimeter wave	——

1.5.3 Power of alternating current

For alternating current, the power obtained by the multiplication of effective current and effective voltage is a calculated value rather than the real power. Therefore it is called apparent power and volt-ampere (VA) is used as its unit. The ratio of the real power and the apparent power is called the power factor (cos θ). The real power of the alternating current is obtained by multiplying this power factor and the apparent power. Watt (W) is used as a unit of real power of alternating current, the same as for direct current.

$P = VI$ (apparent power VA) (1.6)

$P = VI \cos\theta$ (Effective power W) (1.7)

2. MEASUREMENT OF ELECTRICITY

2.1 Measurement of Voltage and Current

Measuring devices (meters) of the moving coil type are mainly used in the measurement of direct current. On the other hand, moving core types are mainly used in the measurement of alternating current. Various types of measuring devices, such as electrodynamic force meter, electrothermal, and hotwire, are also used for alternating current.

Among the various measuring devices, the tester (circuit tester) is quite convenient and widely used since it can measure direct current voltage, alternating current voltage, direct current, resistance, etc.

Measuring devices are available in five grades from 0.2 to 2.5. Devices of 1.5 grade (tolerance ±1.5%) are most commonly used.

Current is measured by inserting an ammeter in series in the circuit as shown in **Fig. 17**, and voltage is measured by connecting a voltmeter in parallel in the circuit as shown in **Fig. 18**.

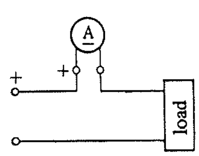


Fig. 17

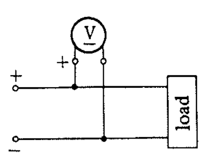


Fig. 18

2.2 Recorders

In addition to measuring devices, recorders are also used to obtain records of the measurement. Two kinds of recorders are available, analog recorders and digital printers. The recorder is selected according to the type of input signal.

If the input is an analog signal, the recorder must be selected carefully considering the following points:

1) Is the input signal a current or voltage signal?
2) Is the input signal direct current or alternating current?

In addition, the magnitude of the signal must also be taken into consideration. Fewer problems occur with digital input since BCD code (binary coded decimal code) is usually used, except for some special cases, for data transmission from the measuring device to the recorder.

3. DIGITAL DISPLAYS

3.1 Analog and Digital Display

The word "analog" implies "similarness" and refers to a quantity that varies continuously or is determined from its position on a scale of continuous graduations. Commonly used measuring tools, such as vernier calipers, micrometers and dial indicators, are analog tools.

3.2 Advantages and Disadvantages of Digital Display

Digital displays have become popular because they have many advantages over analog systems.

The main advantages and disadvantages of digital displays are listed below.

(1) By increasing the number of decimal places in a digital display, it is possible to extend the indication range while keeping the same resolution. However, with an analog display, because the scale range is limited, it is impossible to extend the indication range without making the scale division value larger.

(2) A digital display is easy to read and error-free. Consequently, it eliminates the human error in reading.
(3) Zero setting is possible at any desired position. Moreover, presetting is easy.
(4) Data processing such as printing, recording, calculating, etc. is easy.
(5) Connection to a computer is easy.
(6) It is complicated and expensive.
(7) Quantizing error exists.
(8) If the displayed value fluctuates, the display becomes hard to read. On the other hand, it is possible to read an analog indication to a certain extent even when the pointer fluctuates (drifts).

3.3 Quantizing Error

There is the possibility of quantizing error in digital displays since the value below the last displayed digit is completely unknown. As shown in **Fig. 19**, when the same length 1 is to be measured, the result might be either 5 or 6, depending on the position of zero resetting. Because of this, digital displays always have an error of 1 digit. This is called quantizing error or digital error.

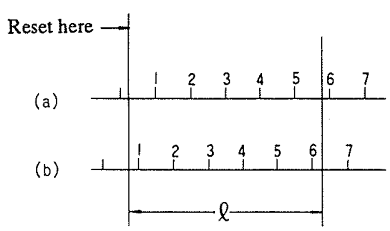


Fig. 19 Different values may result even when measuring the same length.

However, the quantizing error is considered to have a triangular distribution within ±1 as shown in **Fig. 20**. About 80% of the distribution can be considered to be within ±0.5 count.

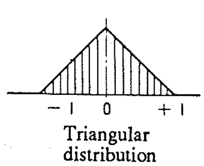


Fig. 20

3.4 BCD Code

In almost all cases, the output from digital displays is used for data processing purposes. Therefore, the output format becomes important.
Numbers used in everyday life are 0,1, ... 9 and are called decimals. However, in digital processing, a binary system is used. That is, only two signals, such as 0 and 1, or ON and OFF, are used to express all values. Therefore, some sort of relationship must be established between the decimal system and the binary system.
In general, BCD code (binary coded decimal code) is widely used. This relationship is shown in **Table 3**. For example, decimal 3 is written as 0011 in BCD code.

Table 3 Decimal numbers expressed in binary system

Decimal numbers	Binary coded decimal code (BCD code)			
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

4. MECHANICAL-ELECTRICAL TRANSDUCERS

4.1 Differential Transformer

Among the various types of converters, the differential transformer is the most widely used. It is also used in our Mu-checkers and Contracers.

The principle of the differential transformer is illustrated in **Fig. 21**. If a source voltage E_p is applied to the primary coil, voltages E_{s1} and E_{s2} are induced in the secondary coils. Because the secondary coils are differentially interconnected, the total induced voltage becomes E_s. The total induced voltage E_s changes as shown in **Fig. 22** depending on the core position. Therefore, the core displacement can be detected from the change in E_s.

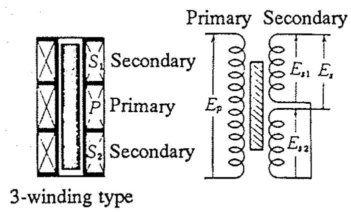


Fig. 21

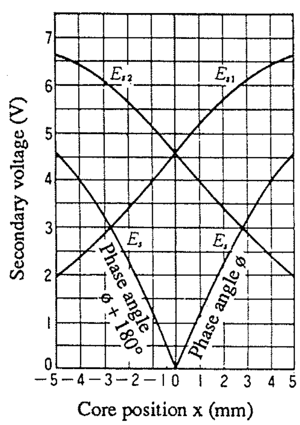
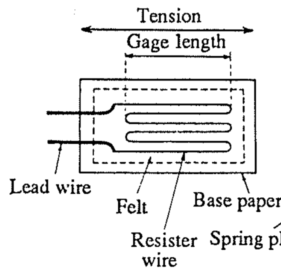


Fig. 22 Secondary voltage characteristics of differential transformer

In the Mu-checker, this core is directly attached to the spindle or the lever contact point. Therefore, the displacement of the contact point is directly detected as the displacement of the core.

4.2 Strain Gage

As explained previously, the resistance of a conductor is proportional to its length and inversely proportional to its sectional area. If a conductor is stretched, its length is extended and its sectional area is reduced. Consequently, its resistance increases. If, using some method, a contact point is attached to an elastic conductor, the resistance of the elastic conductor changes according to the displacement of the probe. Thus, by determining the change in resistance, the displacement of the conductor can be found. See **Fig. 23, 24** and **25**.



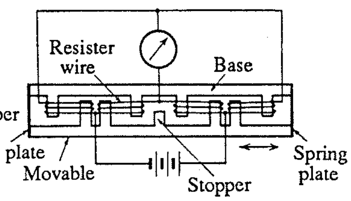


Fig. 23 Adhesive type strain gage **Fig. 24** Nonadhesive type strain gage

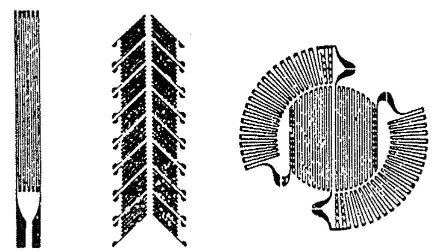


Fig. 25 Thin gage

4.3 Piezoelectric Element

Applying the piezoelectric phenomenon explained earlier, various piezoelectric elements can be produced. These are mainly used in acoustic products, but some are used in surface roughness measuring machines.

4.4 Moving Magnet Type Converter

The moving magnet type converter comprises a magnet and a coil. The magnet is placed in or near the coil. If the magnet is moved, electricity is induced in the coil. If a probe is attached to the magnet, the displacement of the probe can be detected from the induced electricity.
Note that the moving magnet type converter and the piezoelectric element do not exactly measure stylus

displacement, but instead the magnitude of the induced voltage depends on the velocity at which the stylus moves. For this reason, they are called velocity conversion types. On the other hand, differential transformers and strain gages are called displacement conversion types since the displacement itself is converted into voltage regardless of the velocity.

4.5 Magnescale

If pulses, instead of voices or music, are recorded on a tape, it is possible to determine the length of the tape just by counting the pulses. This principle is applied to Magnescale as illustrated in **Fig. 26**. In Magnescale, magnetic signals are recorded every 0.2 mm. This is further divided electrically to obtain resolution of 5µm, 2µm or 1µm.

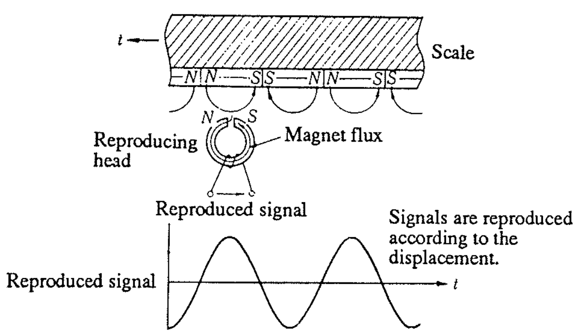


Fig. 26

4.6 Inductsin

Inductsin is similar to a coil that has been stretched out and pressed into a plane. It is made by bonding a copper foil on a metallic base plate with a nonconductive adhesive and etching to obtain a zigzag-shaped coil. If two of these coils (a longer one called the scale and a shorter one called the slider) are placed facing each other, and alternating current is applied to the scale, an induced voltage develops in the slider. Relative motion between the scale and the slider results in the sinusoidal voltage in the slider shown in **Fig. 27**. Therefore, the displacement can be determined by counting the number of waves.
The usual wavelength is 2mm and, in the same manner as the Magnescale, the wave is electrically divided in order to obtain more precise reading. There are two types of Inductsin, linear type and rotary type, which are selected according to the application.

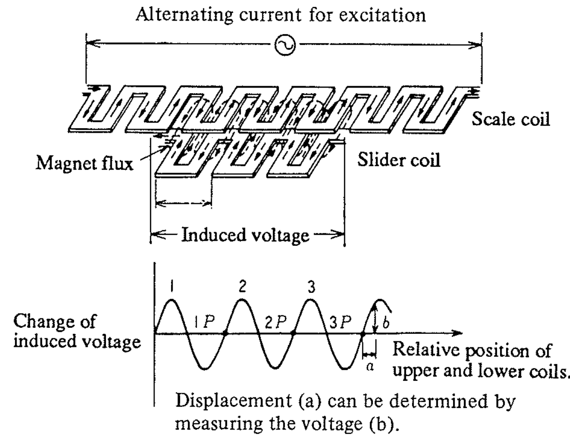


Fig. 27 Scale of a zigzag coil

4.7 Moire Fringes

If two glass plates on which scales of the same pitch have been marked are placed together at a slight angle, the fine intervals are magnified in the vertical direction as shown in **Fig. 28**. If the plates are displaced relatively, the magnified fringes also move up and down. The relative displacement can be detected by photoelectrically counting the magnified fringes with a device as shown in **Fig. 29**.
Various pitches are available, and through electrical division more precise readings can be made. Both linear and rotary types are available.

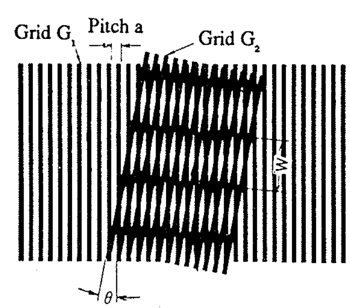


Fig. 28 Principle of moire fringes

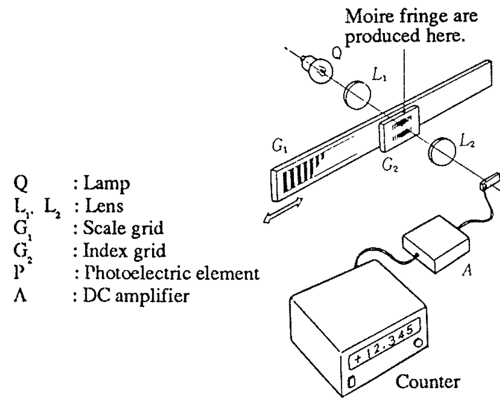


Fig. 29 Digital measurement of moire fringes

4.8 Linear Scale

In the system of moire fringes, two scales are placed together at a slight angle. A system where the two scales are placed together with no angle difference is called a linear scale system. Except for the angle, there is no difference between the moire fringes system and the linear scale system.
The scale of our Linear Scale has 10μm thick gratings at 10 μm intervals. The pitch is 20 μm and again it is electrically divided to obtain 5 μm, 2 μm or 1 μm reading.

5. SEMICONDUCTORS

Germanium (Ge) and silicon (Si) have conductivities between that of insulators and of conductors and are called semiconductors.
In these elements, the attraction between the nuclei and the electrons is very weak. Therefore, depending on the magnitude of energy applied, electrons can freely move within the atomic structure. If a small amount of an impurity is introduced into pure germanium or silicon (doping), depending on the impurity, a state of more electrons than holes (N type semiconductor) or a state of less electrons than holes (P type semiconductor) will result. Combining these two types produces the same functions as produced by a vacuum tube.
Fig. 30 illustrates a semiconductor diode which functions as a rectifier, just like a vacuum tube diode. **Fig. 31** illustrates a transistor which can be used to amplify or oscillate, just like a triode.

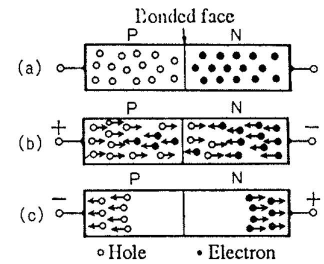


Fig. 30

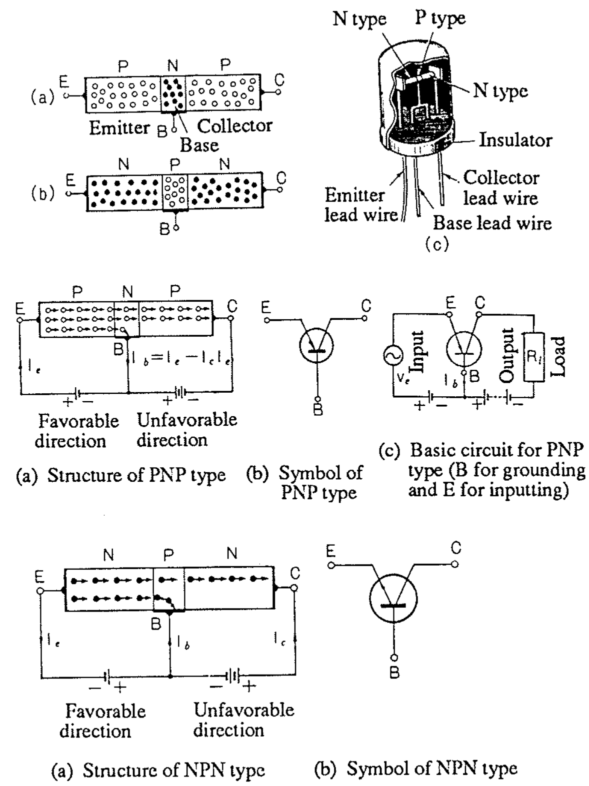


Fig. 31

Presently, vacuum tubes have been completely replaced by semiconductors since diodes and transistors have many advantages over vacuum tubes such as: 1) compact design, 2) light weight, 3) low power consumption, and 4) long life. The advancement of semiconductor technology has yielded an integrated circuit (IC) in which dozens of transistors, diodes, resistors and capacitors can be integrated within a square of a few millimeters. IC technology has further advanced, and now a single silicon chip can contain a large number of ICs. This is called large scale integration (LSI).

6. UNITS AND SYMBOLS

6.1 Units

Many units are used in the fields of electricity and magnetism. Some of the most commonly used quantities and units are listed in **Table 4**. In **Table 5**, metric multipliers are listed.

Table 4

Name and symbol of quantity		Name and symbol of unit	
Voltage	E	Volt	V
Current	I	Ampere	A
Power	P	Watt Voltampere	W VA
Resistance	R	Ohm	Ω
Capacity	C	Farad	F
Inductance	L	Henry	H

Table 5 Metric multiplier

Name	Symbol	Qty	Name	Symbol	Qty
tera	T	10^{12}	deci	d	10^{-1}
giga	G	10^{9}	centi	c	10^{-2}
mega	M	10^{6}	milli	m	10^{-3}
kilo	k	10^{3}	micro	μ	10^{-6}
hecto	h	10^{2}	nano	n	10^{-9}
deca	D	10	pico	p	10^{-12}

6.2 Electrical Element Symbols

Two types of electric circuit diagrams are the wiring diagram, which uses figures as close to the actual configuration as possible, and the circuit diagram, which uses symbols. The symbolic circuit diagram is widely used when representing complicated circuits. The symbols used in these diagrams are prescribed in JIS C 0301. Some of the basic symbols are listed in **Table 6.**

In addition, block diagrams are sometimes used to show the structure of the overall system. **Fig. 32** is an example of a block diagram.

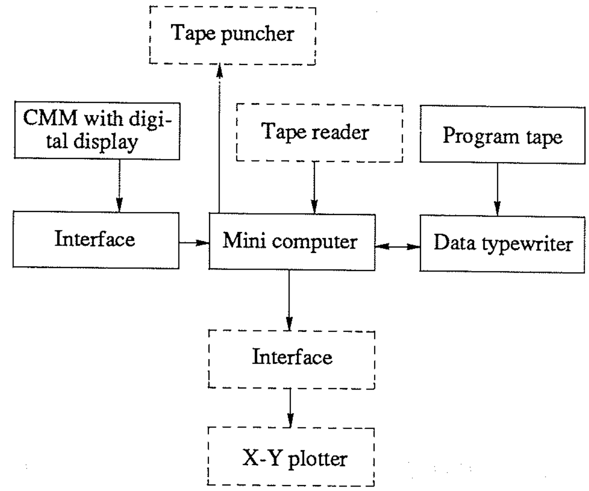
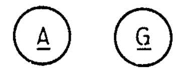
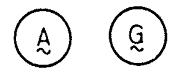
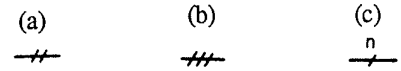
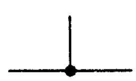
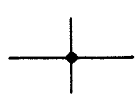
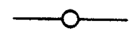
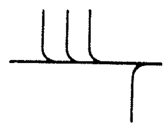
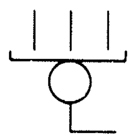
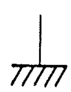
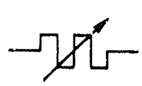
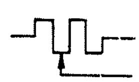
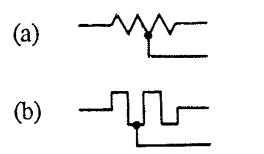
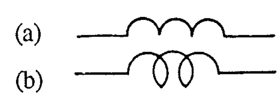
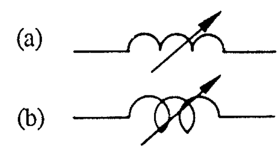
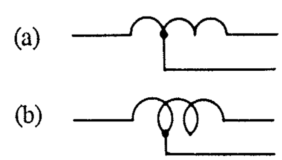
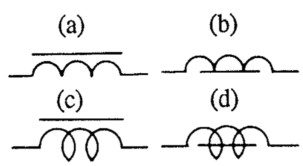
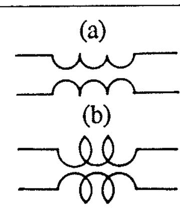
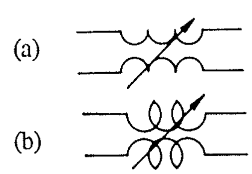
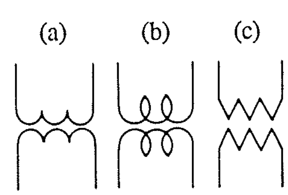
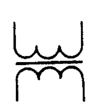


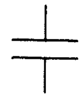
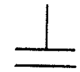
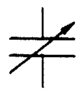
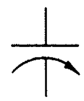
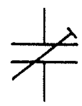
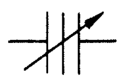
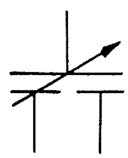
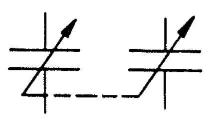
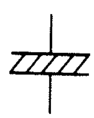
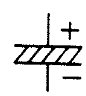
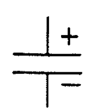
Fig. 32

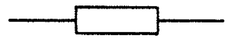
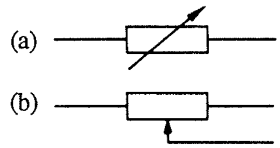
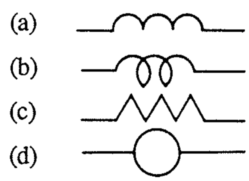
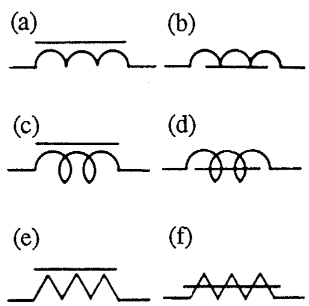
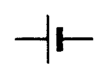
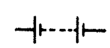
Table 6 Basic symbols

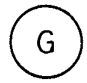
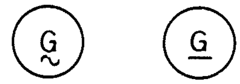
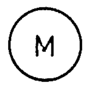
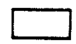
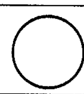
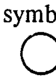
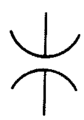
Code	Name	Symbol	Application and remarks
I 1	Direct current	—	Ex: 
I 2	Alternating current	∼	Ex: 
I 3	High-frequency wave		Ex: 
I 4	General symbols expressing "variable"	(a) (b) (c) 	1. (b) is used especially when it is semivariable 2. (c) is used especially when it is a tap changer
I 5	General symbol expressing linkage	– – – –	Ex: See I 30.
I 6	Conductive wire (general)	——	1. Widely used for electric wires, buses etc. 2. Distinction by the width of line is allowed. 3. When it is critical, number of conductives can be expressed as follows. (a) (b) (c)  2 lines 3 lines n lines
I 7	Branching of conductive wire		
I 8	Intersection of conductive wires (connected)		

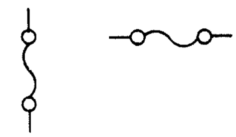
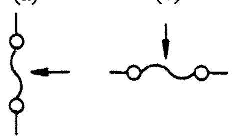
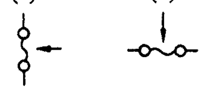
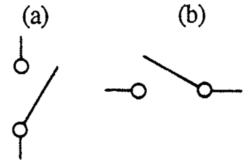
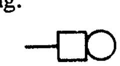
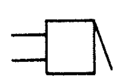
Code	Name	Symbol	Application and remarks
I 9	Intersection of conductive wires (not connected)		
I 10	Terminal	(a) ○ (b) ●	Ex: 
I 11	Bandled wires		Rounded line may well be replaced with inclined line.
I 12	Connected wires		1. Put a reference number in the circle. 2. If the reference number is not necessary, eliminate the circle.
I 13	Ground		
I 14	Grounding to the case		Inclined line may be reduced or eliminated as long as it does not produce any mistake.
I 15	Resister	(a)  (b) 	1. Number of peaks may be changed if necessary. 2. (b) is exclusively used to express non-inductive resister.
I 16	Variable resister	(a)  (b)  (c)  (d) 	1. Number of peaks may be changed if necessary. 2. (b) and (c) are exclusively used to express non-conductive resisters.

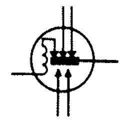
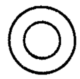
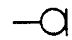
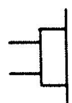
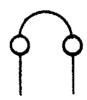
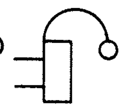
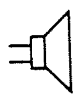
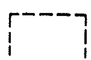
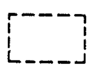
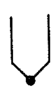
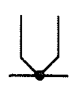
Code	Name	Symbol	Application and remarks
I 17	Resister with tap		1. Number of peaks may be changed if necessary. 2. (b) is exclusively used to express non-inductive resister.
I 18	Inductance		
I 19	Variable inductance		Number of peaks may be changed necessary.
I 20	Inductance with tap		
I 21	Inductance with core		1. Number of peaks may be changed if necessary. 2. The bar may be eliminated if it is manifest to be an inductance with core.
I 22	Mutual inductance		Number of peaks may be changed if necessary.
I 23	Variable mutual inductance		
I 24	Transformer		1. Number of peaks may be changed if necessary. 2. If it is necessary to show that the transformer is with core, following symbol is used. 

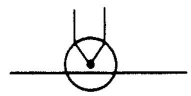
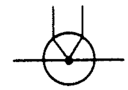
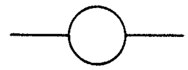
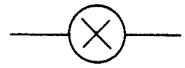
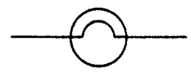
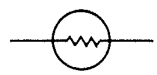
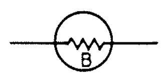
Code	Name	Symbol	Application and remarks
I 25	Capacitor		In a single wire drawing following symbol may be used. 
I 26	Variable capacitor	(a)  (b) 	(b) is specially used to distinguish rotor.
I 27	Semivariable capacitor		
I 28	Variable balancing capacitor		
I 29	Variable capacitor		
I 30	Variable interlocking capacitor		
I 31	Electrolytic capacitor		1. Plus (+) and minus (-) may be added as shown below.  2. The inclined lines may be eliminated as long as it is manifest to be an electrolytic capacitor. 

Code	Name	Symbol	Application and remarks
I 32	Impedance		
I 33	Variable impedance		
I 34	Electromagnetic coil		1. Number of peaks may be changed if necessary. 2. (c) must be used not to be mistaken as a resister.
I 35	Coil with core		1. Number of peaks may be changed if necessary. 2. The bar may be eliminated if it is manifest to be with core. 3. The bar may be replaced with dotted line if it is necessary to show that the core is a dust core.
I 36	Battery or DC source (general)		1. Following symbol may be used to show clearer.  2. Longer line must represent positive pole and shorter line negative. 3. Series may be expressed as follows. 
I 37	Rectifier (general)		Arrow head must be regular triangle and show the direction of DC current.
I 38	Alternating current (general)		

Code	Name	Symbol	Application and remarks
I 39	Generator		Following symbols may be used if the distinction between AC and DC is necessary. AC DC 
I 40	Motor		Following symbols may be used if the distinction between AC and DC is necessary. AC DC 
I 41	Device or instrument		Characters or a symbol is put in the rectangular. 
I 42	Meter		Characters or a symbol is put in the circle. 
I 43	Lightening discharger	(a)  (b) 	
I 44	Discharging gap		
I 45	Rectangular gap		
I 46	Pointed gap		
I 47	Spherical gap		

Code	Name	Symbol	Application and remarks
I 48	Fuse	(a) (b) 	Following symbols may be used to distinguish between open type and closed type. Open type (a) (b)  Closed type (a) (b) 
I 49	Alarm fuse	(a) (b) 	Following symbols may be used to distinguish between open type and closed type. Open type (a) (b)  Closed type (a) (b) 
I 50	Heat coil		Heat coil type fuse is included.
I 51	Switch (general)	(a) (b) 	
I 52	Bell		Following symbol may be used in a single wire drawing. 
I 53	Buzzer		Following symbol may be used in a single wire drawing. 

Code	Name	Symbol	Application and remarks
I 54	Vibrator		Wire connection may be expressed as shown in the following example if necessary. 
I 55	Transformer or microphone	(a)  (c)  (b) 	Following symbol may be used instead of (b) in a single wire drawing. 
I 56	Receiver	(a)  (b)  (c) 	1. (b) and (c) show headphones. 2. Following symbols may be used in a single wire drawing. 
I 57	Speaker (general)		Following symbol may be used in a single wire drawing. 
I 58		(a) (b)  (c) 	
I 59	Thermoelectric couple		
I 60	Direct heated thermoelectric couple		
I 61	Indirectly headed thermo-electric couple		

Code	Name	Symbol	Application and remarks
I 62	Vacuum type indirectly heated thermoelectric couple.		Following symbol must be used for direct heated type. 
I 63	Lamp	(a)  (b)  (c) 	Follow the example below to indicate its color and use. Ex: Write a code such as "RL", "OL", "BL", or "WL" for red, orange, green, blue or white lamp, respectively. Put a code "PL" beside it, if the lamp is a pilot lamp.
I 64	Resister tube		
I 65	Ballast lamp		Barretter is included.
I 66	Element to be measured by oscillograph		Following symbol must be used to show oscillograph. 

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