6. Measurement of the quantity of state

6.1 Measure State Quantity

Something like liquid or gas, which shape defined by container is called fluid. Liquid can be compressed but not gas, if there is something inside of it, this thing will get same pressure from all around. Pressure is scalar and different with strain to solid. Pressure defined as force per unit area. In SI unit, Pa (Pascal: N/m^2) is been used.

Wide industry, pressure meter as industrial, civil engineering, mechanical, industrial chemical, electronics industry, which is the indispensable measurement device to them. From vacuum to extra high pressure, pressure meter can be used in wide field. Fig.6.1 shows different type of pressure meter used in different filed.

When express pressure, pressure to vacuum is called absolute pressure, use atmospheric pressure as standard is called gauge pressure. In practical pressure meter, get absolute pressure by utilizing balance of force is called primary pressure meter, get relative pressure by physical change of substance caused by pressure is called secondary pressure meter. The former one uses liquid column and weight, and the latter one uses elastic deformation, piezoelectric effect and piezo resistance effect.

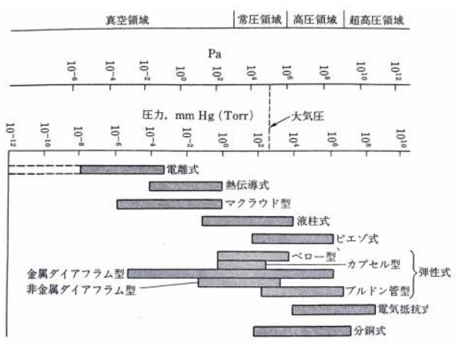


Fig.6.1 Pressure Region and Pressure Gauge Sharing Range

6.2 Measure Pressure

6.2.1 Measure High Pressure

Atmospheric pressure (1 atm) is 1kPa, usually, hundreds MPa is called high pressure. In industry, high pressure is usually means pressure that under 300 MPa, here pressure which use unit MPa is called high pressure.

A. dead-weight tester

A primary meter used for measure area around kPa or GPa. Cause it accuracy is 0.1%, used for standard of secondary meter also.

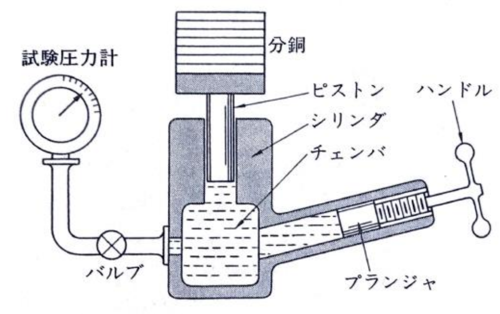


Fig.6.2 Piston-Cylinder Type Dead-Weight Tester

Fig.6.2 shows construction of an example of Piston-cylinder type dead-weight tester. Use oil as pressure mediation, pressure p can be calculated by next equation.

$$p = \frac{Mg}{A}$$

However, M(kg) is mass of piston and weight, A(mm^2) is average sectional area, g(m/s^2) is gravitational acceleration. This method use pascal principle, principle is simple, but gravitational acceleration is different depend on position, and oil leak at area, where is between piston and cylinder. Also, if pressure nearly to 300 MPa, elastic deformation cannot be ignored. The lesser p, the lighter weight, the bigger sectional area. Sectional area is around 10~1/20 cm^2.

B. elastic pressure gauge

Use principle that container or thin plate will deform under pressure, meter could measure 10^4~10^9Pa pressure area is commercially available. In high pressure area, Bourdon type is mostly available.

Bourdon type elastic pressure gauge is shown in Fig.6.3. Bourdon pipe is a hollow bent pipe with elliptical cross section. Freedom side would deform if inside pressure is changing. Measure

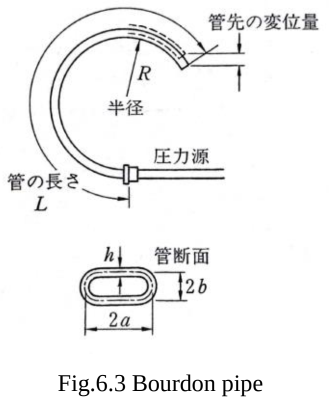


Fig.6.3 Bourdon pipe

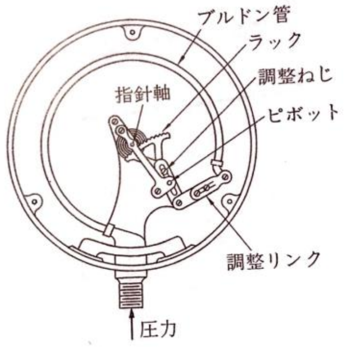


Fig.6.4 Construction of Bourdon Type

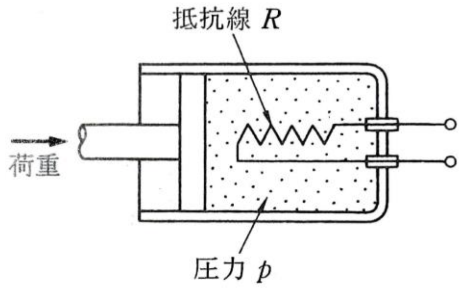


Fig.6.5 Principle of Mental Piezoresistance

the difference of deformation and can get value of pressure. The relation of deformation-pressure is a monotonically increasing function. Here is an example of construction of Bourdon type in Fig.6.4, the movement of pipe side will turn into rotation of pointer with combination of link and gear. Material of Bourdon pipe usually is phosphor bronze and brass, in high pressure, use drawing pipe of ordinary steel, special steel. Accuracy is 1~2%.

C. piezoelectric pressure gauge

Piezoelectric effect is an effect that if add electrode to both sides of a plate of some crystal, potential on surface of crystal will change by pressure p. Or in another word, if a force is applied to an ionic crystal or a strongly ionic crystal, electric polarization proportional to the crystal will occur, and positive and negative electric charges appear on the facing surface.

Tab.6.1 Characteristics of piezoelectric crystals

物　質	方　向	電圧感度 s $\left(\frac{V/m}{Pa}\right)$	誘電率 ε (F/m)
水　晶	X カット　厚み方向	−0.050	4.06×10^{-11}
	Y カット　滑り	0.108	〃
ロシェル塩	X カット　45° 長さ方向	0.098	444
ADP	Z カット　輪郭滑り	0.354	13.8
チタン酸バリウム	分極に平行	0.0106	1,200～1,500

Voltage between two sides of crystal is,

$$E = stp$$

However, p(Pa) is pressure, t(m) is thickness of crystal, s is voltage sensitivity. s is,

$$s = \frac{d}{\varepsilon}$$

However, d is piezoelectric coefficient, ε is dielectric constant. Table.6.1 shows voltage sensitivity of piezoelectric crystal. The output of voltage is different by cut off of the crystal plate to the crystal axis. X-cut means direction of vertical to cut surface is X axis of crystal.

Piezoelectric effect is an effect that charge occur on surface of crystal by pressure, time will not affect value of charge. Cause crystal with large electrical resistance, the charges that appear are lost by the discharge from the device, this method is not suit for measure static pressure.

D. Piezoresistance pressure gauge

Used in pressure meter for measure pressure above Mpa, GPa, resistance change of metal will change by high pressure, this phenomenon is called piezoresistance effect. Piezoresistance effect is a phenomenon that add force to mental or semiconductor crystal, resistance ρ will change. In Fig.6.5, one mental line added by force from some direction, resistance will change. The reason is, crystal lattice of metal changed by force and movement of free electron will change. If change of pressure is small, resistance R to pressure change Δp is,

$$R = R_0(1 + b\Delta p)$$

However, R_0 is the resistance under atmosphere pressure, b is pressure coefficient of resistance. Tab.6.2 shows pressure coefficient of medium metal.

6.2.2 Measure Medium Pressure

10^3~10^6 Pa or can be said kPa is called medium pressure. Atmosphere pressure is 101.3kPa, compressed air machine like air drill or air hammer is 600~700kPa, it is close to our daily life.

A. Tube Manometer

Measure pressure to balance another pressure occur by tube, it is a very simple primary meter. There are three types and shown in Fig.6.6.

Tab.6.2 Pressure Coefficient Of Metal Resistance

材　料	抵抗の圧力係数 b (1/kPa)	比抵抗 (Ω・m)
マンガニン (Cu 84, Mn 12, Ni 4)	$+2.5\times10^{-8}$	45×10^{-4}
金クロム合金 (Cr 2, Au 98)	$+0.98\times10^{-8}$	2.4×10^{-4}

Fig.6.6 (a) is called U-type tube. A side and B side

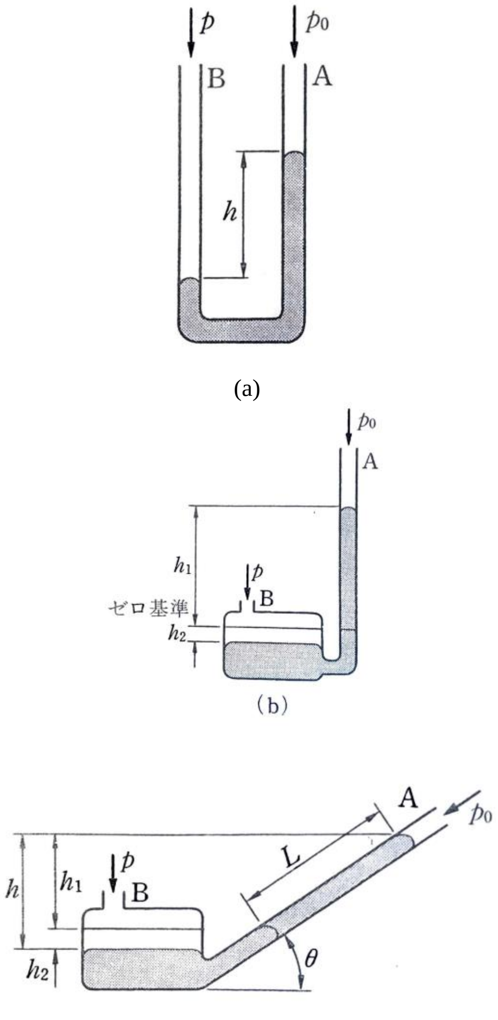


Fig.6.6 Principle of Tube Manometer

are open, and there is liquid like water, mercury or oil in the tube. *A* side is open to atmosphere p_0, add some pressure to *B* side. Density of liquid is ρ (kg/m^3), gravitational acceleration is g(m/s^2), height of liquid is h(m), so difference of pressure (Pa) is

$$p - p_0 = \rho g h$$

If ρ, g are constant, read height h, difference of pressure $p - p_0$ will get.

To U-type tube, read height is troublesome. Therefore, increase area of section like Fig.6.6 (b) is considered. In Fig.6.6(b) zero point means both side pressures are same, measure height to *A*, *B* side h_1, h_2 from zero point. And sectional area of *A*, *B* are *a*, *A*. There is a relation $ah_1 = Ah_2$. Pressure equilibrium equation is,

$$p - p_0 = \rho(h_1 + h_2)g = \left(1 + \frac{a}{A}\right)\rho h_1 g$$

Cause $(1 + a/A)h_1$, read the thinner tube height scale h_1 only and will get $p - p_0$.

In Fig.6.6 (c) is called Inclined tube type.

$$p - p_0 = \rho g \left(\frac{a}{A} + sin\theta\right) L$$

Read L and get pressure. Sensitivity is increased caused of increase length of liquid. This can measure low pressure under few kPa.

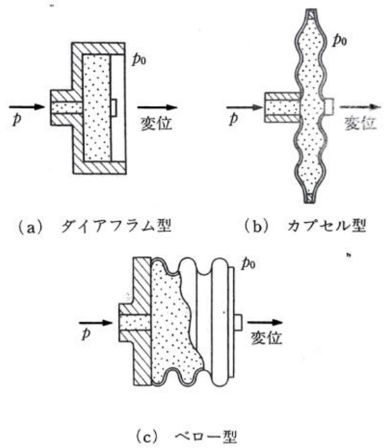


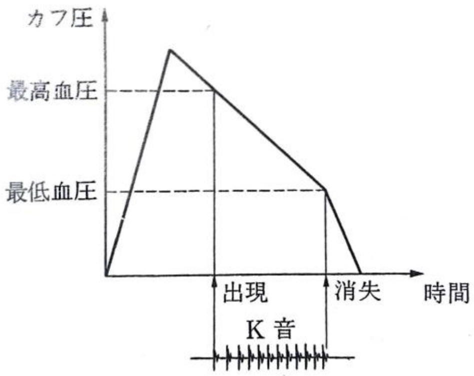
Fig.6.7 Pressure Sensitive of Elastic Deformation Meter

B. Elastic Deformation Meter

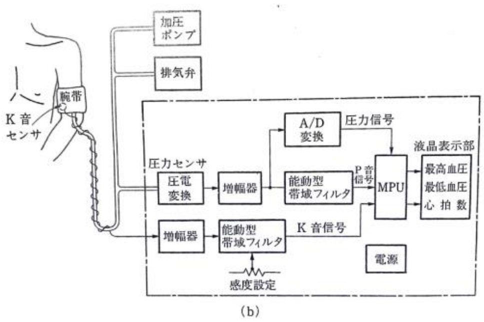
Bourdon tube can also be used in low pressure measurement around 50kPa, but in area kPa, diaphragm type, capsule type and bellow type are main. All use same principle which is part or all of sealed container is made of elastic thin plate, get deformation of the plate by difference between inside and outside. Elastic material means phosphor bronze, brass, steel, also rubber, Si or Ge semiconductor are used. In Fig6.7, p_0 is atmosphere pressure, measure gauge pressure, or measure absolute pressure if in vacuum. Of course, if in vacuum, add pressure p instead of p_0 to avoid too much change of plate.

This method can be used in all area in kPa, especially metal diaphragm type upper limit is 100Mpa, nonmetal diaphragm type lower limit is 10Pa (~1mmH_2O). Accuracy is 1~2%. This meter be used widely in industry and daily life.

Fig.6.8 shows principle of blood pressure measurement and configuration block diagram of automatic blood pressure monitor. Wrap a cuff (arm band) for hold pressure on the upper arm, send air and add pressure to close the brachial artery. And then remove pressure slowly, Stethoscope (mic) at arcuate artery will hear vocal arterial sound. It is a blood vessel sound called Korotkoff sound (K sound), occur by blood flow pressured blood vessel, this pulsation is same as heartbeat. K sound occur when remove pressure and will disappear. The cuff pressure of K sound be heard firstly is systolic blood pressure, and the

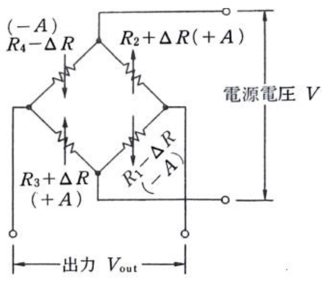


(a) Principle of Blood Pressure Measurement

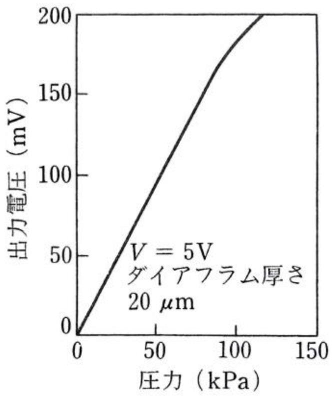


(b) Configuration Block Diagram

Fig.6.8 Automatic Blood Pressure Monitor



(a) Bridge Circuit



(b) I / O Characteristics

Fig.6.10 bridge circuit and I/O characteristics

pressure of K sound disappear is diastolic pressure. K sound can be detected by K sound mic inside cuff, but to avoid noise, use a method of synchronously detecting with the arterial pressure wave (P sound) appearing in the pressure sensor is taken

Gauge pressure of blood pressure to atmosphere pressure is expressed by Torr, diaphragm type pressure sensitive part, which used semiconductor piezoresistive effect, use as pressure sensor be used widely. Fig.6.9 shows one, thickness is $20\mu m$, area of diaphragm is 2×2mm made of silicon pellet. Tiny change of diaphragm, for increase it, use 4 resistance parts of silicon pellet to output increase value of the change by bridge circuit. Caused silicon resistance is sensitivity to temperature, bridge circuit can compensate it. Fig.6.10 shows bridge circuit and I/O characteristics. If gauge pressure is keep around 100kPa, the I/O line will be a straight line, accuracy is $\pm 0.3\%$.

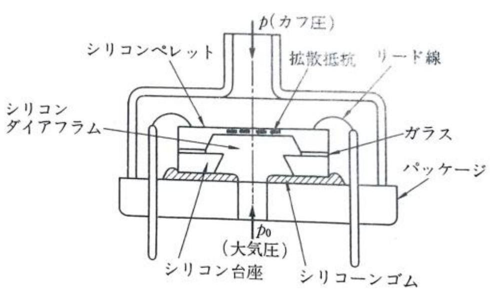


Fig.6.9 diaphragm type pressure sensitive part, used semiconductor piezoresistive effect

Silicon pellet type is cheap and easy for mass production. Not only for industry, but also for daily life. It is also widely used for water depth gauges and bottle residual pressure gauges used as diving gates.

6.2.3 Measure Vacuum

Vacuum packs, vacuum cleaners, vacuum tubes and other everyday familiar sources often hear "vacuum" means an environment that is below atmospheric pressure, but here we define an area of 1 kPa or less. The pressure meter used there is called a vacuum gauge. The pressure measured by the vacuum gauge is mostly absolute pressure.

High integration such as LSI used for household media equipment ranging from TV to PC, a vacuum better than 10^{-7}Pa is required for the manufacture of electronic components. Foods such as dried vegetables and instant coffee, chemicals such as vitamins and vaccines are made by operations such as freeze-drying in vacuum or distillation, and it also needed pressure area that 50kPa~1Pa. Various vacuum gauges are active as pressure gauges in each area of the wide pressure range shown in the Fig.6.11.

A. Liquid Column Type Force Meter

As can be seen from the fact that Torchell's vacuum test of Torricelli, which is a source of Torr's units, started with mercury columns, even from now on, even from simple U-type tube to

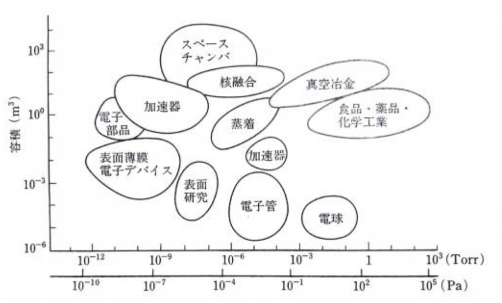


Fig.6.11 Vacuum Technology that Widely Supports from Basic Research to Production

McLeod type, which use gas compression, pressure gauge using mercury column is used from atmospheric pressure to 10^{-6} Pa in the vacuum region.

Here, we will take up the McLeod type shown in Fig.6.12, which can measure up to about 10^{-5} Pa. In Fig.6.12, volume of the spherical part and capillary part above a is V(m^3), sectional area of the thin tube part is S(m^2). Initially, mercury is contained only in the lower mercury dome, but all of the upper part has the degree of vacuum to be measured. Now open the cock B and let air in slowly, mercury rises in the pipe and separates to the left and right at the point a, at that time the air on the right side is divided and confined in the closed tube part. Further raise the mercury and move the cock B to the position shown in Fig.6.12. When closed, the upper part of the left thin tube is at the pressure p to be measured, and at the upper part in the right capillary, the air of the volume V that was in pressure p is compressed and confined.

Measure height h(m) and x(m) in Fig.6.12.

$$pV = (h + p)Sx$$

Where is Boyle's law.

$$p = \frac{Shx}{V - Sx}(Pa)$$

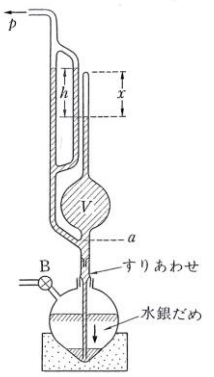


Fig.6.12 McLeod type

Pressure can be calculated. $V \gg Sx$, $p \ll h$ is medium state. If measure it when $h = x$,

$$p = \frac{S}{V}h^2(Pa)$$

If S/V is known, measure height h and p will be calculated.

McLeod type takes time to operate, but accuracy is few $\pm\%$. It also be used as a calibration pressure meter (secondary pressure meter) to electric type pressure meter for high vacuum.

B. Elastic Deformation Type Pressure Gauge

Among elastic deformable pressure gauges for medium pressure, the metal diaphragm type can also be used for vacuum measurement. When using a thin metal diaphragm of about $25\mu m$ and sealed on one side with high vacuum, the amount of deformation of the thin film which becomes a secondary pressure gauge with sensitivity up to $10^{-3}Pa$ is detected as a change in capacitance between the thin film and the counter electrode plate and it is measured with an *AC* bridge or something like it.

Cause it is robust and have accuracy of a few %, used for medicine or food industry etc.

C. Electric Type Manometer

It is a pressure meter that takes out the nature of the gas directly as an electric signal. This method is adopted as a secondary pressure gauge for measuring vacuum usually under 100Pa, and it is widely used not only as a vacuum meter but also as a detection unit for vacuum control in medium and high vacuum systems.

a) Thermal-Conductivity Gauge

Like ordinary incandescent bulbs, it is a simple vacuum tube type head with thin metal wire filaments (tungsten or platinum). In the pressure region where the mean free path of gas molecules is relatively short and the number of collisions is large, the molecules colliding with the heated filament will leave the thermal energy and as the pressure at which the filament is cooled decreases, the number of collisions decreases and the filament since the temperature rises and its resistance value increases, the pressure can be obtained from the change in the resistance value.

b) Ionization Gauge

Under 0.1Pa, a method of measuring vacuum from the number of gas molecules is used. Since pressure and molecular density are almost proportional under constant temperature, ionization type vacuum gauge is to measure ion current by ionizing molecules. There are hot cathode type using thermoelectrons to ionize gas, cold cathode type using discharge, but hot cathode type is widely used because it is superior in terms of accuracy and stability.

The hot cathode type ionization vacuum gauge shows in Fig.6.13. (a) is construction of it , and (b) is circuit of it. The electrons coming from the filament (hot cathode) in the center are accelerated by the voltage applied to the grid and ionize the gas in the tube. The resulting cations are collected by the ion collector at negative voltage, the generated electron enters the grid together with the electrons from the filament. Grid current is i_g, collector current is i_c, the relation to pressure p is,

$$p = \frac{ki_c}{i_g}$$

However, k is proportionality constant, around 1Pa$(mA/\mu A)$, depend on electrode structure, applied voltage and gas type.

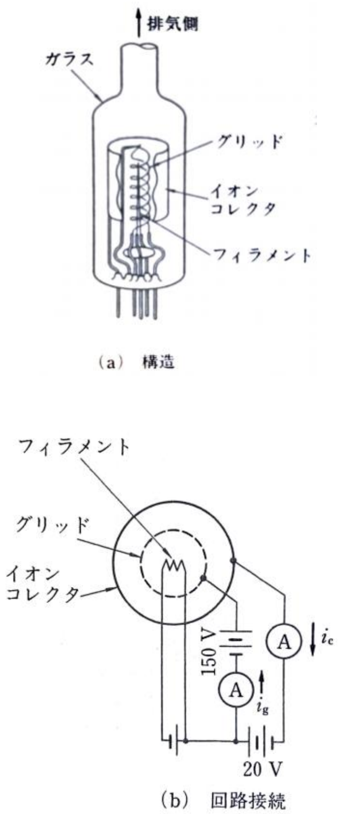


Fig.6.13 Triode Ionization Gauge

6.3 Measure Temperature

Temperature is a physical quantity which is the most closely to our daily life. The human being balances the heat balance between the heat generation by the metabolism in the body and the outside world and it keeps constant body temperature. The fact that body temperature was adopted as the Fahrenheit temperature, it is a close relation that temperature and us.
Measure Temperature is not only used in our daily life, but also widely used in industry.

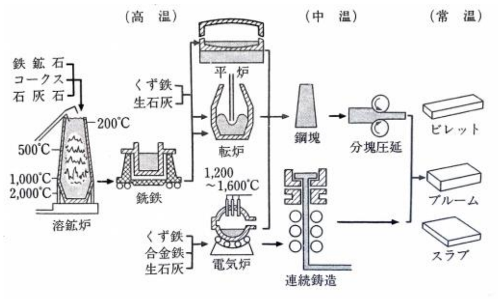


Fig.6.14 Process of Making Iron and Steel

6.3.1 Measure High Temperature

Examples of high temperature measurement at 1000~3000°C, which is seen in the manufacturing industry for metals, ceramics and other materials. Fig.6.14 shows process of making iron and steel. The blast furnace and the rolling Refractory bricks used as blast furnace wall materials such as furnaces and flat furnaces can withstand more than 2000°C.

A. Contact Type Temperature Measurement

The most widely used is a thermocouple, the principle being based on the Seebeck effect that current flows when a temperature difference is given to the junction of a closed circuit formed by connecting both ends of two kinds of metal wires. If one of the junctions is kept at the reference temperature, there is a functional relationship between the temperature at the other junction and the generated current, and the temperature is read in the form of a current. Normally, a closed circuit is opened and a potential difference generated there is read, and this potential difference is called a thermos electromotive force.
In the physical experiment, a simple configuration with the reference junction set at the freezing point (0°C) as shown in Fig.6.15 is used, but at the factory site, it is necessary to supply highly reliable data while withstanding a harsh environment, and additionally cost. There are also many restrictions in invisible places because of the large constraints. It is not practical simply by selecting a combination of materials with high thermos electromotive force.
Fig.6.16 shows an example of a high temperature furnace temperature measurement system. Responding to the various conditions that the thermocouple which is the sensor part is exposed to high temperature and there is a considerable distance to the output measurement point. Accuracy of practical thermometer is 0.2~1.0%.

a. Sensor Head Part

Insertion type as shown in Fig.6.17 is used in the temperature range below 1500°C used without replacing the sensor part for a long time. In 200~1500°C, precious metal thermocouples (Pt and Pt-Rh alloys are paired), Base metal thermocouples (Ni-Cr, Cu-Ni alloys or Fe, Cu as a pair) are used in the low region from around

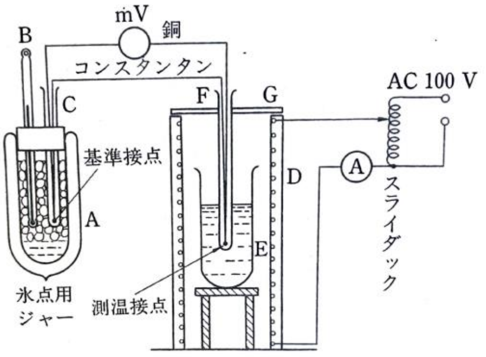


Fig.6.15 Set Up in Physical Experiment

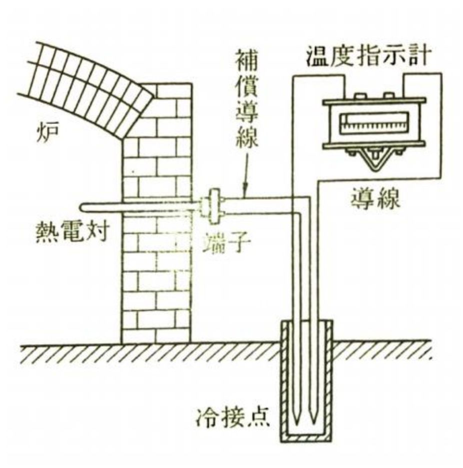


Fig.6.16 Temperature Measurement System for High Temperature Furnace

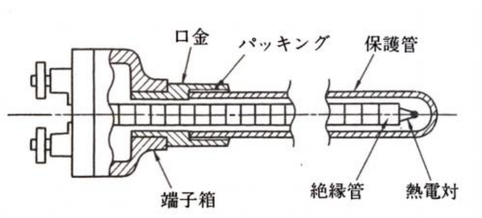


Fig.6.17 Insertion Fixed Head Part

1000 ° C. Tolerance error, the former is 0.5% and the latter is about 1%.

b. Compensating Conductor

In the physical experiment set as shown in Fig.6.15, the wire length of the thermocouple may be short, but in factory measurement such as material manufacturing process, the temperature measuring head part and the reference contact are often separated from each other. As a result, a long thermocouple wire is required and the cost is high. Therefore, a method of replacing a long portion with an inexpensive conductor having a thermoelectric power close thereto is adopted, and this conductor is called a compensating conductor. Fig.6.18 shows the connection method of the compensation wire, and the connection point

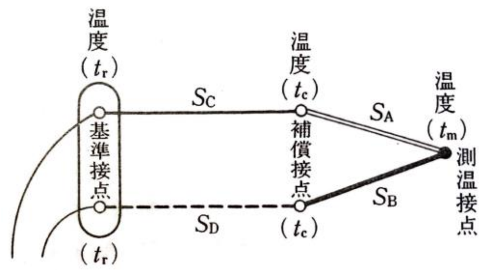


Fig.6.18 Connection Method of The Compensation Wire

between the thermocouple and the compensation wire is called the compensation contact. Thermoelectric power of each wire (symbol: n) is represented by S_n, then the electromotive force appearing at the final output point (display point) is equal to the thermos electromotive force of the thermocouple part. The temperature of the compensating contact point is generally less than 200°C, and it is possible to find inexpensive wires satisfying next equation. Depending on the type of thermocouple, standardized products are available.

$$S_A - S_B = S_C - S_D$$

c. Reference Junction

It is standard usage to keep the reference junction at 0°C. For this reason, a freezing point type as shown in Fig.6.19 is commercially available and is used for highly accurate temperature measurement. In some cases, using electronic cooling, relative temperature is corrected using a reference point close to ambient temperature, in addition to the freezing point which means that the Seebeck effect and its inverse phenomenon, Peltier effect, are used in the temperature measurement system. And it is practically used for simple temperature measurement as a constant temperature type reference point.

d. Display Measuring Instrument

In physics experiments, millivoltmeters are often used, but electrostatic differential meters are good

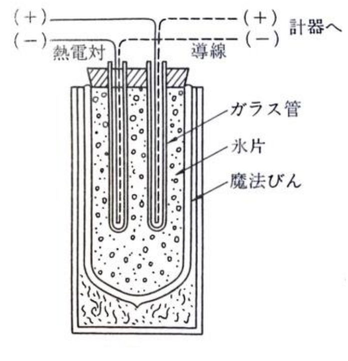


Fig.6.19 Ice-point type reference junction

for accurate measurements · In industrial measurements such as Planck, autonomous balanced recorder has been used conventionally. In a conversion transmitter incorporating a contact compensation circuit, a method of sending it to a remote place as a unified 0~10mV signal is also common, and in recent years it has come to be finally supplied as computer input.

B. Non-contact Temperature Measurement

It is known that all objects radiate electromagnetic waves at absolute zero or more, and this electromagnetic wave is referred to as thermal radiation. Although it can be understood from the common sense that a black object absorbs radiation and a black one absorbs light, an ideal absorber that absorbs 100% of electromagnetic waves of any wavelength is defined as a black body. The wavelength distribution of the object at a certain temperature and the radiation power emitted from it are in accordance with Planck's theoretically derived formula for the blackbody.

There are various expressions in Planck's equation, but the power(W) radiated from the unit area(m^2) to the unit solid angle(sr) per wavelength(μm), which means, the amount $L_\lambda(W/m^2 \cdot sr \cdot \mu m)$, which is called spectral radiance can be expressed by next equation.

$$L_\lambda = \frac{C_1}{\pi\lambda^5}\left(\frac{1}{exp(C_2/\lambda T) - 1}\right)$$

However, λ is wavelength, T is temperature, C_1, C_2 are radiation constant.

$$C_1 = 2\pi c^2 h = 3.7418 \times 10^8 (W \cdot \mu m^4/m^2)$$

$$C_2 = \frac{hc}{k} = 1.4388 \times 10^4 (\mu m \cdot K)$$

However, c is light speed, h is Planck constant, k is Boltzmann constant.

Above equation shows that the radiance L_λ at a certain wavelength λ is determined only by the temperature T, and conversely, T can be found by measuring L_λ. It is a basic formula of a method of measuring the object temperature in a non-contact method.

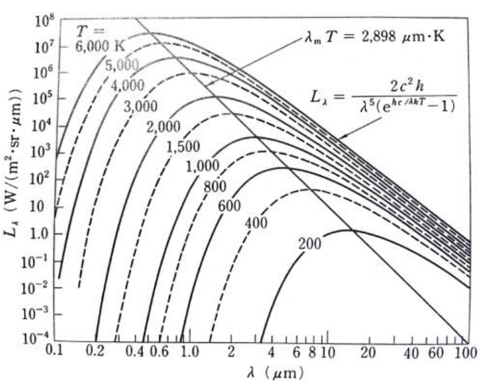


Fig.6.20 Spectral radiance component expressed by Planck's equation

From Fig.6.20, it can also be seen that the color of the filament changes from dark red to red, orange, yellow as the current value flowing through the incandescent bulb gradually increases. Since long ago, attempts have been made to quantify temperature estimation methods for eye by casting craftsmen and swordsmith for a long time, but attempts have also been made to quantify this for a long time, and even now, optical pyrometer, or a two-color thermometer using a photoelectric sensor are active in the field.

Measure temperature by color, cause the wavelength can be seen by eye, so range is 700~2000°C

6.3.2 Measure Medium Temperature

The mediate temperature range of 350 to 1000 ° C is a region that has strong relationships with intermediate production processes of various materials, such as hot working and heat treatment of metals, reaction processes in chemical plants, etc.

A. Contact Type Temperature Measurement

A thermocouple is also widely used, but a metal wire resistance thermometer utilizing the temperature dependence of the metal wire resistance value is suitable for higher precision and stability.

a. Sensor Head Part

Since it is targeted for medium temperature, it is often used as a relatively long-term installation type. In the factory site, like a thermocouple, with a protective pipe is often inserted in the temperature measurement place as in Fig.6.21. In recent years, a sheath type resistor connected small elements at the tip is also used.

In some temperature range, relation of temperature T and resistance R. R_0 is resistance of standard temperature T_0.

$$R = R_0\{1 + a(T - T_0)\}$$

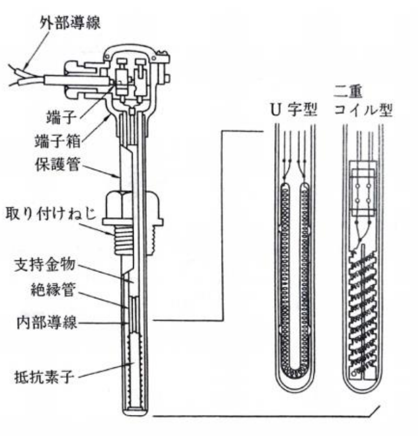


Fig.6.21 Sensor Head Part for Industry

However, α is called Resistance temperature coefficient.

An example of the shape of the head is shown in Fig.6.21 Pure metal is used exclusively as the material of the wire, and platinum is a typical example. Nickel and copper are also used, but the characteristics at high temperatures are not good.

B. Non-contact Temperature Measurement

Under 700°C, in radiation temperature measurement of low and medium temperature, the spectral distribution of thermal radiation shifts to long wavelength and one radiant energy extremely decreases, so using the infrared sensor the entire radiation in the widest possible wavelength range Use the receiving method. Fig.6.22 shows an example of the construction of an infrared radiation ther-mometer, the simplest of which is the method (a) of directly detecting the radiation from the temperature sensor with an infrared sensor. In many cases, an optical chopper is placed near the entrance to the optical system to convert the signal, but the reason for this is not only that it aims at ease of amplification and improvement of the SN ratio but also as an infrared radiator This is to remove the DC component which is a false radiation signal from the working vessel wall and optical system and to identify only the radiation component from the temperature measurement object as the AC component. The detection signal when the chopper is closed is used as a reference, (b) is used when higher precision is desired, and is based on the radiation from the built-in blackbody as a reference. If the temperature control part is variable and the indicator is used for zero-point detection, it becomes the measurement system of the null method like the optical pyrometer.

A wide variety of infrared sensors are commercially available according to the detection wavelength range. Fig.6.23 shows what is used

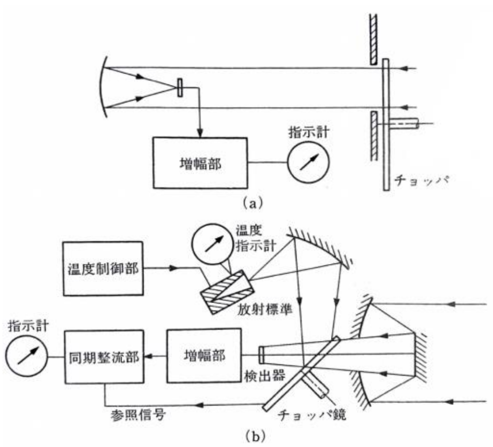


Fig.6.22 an example of the construction of an infrared radiation ther-mometer

for commercial radiation thermometers by temperature range. As can be seen from the figure, many in the medium temperature range use PbS, InSb photoconductive cells and thermoconduction. On average, it has accuracy of about ±1%.

6.3.3 Measure Normal Temperature

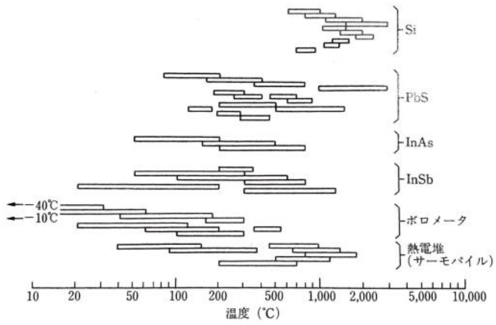


Fig.6.23 Temperature measurement range of commercially available radiation thermometer classified according to sensor type

The normal temperature range of 0~350°C is the temperature range that is closely related to our living environment. In home life, temperature control and danger prevention which are sure to be contained in measurement instruments, such as thermometer for room temperature, thermometer for body temperature, thermometer for cooking, electric kotatsu, iron, including electronic pot, microwave etc. The temperature sensor is a very familiar presence. Of course, similar thermometers are also widely used in industry.

Fig.6.23 is an example of a system block diagram of an electronic clinical thermometer in every household, which is integrated into a small plastic case and is one of the fine electronic measuring instruments. It is generally recognized that the most important part is a sensor transmitter and many thermistors which are resistance temperature sensors are used as temperature sensor elements and it is common to construct a temperature-frequency conversion circuit.

In addition to the thermistor resistance

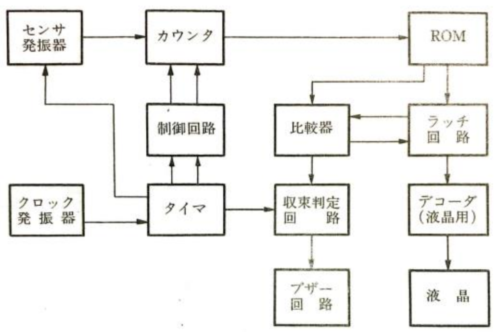


Fig.6.23 block diagram of an electronic clinical thermometer

temperature detector, temperature-electricity conversion type sensors such as thermocouples and metal temperature-measuring resistors that have been described in the section on high-temperature and medium-temperature measurement up to now have been used as the sensors for normal temperature measurement, In principle, from the one using thermal expansion of a simple object to the radiation temperature sensor, an extremely wide variety is practically used.

A. Contact type temperature measurement (temperature-electric conversion type sensor)

Here, we first pick up a thermistor that is common in normal temperature measurement, the one that is commonly used is a sintered oxide such as Mn, Ni, Co, and the temperature coefficient of resistance becomes negative It is an element of negative temperature coefficient (NTC).

relation of temperature T and resistance R. R_0 is resistance of standard temperature T_0.

$$R = R_0 exp B\left(\frac{1}{T} - \frac{1}{T_0}\right)$$

However, $R_0(\Omega)$ is resistance depend on $T_0(K)$, B is called thermistor coefficient, which value is $3500{\sim}6000$K, depend on material.

Fig.6.24 compares the temperature-resistance characteristics of commercially available thermistors with those of platinum resistance temperature detectors. The outer shape of the thermistor is extremely small, including a bead type, a disk type, a rod type, etc. An example of a bead type is shown in Fig.6.25

The thermistor is widely used in the range of $-50{\sim}350°\text{C}$ and has a reliability of $0.5{\sim}2\%$. Although it is not suitable for precise temperature measurement from the point of secular change and compatibility, it is sensitive and inexpensive, and it is widely used from home use to industrial use.

B. Non-contact Temperature Measurement

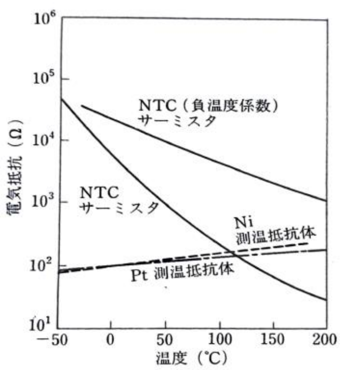


Fig.6.24 Thermistor Temperature-Resistance Characteristics

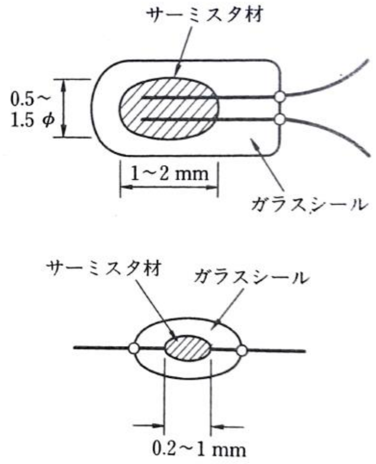


Fig.6.25 Thermistor Elements

Fig.6.26 shows the wavelength range that accounts for 90% of the total radiation, calculated from the spectral energy distribution of the black body radiation shown in the basic matter. As the temperature decreases, the wavelength region shifts to the longer wavelength side, and the radiant energy rapidly decreases therewith. As for the radiation thermometer in the normal temperature region, it has high sensitivity up to the longer wavelength side and occurs It is difficult to have infrared sensors with little noise and to use infrared lenses and reflecting mirrors (especially those of Au vapor deposition) for converging optical systems.

A thermal type infrared sensor such as a thermopile formed by piling a plurality of micro thermocouples or a thermos sensor such as a thermistor has low sensitivity but has a flat spectral sensitivity characteristic up to the long wavelength infrared range and at room temperature It can be used. When receiving radiation from an object at normal temperature with a sensor at normal temperature, the energy flow between them is slight, and the surroundings including the measuring optical system itself are all radiation sources. It can be said that there is a

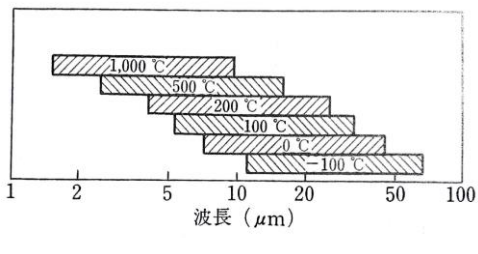


Fig.6.26 Wavelength Region Occupying 90% of Total Black Body Radiation

difficulty equivalent to finding a star in the blue sky. A thermal type infrared sensor such as a thermopile formed by piling a plurality of micro thermocouples or a thermo sensor such as a thermistor has low sensitivity but has a flat spectral sensitivity characteristic up to the long wavelength infrared range and at room temperature It can be used. When receiving radiation from an object at normal temperature with a sensor at normal temperature, the energy flow between them is slight, and the surroundings including the measuring optical system itself are all radiation sources. It can be said that there is a difficulty equivalent to finding a star in the blue sky.

6.3.4 Measure Low Temperature

0°C (273 .2 K) or less, Below the triple point (13.8 K) of equilibrium hydrogen shall be referred to as the low temperature range. Up to minus few ℃ , many of situation can be use the above-mentioned normal temperature thermometer, but when it becomes lower than that, thermocouples using a limited material, resistive thermometers, pressure type thermometers (especially used gas) is used as the material.

Among the thermocouples, those based on base metals such as copper-constantan and alumel-chromel can be used up to −200°C. In the resistance thermometer, the platinum wire can be used up to about −260°C, and for a general NTC thermistor for room temperature measurement it can be used up to −50°C.

Although the transistor circuit is sensitive to external temperature displacement and has

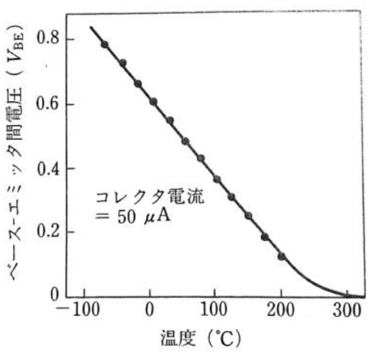


Fig.6.27 The Temperature Dependence of V_{BE}

difficulty due to its stabilization, this disadvantage can be utilized for the temperature sensor. In sensors for ordinary temperature and low temperature, the base-emitter voltage the temperature dependence of V_{BE} is often used. An example of temperature dependence is shown in Fig.6.27.

6.3.5 Temperature Standard

Temperature standards are required for calibrating and calibrating the thermometer, and a method of setting the freezing point, melting point, boiling point, phase equilibrium state (triple point or vapor pressure point) etc. of a pure substance as the temperature fixed point is used.

"International temperature scale (ITS - 90)" is used in 1990. Relation between this method measure temperature T_{90} and International Celsius Temperature measure temperature t_{90} is,

$$t_{90} = T_{90} - 273.15$$

Tab.6.3 shows the definite fixed points of ITS-90.

Tab.6.3 ITS-90

定義定点物質	ITS-90		
(状態)	T_{90}(K)	t_{90}(°C)	補間計器
	0.65		
He(V)	3~5		ヘリウム蒸気圧目盛り
			気体温度計
e-H_2(T)	13.8033	−259.3467	
(B)e-H_2(V)	~17		
(B)e-H_2(V)	~20.3		
Ne(T)	24.5561	−248.5939	
Ne(B)			
O_2(T)	54.3584	−218.7916	
Ar(T)	83.8058	−189.3442	
O_2(C)			
Hg(T)	234.3156	−38.8344	
H_2O(T)	273.16	0.01	白金抵抗温度計
Ga(M)	302.9146	29.7646	
H_2O(V)			
In(F)	429.7485	156.5985	
Sn(F)	505.078	231.928	
Zn(F)	692.677	419.527	
Al(F)	933.473	660.323	
Ag(F)	1,234.93	961.78	
Au(F)	1,337.33	1,064.18	プランクの放射則
Cu(F)	1,357.77	1,084.62	

B：沸　点(1気圧下での液相，気相の平衡状態)
C：凝 縮 点(1気圧下での液相,気相の平衡状態で液相がゼロとなる極限)
F：凝 固 点(1気圧下での液相，固相の平衡状態)
M：融 解 点(1気圧下での液相，固相の平衡状態)
T：三 重 点(液相，気相，固相の平衡状態)
V：蒸気圧点(液相，気相の平衡状態)
e-H_2：オルソ/パラの平衡水素