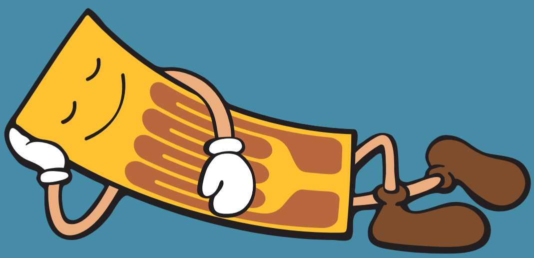
Technical Memo 9

Technical Memo



Technical Memo

SI Units and Conventional Gravitational Units

Quantity	SI Unit	Gravitational Unit
Force	N	kgf
	1	1.01971621 x 10^{-1}
	9.80665	1
Stress	Pa	kgf/mm²
	1	1.01971621 x 10^{-7}
	9.80665 x 10^{6}	1
Pressure	Pa	kgf/cm²
	1	1.01971621 x 10^{-5}
	9.80665 x 10^{4}	1
Torque	N · m	kgf · m
	1	1.01971621 x 10^{-1}
	9.80665	1
Work Energy	J	kgf · m
	1	1.01971621 x 10^{-1}
	9.80665	1
Power	W	PS
	1	1.359619 x 10^{-3}
	735.5001658	1

Mechanical Properties of Industrial Materials

Material	Young's Modulus E (GPa)	Shearing Modulus G (GPa)	Tensile Strength (MPa)	Poisson's Ratio ν
Carbon steel (C0.1 to 0.25%)	205	78	363 to 441	0.28 to 0.3
Carbon steel (C > 0.25%)	206	79	471 to 569	0.28 to 0.3
Spring steel (Quenched)	206 to 211	79 to 81	588 to 1667	0.28 to 0.3
Nickel steel	205	78	549 to 657	0.28 to 0.3
Cast iron	98	40	118 to 235	0.2 to 0.29
Brass (Casting)	78	29	147	0.34
Phosphor bronze	118	43	431	0.38
Aluminum	73	27	186 to 500	0.34
Concrete	20 to 29	9 to 13	—	Approx. 0.2

$$G = \frac{E}{2(1+\nu)}$$

Linear Expansion Coefficients of Materials

Material	Linear Exp. Coef.	Material	Linear Exp. Coef.
Quartz glass	0.4	Beryllium	11.5
Amber	1.1	Common steel	11.7
Brick	3.0 to 5.0	Nickel	13.3
Tungsten	4.5	Gold	14.0
Lumber (Grain dir.)	5.0	SUS 304	16.2
Molybdenum	5.2	Beryllium copper	16.7
Zirconium	5.4	Copper	16.7
Kovar	5.9	Brass	21.0
Concrete	6.8 to 12.7	A2024-T4	23.2
Titanium alloy	8.5	A2014-T4	23.4
Platinum	8.9	Magnesium alloy	27.0
Soda-lime glass	9.2	Lead	29.0
SUS 631	10.3	Acrylic resin	Approx. 65 to 100
SUS 630	10.6	Polycarbonate	66.6
Cast iron	10.8	Rubber	Approx. 77
NiCrMo steel	11.3		

(x 10^{-6}/°C)

Metric Prefix

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	μ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	attp	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deca	da	10^{-24}	yocto	y

Examples of Strain-gage Measurement of Tensile/Compressive Stress

(1) Quarter-bridge System (1-gage System)

See the figure below. If a strain gage is bonded on a surface of a pillar which receives uniform load from one direction and the gage axis is aligned to the direction, stress σ is calculated by the following equation :

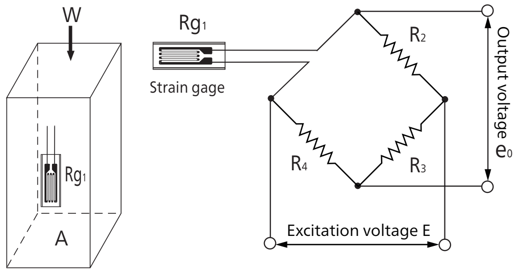
$$\text{Stress }(\sigma) = \varepsilon_0 \cdot E$$

where, E : Young's modulus (See table "Mechanical Properties of Industrial Materials" at the left.)
ε_0 : Indicated strain

And, the load W applied to the pillar is obtained by the following equation:

$$\text{Load } W = A \cdot \sigma$$

where, A : Cross-sectional area of the pillar



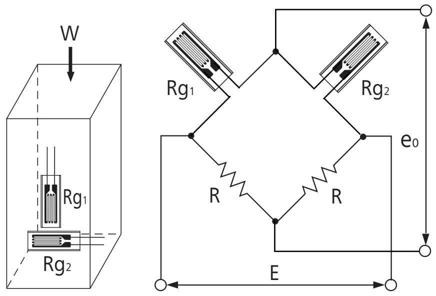
Tensile/Compressive Stress Measurement
with Quarter-bridge System

(2) Half-bridge System (2-gage System)

If another strain gage is bonded to the pillar at a right angle to the loading directions and 2 gages are connected to adjacent legs of the bridge, the surface stress σ on the pillar is expressed by the following equation:

$$\text{Surface Stress }(\sigma) = \frac{\varepsilon_0}{1+\nu} \cdot E$$

where, ν: Poisson's ratio



Tensile/Compressive Stress Measurement
with Half-bridge System

If 2 more strain gages are bonded to the opposite sides of the pillar to eliminate bending strain and full-bridge system is adopted, the surface stress σ is calculated by the following equation:

$$\text{Surface Stress }(\sigma) = \frac{\varepsilon_0}{2(1+\nu)} \cdot E$$

Bending Stress Measurement

(1) Quarter-bridge System

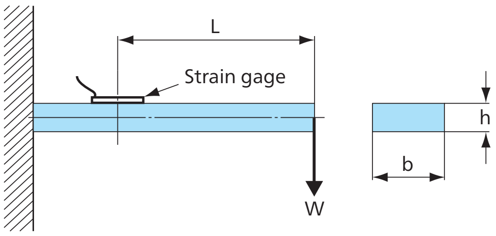
See the figure below. If a strain gage is bonded on the surface of a rectangular section of a cantilever of which one side end is fixed and load W is applied to another side, the surface stress σ which the bonded strain gage will detect is as follows :

$$\sigma = \varepsilon \cdot E$$

Strain ε is obtained by the following equation:

$$\varepsilon = \frac{6WL}{Ebh^2}$$

where, b: Width of the cantilever
h: Thickness of the cantilever
L: Distance from the load point to the center of strain gage



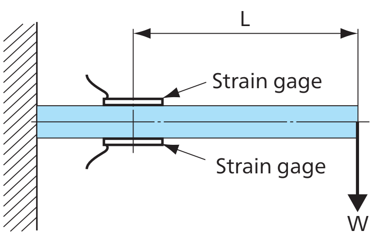
Bending Stress Measurement with Quarter-bridge System

(2) Half-bridge System (Adjacent-leg Bridge Connection)

As illustrated below, strain gages bonded symmetrically on the front and rear surfaces of the cantilever output positive and negative signals, respectively, with an equal absolute value. If these 2 gages are connected to adjacent legs of the bridge, the output of the bridge corresponding to the bending strain is doubled and the surface stress σ at the strain-gage bonding site is obtained by the following equation:

$$\text{Surface Stress }(\sigma) = \frac{\varepsilon}{2} \cdot E$$

The adjacent-leg active half-bridge system cancels out the output of the strain gage corresponding to the force applied in the axial direction of the cantilever.



Bending Stress Measurement with Half-bridge System

Equation of Strain on Beams

Strain ε on the beam is obtained by the following equation :

$$\varepsilon = \frac{M}{ZE}$$

where, M: Bending moment (See Table 1)
Z: Section modulus (See Table 2)
E: Young's modulus (See table "Mechanical Properties of Industrial Materials.")

Typical shapes of beams, their bending moments M and section modulus Z are shown in Tables 1 and 2.

Table 1. Typical Equations to Calculate Bending Moment

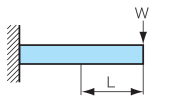
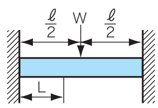
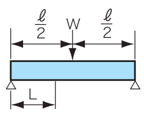
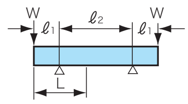
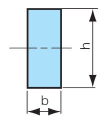
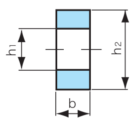
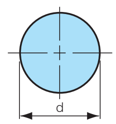
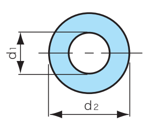
Shape of Beam	Bending Moment M
	M=WL
	$0 \le L \le \frac{\ell}{2} \longrightarrow M=\frac{W\ell}{2}\left(\frac{1}{4}-\frac{L}{\ell}\right)$ $L=0 \quad L=\frac{\ell}{2} \longrightarrow M=\pm\frac{W\ell}{8}$ $\frac{\ell}{2} \le L \le \ell \longrightarrow M=\frac{W\ell}{2}\left(\frac{L}{\ell}-\frac{3}{4}\right)$
	$0 \le L \le \frac{\ell}{2} \longrightarrow M=-\frac{WL}{2}$ $L=\frac{\ell}{2} \longrightarrow M=-\frac{W\ell}{4}$ $\frac{\ell}{2} \le L \le \ell \longrightarrow M=-\frac{W(\ell-L)}{2}$
	$0 \le L \le \ell_1 \longrightarrow M=WL$ $\ell_1 \le L \le (\ell_1+\ell_2) \longrightarrow M=W\ell_1$

Table 2. Typical Equations to Calculate Section Modulus

Cross Section	Section Modulus Z
	$\frac{1}{6}bh^2$
	$\frac{1}{6} \cdot \frac{b(h_2^3-h_1^3)}{h_2}$
	$\frac{\pi}{32}d^3$
	$\frac{\pi}{32} \cdot \frac{d_2^4-d_1^4}{d_2}$

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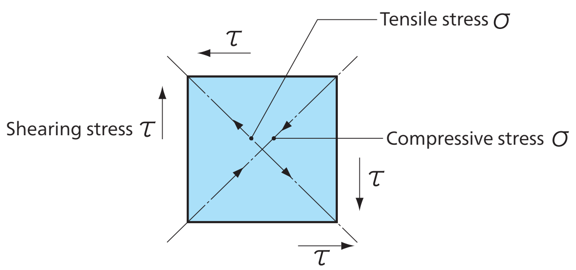
Torsional and Shearing Stress Measurement of Axis

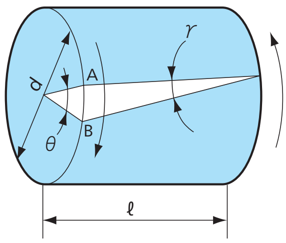
When an object is twisted, shearing stress τ occurs. At the same time, tensile stress and compressive stress, which are equivalent to the shearing stress, occur in 2 directions inclined by 45° from the axial line.
In measurement of axial twist under simple shearing stress condition, a strain gage does not directly measure the shearing stress. Instead, a strain gage detects tensile or compressive strain resulting from tensile or compressive stress simultaneously generated with the shearing stress. These stress conditions on a surface of axis are illustrated below.



Shearing strain γ is defined as illustrated below, and the magnitude is calculated by the following equation:

$$\gamma = \frac{\tau}{G}$$

where, G: Shearing modulus (See table "Mechanical Properties of Industrial Materials.")
τ: Shearing stress



When the axis is twisted, point A moves to point B, thereby initiating torsional angle θ.

$$\theta = \frac{\ell\gamma}{\left(\frac{d}{2}\right)} = \frac{2\ell\gamma}{d}$$

(1) Stress Measurement with Quarter-bridge System

Bond the strain gage on the twisted axis in the direction inclined by 45° from the axial line. The relations between strain ε_0 and stress σ are expressed with the following equation to calculate tensile or compressive stress σ :

$$\sigma = \frac{\varepsilon_0 \cdot E}{1+\nu}$$

where, ε_0: Indicated strain
E: Young's modulus (See table "Mechanical Properties of Industrial Materials.")
ν: Poisson's ratio

Stress σ and shearing stress τ are equal in magnitude, and thus,

$$\tau = \sigma$$

(2) Stress Measurement with Half-bridge or Full-bridge System

Half-bridge or full-bridge system increases strain output by 2 (half-bridge system) or 4 times (full-bridge system), because each strain gage in the half-bridge or full-bridge system detects equal strain. To calculate true strain, divide measured strain by 2 (half-bridge system) or 4 (full-bridge system).

(3) Application to Torque Measurement

Strain on the surface of the axis is proportional to the torque applied to the axis. Thus, the torque is obtained by detecting the strain on the surface.
Shearing stress distributed on the lateral section is balanced with the applied torque T, establishing the following equation:

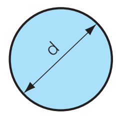
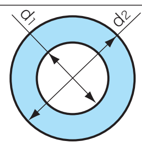
$$T = \tau \cdot Z_p$$

where, Z_p: Polar modulus of section

Converting shearing stress in the above equation to tensile strain produces an equation as follows:

$$T = \frac{\varepsilon_0 \cdot E \cdot Z_p}{1+\nu}$$

The polar modulus of the section is specific to each shape of the cross-section as follows:

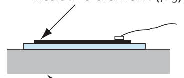
Cross Section	Polar Modulus of Section Z_p
	$\frac{\pi d^3}{16}$
	$\frac{\pi}{16}\left(\frac{d_2^4 - d_1^4}{d_2}\right)$

A strain gage torque transducer is designed using the above relational expression of ε_0 and T.
Obtain ε_0 from the allowable stress for the material, and determine the width d of the axis which is matched with the magnitude of the applied torque. Then, amplify the strain output with a strain amplifier and read the output voltage with a measuring instrument.

Principles of Self-temperature-compensation Gages (SELCOM Gages)

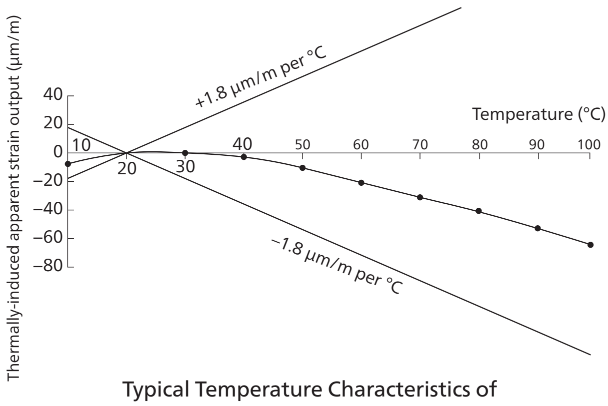
The measuring object and the resistive element of the strain gage have linear expansion coefficients β_s and β_g, respectively. The strain gage bonded on the surface of the object provides a thermally-induced apparent strain ε_T per °C that is expressed with the following equation:

$$\varepsilon_T=\frac{\alpha}{K_s}+(\beta_s-\beta_g)$$



where,
α: Resistive temperature coefficient of resistive element
Ks: Gage factor of strain gage

Self-temperature-compensation strain gages are designed to adjust the resistive temperature coefficient of their resistive elements to match the linear expansion coefficient of the measuring objects in order to get ε_T close to zero. Kyowa's SELCOM gages have been adjusted so that, when they are bonded to suitable measured materials, the average value of the apparent strain in the self-temperature-compensation range is within ±1.8 μm/m per °C (representative value). (Graph below shows apparent strain output of strain gages without lead wires.)



Typical Temperature Characteristics of Self-temperature-compensation Foil Gage

Temperature Effect on Lead Wires with 2-wire System

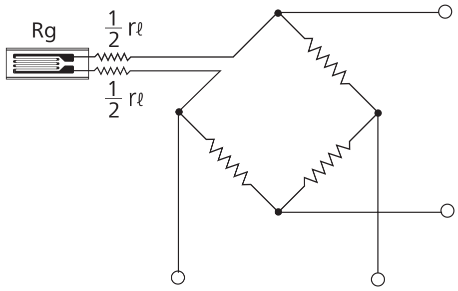
Lead Wire Model	Cross-section Area of Conductor (mm^2)	Reciprocating Resistance of 1 m long lead wire (Approx.)(Ω)	Apparent Strain* with 1 m Extension (Approx.) (μm/m per °C)
L-5	0.5	0.07	1.14
L-9	0.11	0.32	5.19
L-6	0.08	0.44	7.12
N (Polyester-coated copper cable)	0.015	2.24	35.7

*120Ω gage

Thermally-induced apparent strain ε_r (μm/m per °C) is calculated by the following equation.

$$\varepsilon_r=\frac{r\ell}{Rg+r\ell}\cdot\frac{\alpha}{Ks}$$

where, Rg: Resistance of strain gage (Ω)
rℓ: Reciprocating resistance of lead wires (Ω)
Ks: Preset gage factor of strain amplifier, usually 2.00
α: Resistive temperature coefficient of copper wire ($\Delta R/R$ per °C), 3.9×10^{-3}/°C

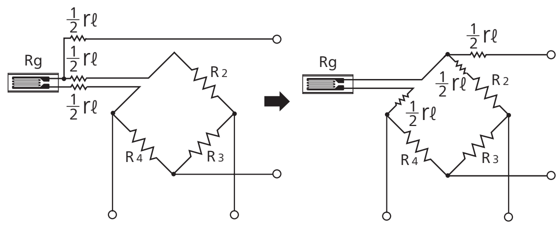


Compensation Methods of Temperature Effect of Lead Wires (3-wire System)

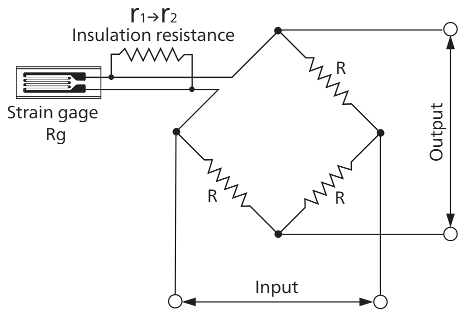
For effective self-temperature-compensation, SELCOM gages adopt the quarter-bridge system. However, if the lead wire cable is the 2-wire system, strain output from the bridge is affected by the temperature effect of the lead wire. To avoid such adverse effect, the 3-wire system is adopted.

If 3 lead wires are connected to a strain gage as shown below, a half lead wire resistance is applied to the adjacent side of a bridge to compensate for the temperature effect of lead wires in bridge output. The temperature effect of the lead wires connected to a measuring instrument outside of the bridge is ignored because the input impedance of the measuring instrument is high.

As a precaution when using the 3-wire system, the 3 lead wires should be the same type, length, and cross-section to equalize temperature effects of each lead wire. If lead wires are directly exposed to sunlight, the coating color should also be the same.



Influence of Insulation Resistance



Bridge Circuit Designed with Insulation Resistance

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If the insulation resistance descends from r_1 to r_2 in the figure

$$\text{Error strain}(\varepsilon) \fallingdotseq \frac{Rg(r_2 - r_1)}{Ks\, r_1\, r_2}$$

Rg: Resistance of strain gage
Ks: Gage factor of strain gage
r_1: Original insulation resistance
r_2: Changed insulation resistance

Insulation resistances of strain gages including lead wires do not affect measured values if they are higher than 100 MΩ. However, if they change drastically during measurement, errors may occur in measured values.

Resistance Change of Strain Gages Bonded to Curved Surfaces

The strain ε occurring on the resistive element of a strain gage bonded to a curved surface may be expressed by the following equation:

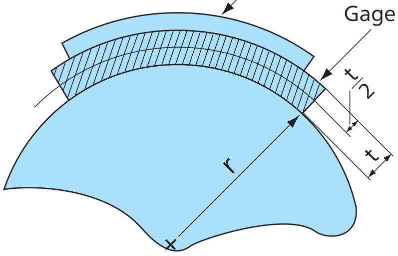
$$\varepsilon = \frac{t}{2r+t}$$

where, t: Thickness of gage base plus adhesive layer
r: Radius of gage-bonded surface

For example, if a uniaxial KFGS gage, of which the gage base including the adhesive layer is 0.015 mm thick, is bonded to a curved surface of 1.5r, the strain gage already receives strain of approximately 5000 μm/m.
If the gage factor Ks is 2.00,

$$\Delta R/R \fallingdotseq 10000 \times 10^{-6}$$

If the gage resistance is 120 Ω, it increases by approximately 1.2 Ω. If the gage is bonded inside the curve, the resistance decreases.



Strain Gage Bonded on the Curved Surface

Compensation Methods of Different Gage Factors

If the gage factor of the strain gage (2.00) is different from that of the strain amplifier, the true strain ε is obtained by the following equation:

$$\varepsilon = \frac{2.00}{Ks} \times \varepsilon_0$$

where, ε_0: Measured strain
Ks: Gage factor of strain gage

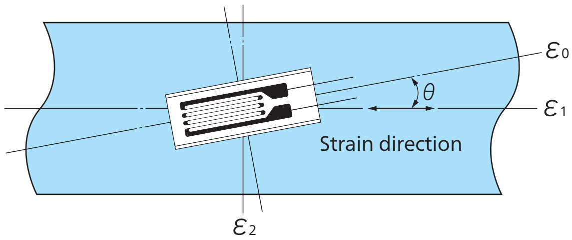
Misalignment Effect of Bonding Strain Gages

Strain ε_0 misaligned by angle θ from the direction of the principal strain ε_1 is calculated by the following equation:

$$\varepsilon_0 = \frac{1}{2}\{(\varepsilon_1 + \varepsilon_2) + (\varepsilon_1 - \varepsilon_2)\cos 2\theta\}$$

If $\varepsilon_2 = -\nu\varepsilon_1$ (ν: Poisson's ratio) under the uniaxial stress condition,

$$\varepsilon_0 = \frac{1}{2}\varepsilon_1\{(1-\nu) + (1+\nu)\cos 2\theta\}$$



Compensation Methods of Effect of Lead Wire Extension

If the lead wire or cable is extended with the quarter-bridge or half-bridge system, additional resistance is initiated in series to the strain gage, thereby decreasing the apparent gage factor. For example, if a 10 m long lead wire with 0.3 mm² conductors is used, the gage factor decreases by 1%. In the case of the full-bridge system (transducer), the extension decreases the excitation voltage too. In these cases, the true strain ε is obtained by the following equation.

$$\varepsilon = \left(1 + \frac{r\ell}{Rg}\right) \times \varepsilon_i$$

where, ε_i: Measured strain
Rg: Resistance of strain gage
$r\ell$: Total resistance of lead wires (For reciprocating resistance, see the table below.)
One-way resistance in the case of 3-wire system

Lead wire resistance values

Cross Section (mm²)	Number of Strands/ Wire Diam. (mm)	Reciprocating Resistance per 10 m (Ω)	Remarks
0.08	7 / ϕ0.12	4.4	L-6
0.11	10 / ϕ0.12	3.2	L-9
0.3	12 / ϕ0.18	1.2	L-2
0.5	20 / ϕ0.18	0.7	L-5

Compensation Methods of Nonlinearity Error of Quarter-bridge System

An error of nonlinearity in high-elongation strain measurement with quarter-bridge system is found by calculating true strain ε in the following equation:

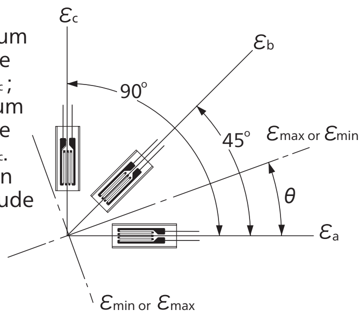
$$\varepsilon = \frac{\varepsilon_0}{1-\varepsilon_0}$$

where, ε_0: Measured strain

Methods of Obtaining Magnitude and Direction of Principal Stress (Rosette Analysis)

Generally, if the direction of principal stress is uncertain in structure stress measurement, a triaxial rosette gage is used and measured strain values are calculated in the following equation to find the direction of the principal stress. (The following equation is only for specified angle triaxial rosette gages.)

(1) Regard $\varepsilon_a \rightarrow \varepsilon_b \rightarrow \varepsilon_c$ as the forward direction.
(2) Angle θ is:
Angle of the maximum principal strain to the ε_a axis when $\varepsilon_a > \varepsilon_c$;
Angle of the minimum principal strain to the ε_a axis when $\varepsilon_a < \varepsilon_c$.
Comparison between ε_a and ε_c in magnitude includes plus and minus signs.



Max. principal strain

$$\varepsilon_{max} = \frac{1}{2}\left[\varepsilon_a+\varepsilon_c+\sqrt{2\{(\varepsilon_a-\varepsilon_b)^2+(\varepsilon_b-\varepsilon_c)^2\}}\right]$$

Min. principal strain

$$\varepsilon_{min} = \frac{1}{2}\left[\varepsilon_a+\varepsilon_c-\sqrt{2\{(\varepsilon_a-\varepsilon_b)^2+(\varepsilon_b-\varepsilon_c)^2\}}\right]$$

Direction of principal strain (From ε_a axis)

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2\varepsilon_b-\varepsilon_a-\varepsilon_c}{\varepsilon_a-\varepsilon_c}\right]$$

Max. shearing strain

$$\gamma_{max} = \sqrt{2\{(\varepsilon_a-\varepsilon_b)^2+(\varepsilon_b-\varepsilon_c)^2\}}$$

Max. principal stress

$$\sigma_{max} = \frac{E}{2(1-\nu^2)}\left[(1+\nu)(\varepsilon_a+\varepsilon_c)+(1-\nu)\times\sqrt{2\{(\varepsilon_a-\varepsilon_b)^2+(\varepsilon_b-\varepsilon_c)^2\}}\right]$$

Min. principal stress

$$\sigma_{min} = \frac{E}{2(1-\nu^2)}\left[(1+\nu)(\varepsilon_a+\varepsilon_c)-(1-\nu)\times\sqrt{2\{(\varepsilon_a-\varepsilon_b)^2+(\varepsilon_b-\varepsilon_c)^2\}}\right]$$

Max. shearing stress

$$\tau_{max} = \frac{E}{2(1+\nu)}\times\sqrt{2\{(\varepsilon_a-\varepsilon_b)^2+(\varepsilon_b-\varepsilon_c)^2\}}$$

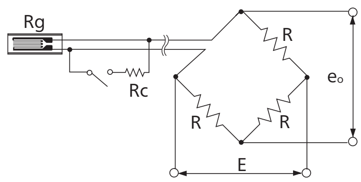
ν: Poisson's ratio
E: Young's modulus
(See table "Mechanical Properties of Industrial Materials.")

Generating Calibration Values Based on the Tip Parallel Resistance Method

When extending lead wires by several hundred meters or finding accurate calibration values, the tip parallel resistance method is adopted. The parallel resistance Rc is calculated by the following equation:

$$Rc = \frac{Rg}{Ks\cdot\varepsilon} - Rg$$

where, Rg: Resistance of strain gage
Ks: Gage factor of strain gage
ε: Calibration strain value

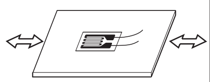
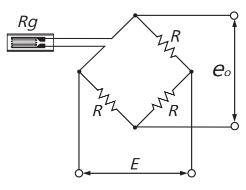
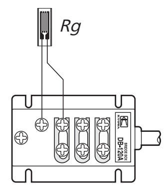
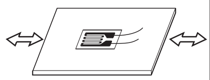
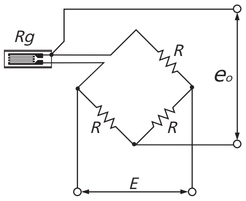
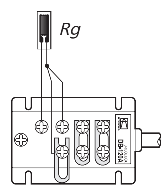
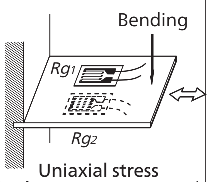
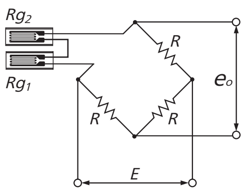
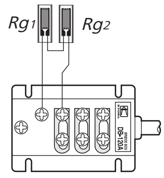
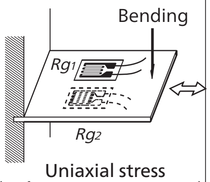
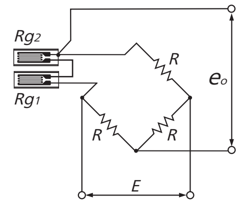
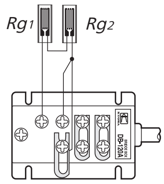
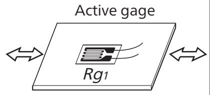
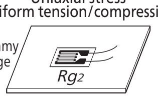
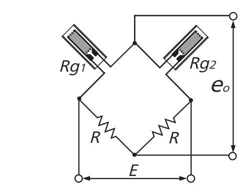
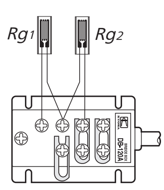
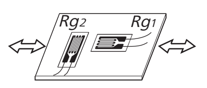
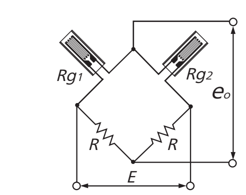
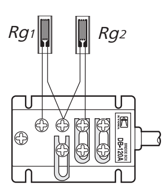
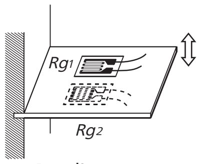
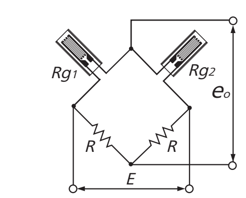
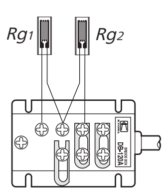
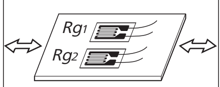
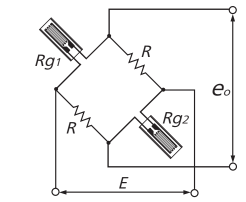
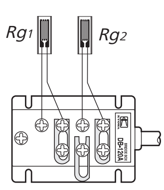


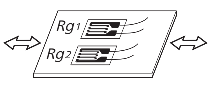
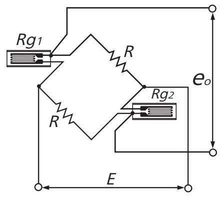
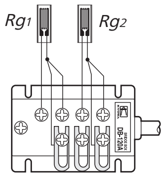
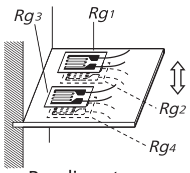
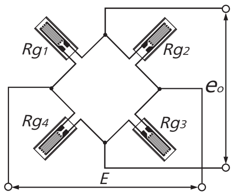
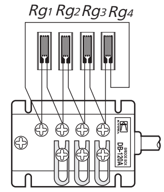
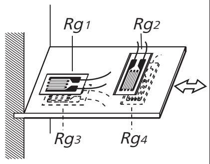
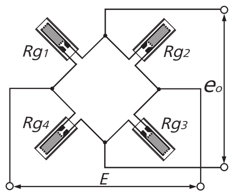
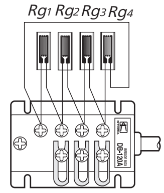
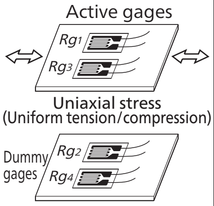
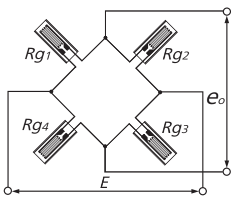
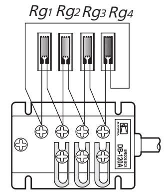
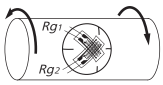
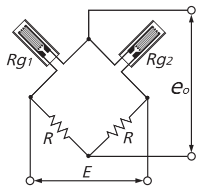
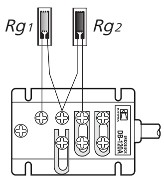
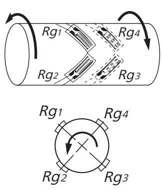
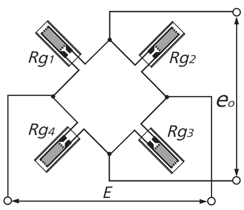
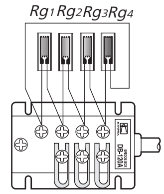
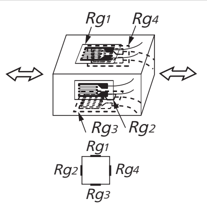
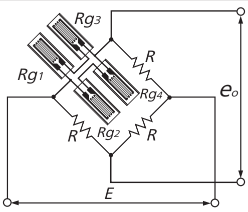
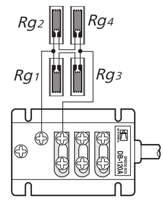
Examples of Calibration Strain Values and Resistance (Rg = 120 Ω, gage factor Ks = 2.00)

Calibration Strain Value ε	Resistance Rc (Approx.)
100 μm/m	600 kΩ
200 μm/m	300 kΩ
500 μm/m	120 kΩ
1000 μm/m	60 kΩ
2000 μm/m	30 kΩ

Technical Memo

■How to Form Strain-gage Bridge Circuits

No.	Names	Sample Application	Circuits	Output	Remarks	Bridge Box DB-120A/350A
1	Active quarter-bridge 2-wire system Number of gages: 1	 Uniaxial stress (Uniform tension/compression)		$e_o=\frac{E}{4}K_s\cdot\varepsilon_o$ K_s: Gage factor ε_o: Strain E: Excitation voltage e_o: Output voltage Rg: Gage resistance R: Fixed resistance	Suitable for environments with little ambient temperature change; no temperature compensation. x 1 output	
2	Active quarter-bridge 3-wire system Number of gages: 1	 Uniaxial stress (Uniform tension/compression)		$e_o=\frac{E}{4}K_s\cdot\varepsilon_o$ K_s: Gage factor ε_o: Strain E: Excitation voltage e_o: Output voltage Rg: Gage resistance R: Fixed resistance	No temperature compensation; thermal effect of lead wires cancelled. x 1 output	
3	Active quarter-bridge (Dual series gages) 2-wire system (For cancelling bending strain) Number of gages: 2	 Uniaxial stress (Uniform tension/compression)		$e_o=\frac{E}{4}K_s\cdot\varepsilon_o$ Rg_1 ……Strain: ε_1 Rg_2 ……Strain: ε_2 $\varepsilon_o=\frac{\varepsilon_1+\varepsilon_2}{2}$ R: Fixed resistance $R=Rg_1+Rg_2$ E.g. Rg_1 & Rg_2 are 60-ohm gages, if using a DB-120A.	No temperature compensation; bending strain cancelled. x 1 output	
4	Active quarter-bridge (Dual series gages) 3-wire system (For cancelling bending strain) Number of gages: 2	 Uniaxial stress (Uniform tension/compression)		$e_o=\frac{E}{4}K_s\cdot\varepsilon_o$ Rg_1 ……Strain: ε_1 Rg_2 ……Strain: ε_2 $\varepsilon_o=\frac{\varepsilon_1+\varepsilon_2}{2}$ R: Fixed resistance $R=Rg_1+Rg_2$ E.g. Rg_1 & Rg_2 are 60-ohm gages, if using a DB-120A.	No temperature compensation; bending strain cancelled; thermal effect of lead wires cancelled. x 1 output	
5	Active-dummy half-bridge system Number of gages: 2	Active gage  Uniaxial stress (Uniform tension/compression) Dummy gage 		$e_o=\frac{E}{4}K_s\cdot\varepsilon_o$ K_s: Gage factor ε_o: Strain E: Excitation voltage e_o: Output voltage Rg_1 ……Strain: ε_o R: Fixed resistance Rg_2 ……Strain: 0	Temperature compensation; thermal effect of lead wires cancelled. x 1 output	
6	Orthogonal* active half-bridge system Number of gages: 2 * at a right angle	 Uniaxial stress (Uniform tension/compression)		$e_o=\frac{(1+\nu)E}{4}K_s\cdot\varepsilon_o$ ν: Poisson's ratio Rg_1, Rg_2: Gage resistance Rg_1 ……Strain: ε_o Rg_2 …Strain: $-\nu\varepsilon_o$ R: Fixed resistance	Temperature compensation; thermal effect of lead wires cancelled. x $(1+\nu)$ output	
7	Active half-bridge system (For bending strain measurement) Number of gages: 2	 Bending stress		$e_o=\frac{E}{2}K_s\cdot\varepsilon_o$ Rg_1 ……Strain: ε_o Rg_2 …Strain: $-\varepsilon_o$ R: Fixed resistance	Temperature compensation; thermal effect of lead wires cancelled; compressive/tensile strain cancelled. x 2 output	
8	Opposite-leg active half-bridge 2-wire system Number of gages: 2	 Uniaxial stress (Uniform tension/compression)		$e_o=\frac{E}{2}K_s\cdot\varepsilon_o$ Rg_1 ……Strain: ε_o Rg_2 ……Strain: ε_o R: Fixed resistance	No temperature compensation; x 2 output bending strain cancelled by bonding to the front and rear.	

No.	Names	Sample Application	Circuits	Output	Remarks	Bridge Box DB-120A/350A
9	Opposite-leg active half-bridge 3-wire system Number of gages: 2	 Uniaxial stress (Uniform tension/compression)		$e_0=\frac{E}{2}K_s\cdot\varepsilon_0$ Rg1 ……Strain: ε_0 Rg2 ……Strain: ε_0 R: Fixed resistance	No temperature compensation; thermal effect of lead wires cancelled; x 2 output bending strain cancelled by bonding to the front and rear.	
10	Active full-bridge system (For bending strain measurement) Number of gages: 4	 Bending stress		$e_0=K_s\cdot\varepsilon_0\cdot E$ Rg1, Rg3 …… Bending strain: ε_0 Rg2, Rg4 …… Bending strain: $-\varepsilon_0$	Temperature compensation; thermal effect of lead wires cancelled; compressive/tensile strain cancelled. x 4 output	
11	Orthogonal active full-bridge system Number of gages: 4	 Uniaxial stress (Uniform tension/compression)		$e_0=\frac{(1+\nu)E}{2}K_s\cdot\varepsilon_0$ ν: Poisson's ratio Rg1, Rg3…… Strain: ε_0 Rg2, Rg4 …… Strain: $-\nu\varepsilon_0$	Temperature compensation; thermal effect of lead wires cancelled. bending strain cancelled. x2 $(1+\nu)$ output	
12	Active-dummy full-bridge system Number of gages: 4	Active gages  Uniaxial stress (Uniform tension/compression)		$e_0=\frac{E}{2}K_s\cdot\varepsilon_0$ Rg1, Rg3 …… Strain: ε_0 Rg2, Rg4 …… Strain: 0	Temperature compensation; thermal effect of lead wires cancelled; x 2 output bending strain cancelled by bonding to the front and rear.	
13	Active half-bridge system (For twisting strain measurement) Number of gages: 2			$e_0=\frac{E}{2}K_s\cdot\varepsilon_0$ Rg1 …… Twisting strain: ε_0 Rg2 …… Twisting strain: $-\varepsilon_0$ R: Fixed resistance	Temperature compensation; thermal effect of lead wires cancelled. x 2 output	
14	Active full-bridge system (For twisting strain measurement) Number of gages: 4			$e_0=K_s\cdot\varepsilon_0\cdot E$ Rg1, Rg3 …… Twisting strain: ε_0 Rg2, Rg4 …… Twisting strain: $-\varepsilon_0$	Temperature compensation; thermal effect of lead wires cancelled. bending strain cancelled; compressive/tensile strain cancelled. x 4 output	
15	4-active quarter-bridge system (For average strain measurement) Number of gages: 4			$e_0=\frac{E}{4}K_s\cdot\varepsilon_0$ $\varepsilon_0=\frac{\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4}{4}$ R: Fixed resistance Rg = R R=Rg1=Rg2=Rg3=Rg4	No temperature compensation; average strain x 1 output	

●Relationship between equivalent strain and voltage

The output of a strain-gage bridge is expressed as equivalent strain ($\times10^{-6}$ strain) or an output voltage (mV/V or μV/V) against the excitation voltage. The strain quantity and the output voltage have the following relation:

$$e_0=\frac{E}{4}K_s\cdot\varepsilon_0$$

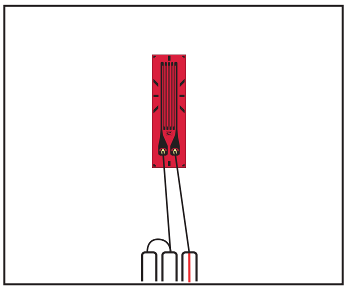
If the excitation voltage E = 1 V and the gage factor Ks = 2.00, $2e_0=\varepsilon_0$.
Thus, equivalent strain output is always 2 times larger than bridge output voltage.
E.g. 1.5 mV/V = 1500 μV/V → 3000 $\times10^{-6}$ strain

Technical Memo

●Strain Gage Bonding Procedure

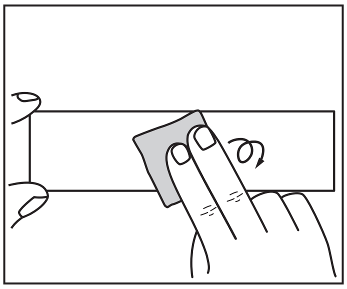
The strain gage bonding method differs depending on the type of the strain gage, the applied adhesive and operating environment. Here, for strain measurement at normal temperatures in a room, we show how to bond a typical strain gage (leadwire-equipped KFGS gage) to a test piece (mild steel specimen) using quick-curing adhesive (cyanoacrylate adhesive CC-33A).

①Select strain gage.



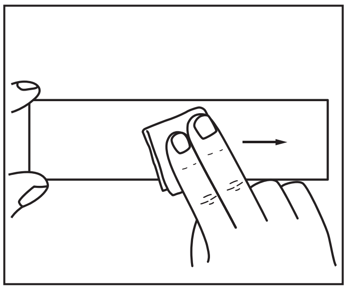
Select the strain gage model and gage length which meet the requirements of the measuring object and purpose. For the linear expansion coefficient of the gage applicable to the measuring object, refer to Linear Expansion Coefficients of Materials (page 9-1).

②Remove rust and paint.



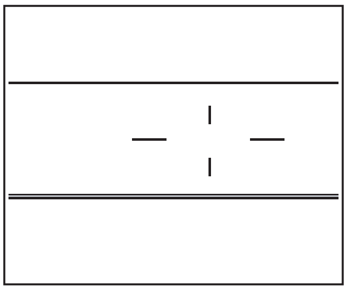
Using a sand cloth (#320), polish the strain-gage bonding site over a wider area than the strain gage size. Wipe off paint, rust and plating, if any, with a grinder or sandblast before polishing.

③Remove grease from bonding surface and clean.



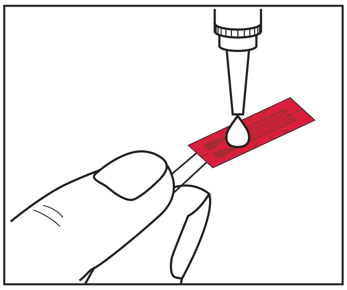
Using an industrial tissue paper dipped in acetone, clean the gage bonding site. Strongly wipe the surface in a single direction to collect dust and then remove by wiping in the same direction. Reciprocal wiping causes dust to move back and forth and does not ensure cleaning.

④Decide bonding position.



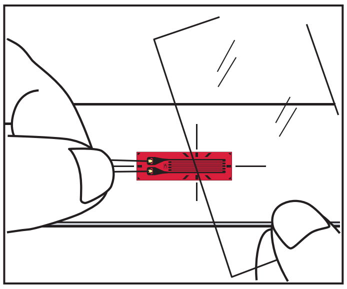
Mark the measuring site in the strain direction. Use a 4H pencil or a marking-off pin. When using a marking-off pin, take care not to deeply scratch the gage bonding surface.

⑤Apply adhesive.



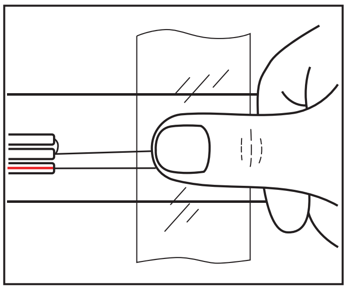
Ascertain the back and front of the strain gage. Apply a drop of adhesive (CC-33A) to the back of the strain gage.

⑥Bond strain gage.



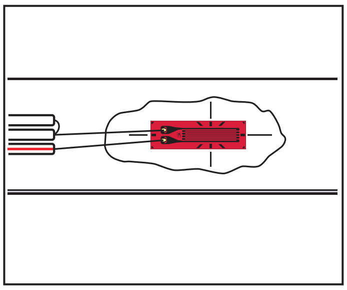
After applying a drop of the adhesive, put the strain gage on the measuring site while lining up the center marks with the marking-off lines. Cover the strain gage with the accessory polyethylene sheet.

⑦Press strain gage.



Press it over the sheet with a thumb. Quickly perform steps ⑤ to ⑦ as a series of actions.

⑧Complete bonding work.



After pressing the strain gage with a thumb for one minute or so, remove the polyethylene sheet and make sure the strain gage is securely bonded. The above steps complete the bonding work. However, good measurement results are available after 60 minutes of complete curing of the adhesive.

● Relations between SI Units and Conventional Gravitational Units

■ Force

SI Units	Conventional Units	
	4 digits	5 digits
10 mN	1.020 gf	1.0197 gf
20 mN	2.039 gf	2.0394 gf
30 mN	3.059 gf	3.0591 gf
50 mN	5.099 gf	5.0986 gf
100 mN	10.20 gf	10.197 gf
200 mN	20.39 gf	20.394 gf
300 mN	30.59 gf	30.591 gf
500 mN	50.99 gf	50.986 gf
1 N	102.0 gf	101.97 gf
2 N	203.9 gf	203.94 gf
3 N	305.9 gf	305.91 gf
5 N	509.9 gf	509.86 gf
10 N	1.020 kgf	1.0197 kgf
20 N	2.039 kgf	2.0394 kgf
30 N	3.059 kgf	3.0591 kgf
50 N	5.099 kgf	5.0986 kgf
100 N	10.20 kgf	10.197 kgf
200 N	20.39 kgf	20.394 kgf
300 N	30.59 kgf	30.591 kgf
500 N	50.99 kgf	50.986 kgf
1 kN	102.0 kgf	101.97 kgf
2 kN	203.9 kgf	203.94 kgf
3 kN	305.9 kgf	305.91 kgf
5 kN	509.9 kgf	509.86 kgf
10 kN	1.020 tf	1.0197 tf
20 kN	2.039 tf	2.0394 tf
30 kN	3.059 tf	3.0591 tf
50 kN	5.099 tf	5.0986 tf
100 kN	10.20 tf	10.197 tf
200 kN	20.39 tf	20.394 tf
300 kN	30.59 tf	30.591 tf
500 kN	50.99 tf	50.986 tf
1 MN	102.0 tf	101.97 tf
2 MN	203.9 tf	203.94 tf
3 MN	305.9 tf	305.91 tf
5 MN	509.9 tf	509.86 tf

Calculated based on a conversion factor of 1 kgf = 9.80665 N, and 5th or 6th digit is rounded.

■ Acceleration

SI Units	Conventional Units
10 m/s²	1.020 G
20 m/s²	2.039 G
30 m/s²	3.059 G
50 m/s²	5.099 G
100 m/s²	10.20 G
200 m/s²	20.39 G
300 m/s²	30.59 G
500 m/s²	50.99 G
1000 m/s²	102.0 G
2000 m/s²	203.9 G
3000 m/s²	305.9 G
5000 m/s²	509.9 G
10000 m/s²	1020 G

Calculated based on a conversion factor of 1 G = 9.80665 m/s², and 5th digit is rounded.

■ Pressure/Stress

SI Units	Conventional Units
100 Pa	1.020 gf/cm²
200 Pa	2.039 gf/cm²
300 Pa	3.059 gf/cm²
500 Pa	5.099 gf/cm²
1 kPa	10.20 gf/cm²
2 kPa	20.39 gf/cm²
3 kPa	30.59 gf/cm²
5 kPa	50.99 gf/cm²
10 kPa	102.0 gf/cm²
20 kPa	203.9 gf/cm²
30 kPa	305.9 gf/cm²
50 kPa	509.9 gf/cm²
100 kPa	1.020 kgf/cm²
200 kPa	2.039 kgf/cm²
300 kPa	3.059 kgf/cm²
500 kPa	5.099 kgf/cm²
1 MPa	10.20 kgf/cm²
2 MPa	20.39 kgf/cm²
3 MPa	30.59 kgf/cm²
5 MPa	50.99 kgf/cm²
10 MPa	102.0 kgf/cm²
20 MPa	203.9 kgf/cm²
30 MPa	305.9 kgf/cm²
50 MPa	509.9 kgf/cm²
100 MPa	1.020 tf/cm²
200 MPa	2.039 tf/cm²
300 MPa	3.059 tf/cm²
500 MPa	5.099 tf/cm²

Calculated based on a conversion factor of 1 kgf/cm² = 98.0665 kPa, and 5th digit is rounded.

■ Torque/Torsion

SI Units	Conventional Units
100 mN·m	1.020 kgf·cm
200 mN·m	2.039 kgf·cm
300 mN·m	3.059 kgf·cm
500 mN·m	5.099 kgf·cm
1 N·m	10.20 kgf·cm
2 N·m	20.39 kgf·cm
3 N·m	30.59 kgf·cm
5 N·m	50.99 kgf·cm
10 N·m	1.020 kgf·m
20 N·m	2.039 kgf·m
30 N·m	3.059 kgf·m
50 N·m	5.099 kgf·m
100 N·m	10.20 kgf·m
200 N·m	20.39 kgf·m
300 N·m	30.59 kgf·m
500 N·m	50.99 kgf·m
1 kN·m	102.0 kgf·m
2 kN·m	203.9 kgf·m
3 kN·m	305.9 kgf·m
5 kN·m	509.9 kgf·m
10 kN·m	1.020 tf·m
20 kN·m	2.039 tf·m
30 kN·m	3.059 tf·m
50 kN·m	5.099 tf·m
100 kN·m	10.20 tf·m

Calculated based on a conversion factor of 1 kgf·m = 9.80665 N·m, and 5th digit is rounded.

Technical Memo

Terms to Express Characteristics of Strain-gage Transducers

Common to All Transducers

Rated Capacity
Upper limit of the measuring range and the prescribed design value.

Rated Load
Upper limit of load at which the transducer performs to the specifications.

Overload
Load exceeding the rated capacity.

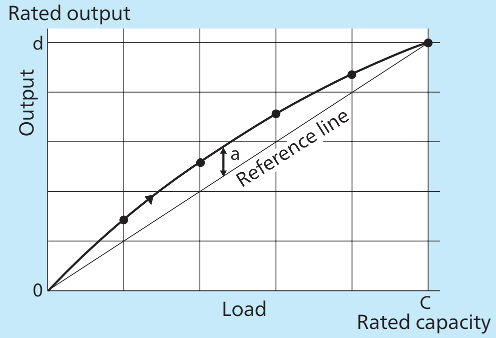
Safe Overload Rating
Maximum overload which may not cause any permanent change to stated specifications, expressed in percentage of the rated capacity.
If the rated load is exceeded, the transducer will temporarily fail to perform to the specifications, but it will again perform to the specifications once it is returned to within the rated load.

Overload Limit
Maximum overload which allows to be applied without causing any structural damage, expressed in percentage of the rated capacity.
However, the transducer might not perform to the specifications after the load is applied.

Rated Output
Value obtained by subtracting the output under no load from the output under the rated capacity. Usually, it is expressed in mV/V, mA or equivalent strain.
In the case of positive and negative sensitivity, the "-" sign is indicated on the negative side.
No sign is indicated on the positive side.
Note: Because equivalent strain is not generally used overseas, this is only used in the Japanese (not in the English).
* Refer to the "Acceleration Transducer" for its rated output.

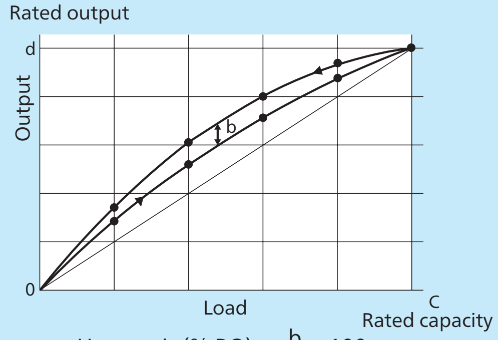
Sensitivity
Ratio of changing output to changing load. Usually, this is expressed as the value per 1 V of excitation voltage (mV/V) or the equivalent strain ($x10^{-6}$ strain) for the unit load. In the case of positive and negative sensitivity, the "-" sign is indicated on the negative side. No sign is indicated on the positive side.

Nonlinearity
Maximum deviation of output between the calibration curve in the increasing load cycle and the reference line (Straight line drawn from the output under no load to the rated output under the rated capacity); expressed in percentage of the rated output.



$$\text{Nonlinearity (\% RO)} = \frac{a}{d} \times 100$$

Hysteresis
Difference of output between the calibration curve traced in the increasing load cycle and that in the decreasing load cycle. Usually, the calibration curve is reciprocated between the no load and the rated capacity and the maximum difference in outputs corresponding to the same load is defined as the hysteresis, expressed in percentage of the rated capacity.



$$\text{Hysteresis (\% RO)} = \frac{b}{d} \times 100$$

Natural Frequency
Frequency due to free vibration of the transducer under no load.

Frequency Response Range
Frequency range in which the output responds to the input at the same amplitude and phase within certain range of error when the input is a steady state sine wave.

Excitation Voltage
Voltage applied to the input terminal of transducer.

Recommended Excitation Voltage
Excitation voltage with which the transducer can continuously perform to the specifications (generally expressed as a range).

Safe Excitation Voltage
Maximum excitation voltage with which the transducer may not perform to the specifications but when the recommended excitation voltage is applied again, the transducer performs to the specifications.

Input & Output Resistance
Resistance of input or output terminal. Use of the term is limited to the indication of the nominal resistance of an input or output terminal.

Input Terminal Resistance
Resistance between input terminals with output terminals open under no load.

Output Terminal Resistance
Resistance between output terminals with input terminals open under no load.

Temperature Effect on Zero Balance
Change of zero due to change of ambient temperature; expressed as a change of zero per °C in percentage of the rated output (xx% RO/°C).

Temperature Effect on Output
Change of gain due to change of ambient temperature, expressed as a change of zero per °C in percentage (xx%/°C).

Compensated Temperature Range
Temperature range which guarantees that the transducer performs to the specifications with regard to temperature effects on output and zero balance.

Safe Temperature Range
Temperature range at which the transducer will temporarily fail to perform to the specifications, but it will not receive any permanent change in its characteristics, and it will again perform to the specifications once it is returned to within the compensated temperature range.

Repeatability
Maximum difference between output variables initiated by repeatedly applying the same load under the same conditions. Usually, it is measured under the rated load and expressed in percentage of the average rated output.

Zero Balance
Output under no load with the transducer placed in the prescribed posture. Usually, this is expressed as mV/V, equivalent strain (x10^{-6} strain), or a percentage of the rated output.

Zero Stability
The change in the zero point of the transducer under prescribed conditions, expressed as a percentage of the rated output (xx% RO).

Stability
Capability of the transducer to keep the characteristics for a comparatively long term. Unless noted, it is the capability to maintain the characteristics such as calibration factor and nonlinearity obtained at the initial calibration, under room conditions and for a prescribed period. If it is expressed by quantitatively numeric values, stability also is called as "degree of stability".

Interference
With a multiple component transducer, effects of the rated output applied to one component on output signals of other components are expressed in percentage of the rated output of each component

Recommended Fastening Torque
Tightening torque required to let the transducer perform to the specifications.

Calibration Constant
Ratio of the rated load to the rated output.

Resonant Frequency
Frequency of input mechanical vibration causing maximum response output of the transducer.

Cycling Life
Minimum number of repeated operations under the rated or prescribed load without exceeding allowable ranges of specified characteristics.

Degree of Protection
Degree of protection against invasion of a solid matter or water; expressed using IP rating expressed in IEC 60529

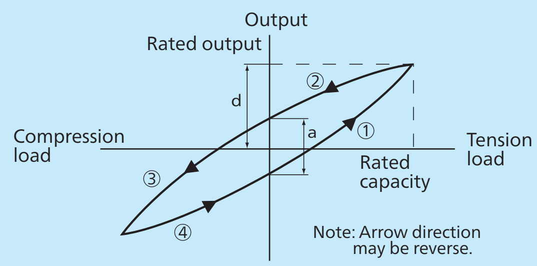
Weight
Weight of the main product body (excluding cables and accessories).
Expressed in kg or g. If items other than the mainframe are included, the fact is noted.

Material
Material of the mainframe, bottom panel or cable outlet is expressed using the type code expressed in JIS. Surface treatment such as plating or painting is also noted.
If there is any possibility of doubt, it is okay to indicate general names (such as aluminum or steel).

Cable
Cable to be connected to the transducer by the connector or the cable directly to the internal circuit. Nominal cross section of conductor, number of conductors, material of shield or sheath, length and nominal outer diameter and condition of the tip are stated.

Load Cells

Zero Float
Zero float due to the application of one cycle of rated tension and compression loads.
Our company also calls this cyclic zero shift.



$$\text{Zero float} = \frac{a}{d} \times 100\ (\%\ \text{RO})$$

Pressure Transducers

Line Pressure, Reference Pressure
Reference pressure for differential pressure measurement with differential pressure transducers
This is also called the reference pressure.

Acceleration Transducers

Center of Seismic Mass
The center of seismic mass.

Rated Output
Regarding the rated output (refer to "Common to All Transducers"), the average rated output of the positive side and the negative side.

Damping Ratio
Ratio of the actual damping (the damping coefficient) to the critical damping (the critical damping coefficient).

Transverse Sensitivity
The Transverse Sensitivity is expressed in percentage for Rated Output by the ratio of X which is transducer output by the acceleration on a parallel plane at right angles for a sensitivity axis, and Y which is transducer output by the acceleration to a parallel sensitivity axis (xx% RO).

Sensitive Axis
Axis in the sensitive direction of acceleration transducer

Mounted Resonant Frequency
Resonant frequency measured by mounting the transducer to a shaker.

Displacement Transducers

Tip Force, Pull Out Force
Force applied to the measuring object by a measuring element that has rod-type, wire-type, or other spring force. Expressed in N.

Torque Transducers

Moment of Inertia
Magnitude of the inertia for torque-transducer rotational motion.

Technical Memo

Equations to Calculate Centrifugal Acceleration

Centrifugal acceleration $a\ (m/s^2) = \dfrac{4\pi^2 N^2 \ell}{3600}$

where, N : Rotating speed (rpm)
ℓ : Distance from the center to the center of gravity of acceleration transducer (m)

Units of Acceleration "gal" and Gravitational Acceleration "g"

Belonging to CGS unit system, gal is a unit used to express gravitational acceleration in geophysics, etc. It is tentatively approved to use in combination with the SI unit.

$$1\text{gal} = 1\text{cm/s}^2 = 10^{-2}\ \text{m/s}^2$$

Standard gravitational acceleration $g = 9.80665\ \text{m/s}^2$

Countermeasures against Failure in Initial Balance (Resistant Balance)

When bonding a strain gage to a curved surface or when using a semiconductor gage providing a wide resistance range, initial balance may not be taken occasionally. As an emergency countermeasure against such the case, there is a parallel resistance method described below.
Insert the following parallel resistance Rp into the bridge:

$$Rp = R \cdot Rg / | R - Rg |$$

where, Rg : Resistance of strain gage
R : Nominal resistance of bridge (120 or 350 Ω)

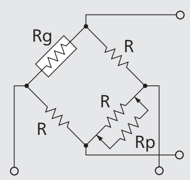
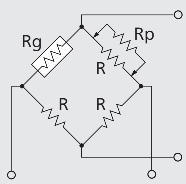
The side of the bridge to which the parallel resistance is inserted is the opposite side of the strain gage if Rg is larger than R, meanwhile the adjacent side if Rg is smaller than R.

In the case of R=120 Ω

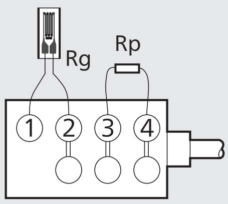
Resistance Difference from R (+Ω)	0.6	1.2	1.8	2.4	3.0
Rp (kΩ)	24.1	12.1	8.1	6.1	4.9

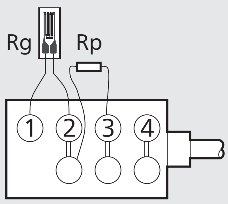
Precaution : When using resistors of E24 system

Parallel Resistance Inserting Side

If Rg > R	If Rg < R
	

Example of a DB-120A bridge box

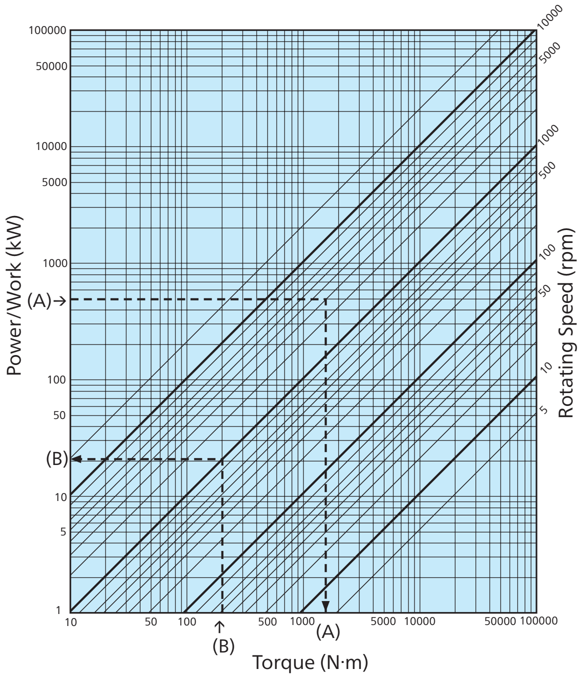




Precaution : Avoid inserting Rp to the side where the strain gage is connected. Such connection adversely affects the sensitivity.

Graphs to Obtain Power or Work, Rotary Speed and Torque

Example (A) : Torque is 1592 N·m when power and rotating speed are 500 kW and 3000 rpm, respectively.
Example (B) : Power is 20.9 kW when torque and rotating speed are 200 N·m and 1000 rpm, respectively.



Relational Expression of Torque, Power or Work, and Rotary Speed

Power or work

$$P\ (W) = \frac{2\pi TN}{60}$$

where, T : Torque (N·m)
N : Rotating speed (rpm)

Relations between Transducer Output Signals in Equivalent Strain and Voltage

■The output of a transducer is expressed as either equivalent strain (×10⁻⁶ strain) or voltage (mV/V or μV/V) per 1 V of bridge excitation voltage. Regarding equivalent strain, based on the fact that the voltage output of a strain gage configured using the Wheatstone-bridge quarter bridge system is equivalent to e [μV] = ε [×10⁻⁶ strain] when the gage factor is 2 and the excitation voltage is 2 V based on the equation below, the strain-gage-transducer voltage output is expressed as strain for convenience.

$$\text{Bridge output voltage (e)} = \frac{1}{4} Ks \cdot E \cdot \varepsilon$$

where, Ks: Gage factor of strain gage
E: Excitation voltage
ε: Strain

In the above equation, if Ks = 2 and E = 2 [V], then e [μV] = ε [$\times 10^{-6}$ strain].

■In general, if the transducer output is expressed as voltage, it is expressed as voltage (mV/V or μV/V) per 1 V of bridge excitation voltage, so the equivalent strain output is always two times as high as the voltage output.

E.g. 1.5 [mV/V] = 1500 [μV/V] → 3000 [$\times 10^{-6}$ strain]

Because equivalent strain has no relationship with mechanical strain, which is calculated based on the length rate of change ΔL/L, it is equivalent to strain and is therefore named accordingly.

Conversion of Strain Quantities (Voltage) Measured by Transducers into Proper Physical Quantities

Strain quantity (or voltage) measured by a transducer such as load cell or pressure transducer is converted into the physical quantity in proper engineering unit as follows.

- The following 2 types of calibration coefficients are stated in Kyowa's Test Data Sheet. Use a proper one for the applied measuring instrument.

  A : Calibration coefficient indicating the physical quantity corresponding to a reference equivalent strain of 1 $\times 10^{-6}$ strain

  B : Calibration coefficient indicating the physical quantity corresponding to an output voltage of 1μV against a bridge excitation voltage of 1 V.

- When using a strain amplifier

  Physical quantity = Measured strain ($\times 10^{-6}$ strain) x A

- When using an amplifier other than strain amplifier or recorder

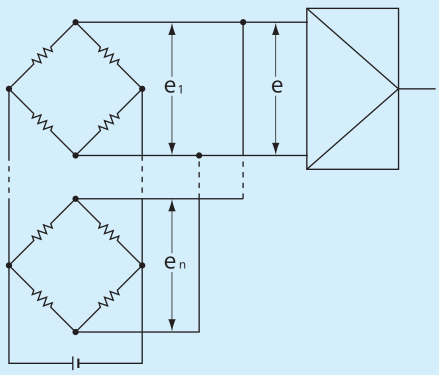
$$\text{Physical quantity} = \frac{\text{Bridge output voltage } (\mu V)}{\text{Bridge excitation voltage (V)}} \times B$$

Connection to Calculate Average Output Voltage of the Same Model Transducers

If multiple same model transducers are connected in parallel, their average output voltage, " e ", is calculated by the following equation.

$$\text{Average output voltage} \quad e = \frac{e_1 + e_2 + \cdots + e_n}{n}$$

where, e_1, e_2, ... e_n : Output voltage of each transducer
Also, output resistances of each transducer are equal.



Advantages of Remote-sensing Method

In measurement with the highly-accurate transducer connected by a long extension cable, cable conductor resistance and ambient temperature change cause measurement errors. The remote-sensing function removes these factors causing errors and stabilizes the excitation voltage.

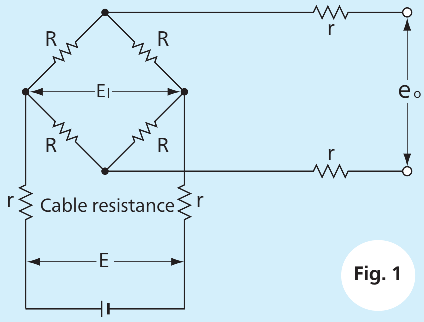


Fig. 1

If, for example, the 0.5 mm²-conductor cabtyre cable is extended by 100 m, the conductor resistance is approximately 4.0 Ω. If the cable resistance " r " in Fig. 1 is 4.0 Ω, the reciprocating resistance on the input circuit is 8.0 Ω. Suppose input and output resistances are 350 Ω, then the voltage at both ends of the bridge is:

$$\frac{350E}{350+8.0} = 0.978E\,(V)$$

where, E: Supply voltage (V)

Since there exists a relation of $e_0 = \frac{E_I}{4} Ks \cdot \varepsilon$,

the sensitivity of the transducer lowers by approximately 2.2%. Furthermore, if ambient temperature changes by 10℃ during measurement, voltages at both ends of a transducer fluctuates by about 0.1% and accuracy of transducer even 0.02%RO is reduced. As shown in Fig.2, the remote-sensing method has one additional pair of cable for detecting errors resulting in 6-conductors.
In the remote-sensing method, although excitation voltage is lowered by cable resistances " r ", this lowered voltage is leaded by detecting wires to an error amplifier and then be compared to standard voltage. This different voltage is amplified by an error amplifier with high-amplification and high-impedance. Then, this voltage output drives a control circuit. As a result, input voltage to bridge is kept constantly without effects of cable resistances, leading to accurate and stable measurements. In this case of remote-sensing method, connections and conductor colors are shown in Fig.2.

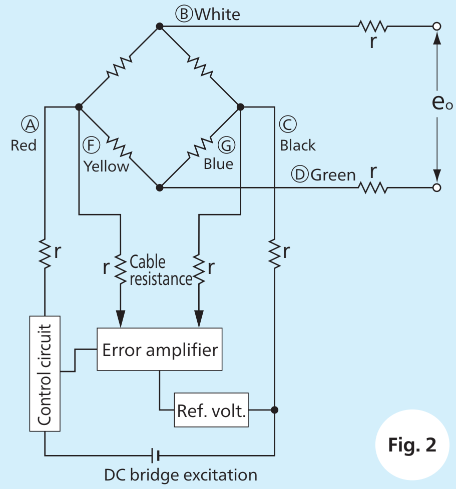


Fig. 2

Technical Memo

Installation of Load Cells to Hoppers or Tanks

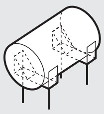
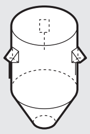
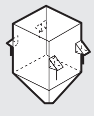
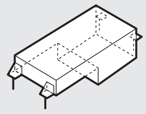
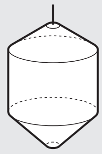
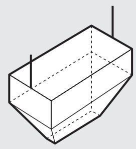
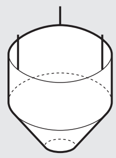
Usually, it is desirable that a total weight including the tare of hopper or tank is evenly loaded onto each load cell. If the loading point moves and the centroid is not fixed, estimate the locus of the centroid and referring to the typical position, arrange each load cell so that a maximum load is evenly applied on each load cell.
There may be two installation methods: standard and simplified. With the standard method, a load is wholly received by only all load cells. With the simplified method, a load is received by combinations of load cells, dummies, pivots and hinges. General installation methods of hoppers and tanks are shown in the below table.

《Features of Standard Methods》

- Load cells receive the whole load, thereby enabling measurement with minimal effect of fluctuation of the centroid.
- Applicable to most substances: solid, powder, or liquid.
- Measurement accuracy receives minimal effect of external factors such as temperature, vibration and installation conditions.
- Accuracy of load cells is fully utilized.

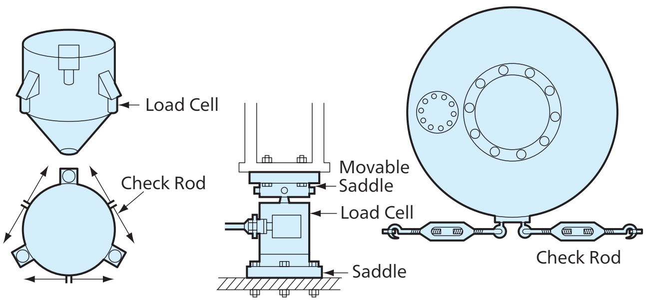
《Features of Simplified Methods》

- Reasonable price due to dummies and hinges.
- Applicable to only liquid substances.
- Difficult to be used in special types of hoppers and tanks and inapplicable to tanks and hoppers which centroids move.
- Hinges should be installed carefully.
- Subject to adverse effects of vibration and temperature.

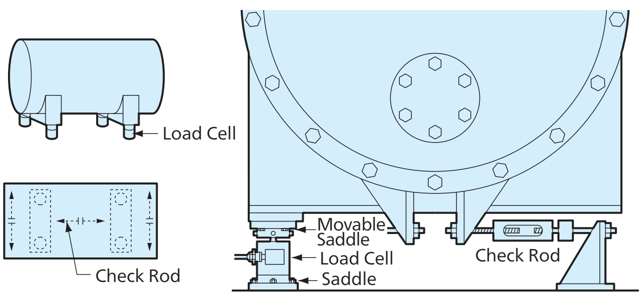
Types		Horizontal	Vertical Cylinders	Square-shaped	Special	1-point Hanging	2-point Hanging	3-point Hanging
Shapes								
Standard Methods	Load Cells	4	3	4	4	1	2	3
	Check Rods	6 to 8	6	4 to 8	8	4 to 6	4 to 8	6
Simplified Methods	Load Cells	2	1	2	As a rule, the simplified methods are not applicable for special type of hoppers or tanks.	———	———	———
	Dummies	2	2	2				
	Check Rods	4	4	4				

■Typical Installations of Load Cells

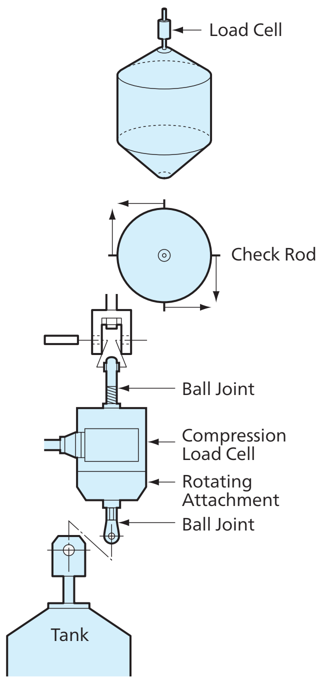
Vertically Cylindrical Tank



Horizontal Tank



1-point Hanging



How to Obtain Proper Rated Capacity of Load Cells

- If the weighing object is a low-viscosity liquid showing less horizontal movement with both the tare and content and initiating less impact,

$$\text{Rated Capacity } L \geq \frac{H+F}{n} \times 1.1$$

where, H: Estimated weight of subject liquid
F: Tare
n: Number of load cells

- If there is vibration, use a higher factor in a range of 1.1 to 1.5 according to the degree of acceleration.
- If the weighing object is powder or high-viscosity liquid, increase the above-mentioned factor to 1.3. If there is vibration, use a higher factor in a range of 1.3 to 1.5.
- If the weighing object shows less horizontal movement with both the content and tare but initiates large impact,

$$\text{Rated Capacity } L \geq \frac{S+F}{n} \times 1.3$$

where, S: Maximum impact load

- If the weighing object shows horizontal movement with both the content and tare and initiates large impact,

$$\text{Rated Capacity } L \geq \frac{2S+F}{n} \times 1.3$$

Increase the factor to 1.7 if impact is repeatedly applied.

*Equations above are on the supposition that the load is evenly allotted to all load cells used in a multiple number. If the load is unevenly allotted, determine the rated capacity considering the load given to the load cell to which the biggest burden is allotted.

*In the case of a hanging application, it is recommended to select a rated capacity 2 times higher than obtained by equations above, to ensure safe operation.

How to Obtain Accuracy of Load-cell Based Weighing System

To obtain the accuracy of an electronic load-cell based weighing system, load-cell installation quality and errors due to vibration, etc. should be considered together with individual errors of load cells and amplifiers and ambient temperature change. Here, we simplify to explain the method of calculating the system accuracy by taking the case where static errors of load cell and amplifier are main factors affecting the system accuracy. Obtain the accuracy of the detecting system including the load cell and the accuracy of the amplifier. Then, obtain the system accuracy by calculating the square root of the sum of their squares.

$$\text{System accuracy } E = \sqrt{Er^2 + Ei^2}$$

where, Er: Accuracy of detecting section
Ei: Accuracy of amplifier

Generally, the accuracy of the detecting system is obtained by the following equation:

$$Er = \sqrt{E_1^2 + E_2^2 + E_3^2 + (E_4 \times \varDelta t)^2 + (E_5 \times \varDelta t)^2}$$

where, E_1: Nonlinearity
E_2: Hysteresis
E_3: Repeatability
E_4: Temperature effect on zero balance (per °C)
E_5: Temperature effect on output (per °C)
$\varDelta t$: Change of ambient temperature

If multiple load cells are used,

$$Er\,(n) = \frac{Er}{\sqrt{n}} \quad \text{where, n: Number of load cells}$$

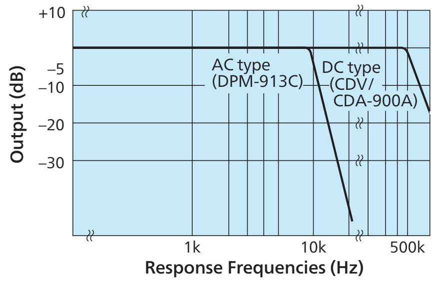
Generally, the accuracy of the amplifier is obtained by the following equation:

$$Ei = \sqrt{E_{11}^2 + (E_{12} \times \varDelta t)^2 + (E_{13} \times \varDelta t)^2 + E_{14}^2 + E_{15}^2}$$

where, E_{11}: Nonlinearity
E_{12}: Temperature effect on zero balance (per °C)
E_{13}: Temperature effect on sensitivity (per °C)
E_{14}: Aging effect on zero balance
E_{15}: Aging effect on sensitivity

Differences between Strain Amplifiers and Signal Conditioners

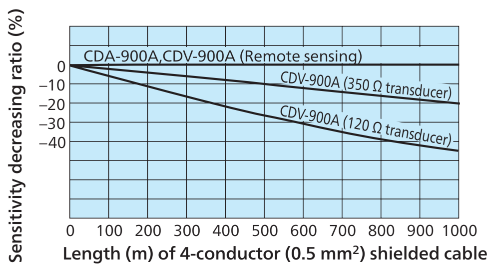
Amplifiers for measurement of dynamic variables are available in 2 types: AC bridge excitation and DC bridge excitation. In Kyowa, amplifiers using AC bridge excitation is called Strain Amplifiers and amplifiers using DC bridge excitation, Signal Conditioners.
Since the strain amplifiers have the bridge circuit affected by capacitive components, both resistive and capacitive components should be balanced at the initial adjustment. In addition, the AC frequency of the bridge excitation limits the frequency response to lower than the DC system. But the AC bridge excitation system provides higher sensitivity and is highly resistant against external noise, thereby making strain amplifiers excellent in SN ratio and zero stability and free from thermoelectromotive force. Thus, strain amplifiers are most frequently used for strain measurement with strain gages. Furthermore, current strain amplifiers adopt the CST method, which automatically balances capacitive components and requires no adjustment by the operator for improved operational efficiency.
The signal conditioners using DC bridge excitation requires balance of resistive components only at the initial adjustment and provide higher frequency response but SN ratio and stability are inferior to the strain amplifiers. But the DC bridge excitation system provides higher output voltage than the AC bridge excitation system, and thus signal conditioners are frequently used for measurement with strain-gage transducers.



Differences between Constant-voltage System and Constant-current System in Bridge Excitation

Signal conditioners using DC bridge excitation are available in 2 types: CDV series having the bridge circuit excited on constant voltage and CDA series having the bridge circuit excited on constant current. Generally, the constant-voltage system is used but if the cable is extended between the signal conditioner and strain gage transducer, the cable resistance lowers the voltage to be applied to the transducer, thereby resulting in decreased sensitivity (≈–6%/100 m, 120 Ω). On the contrary, the constant-current system keeps the current constant against increased cable resistance, and thus the voltage applied to the transducer is always constant and remains unaffected by cable extension. With the constant-current system, however, the bridge resistance should be compensated if it differs from the nominal bridge resistance.

$$\text{True value} = \frac{\text{Nominal bridge resistance}}{\text{Actual bridge resistance}} \text{ x Measured value}$$

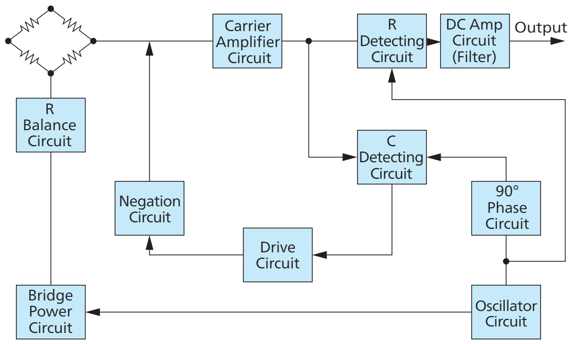


Note that the CDV-900A has a built-in remote-sensing circuit, and thus use of a 6-conductor (0.5 mm^2) shielded cable prevents the sensitivity from decreasing up to approximately 2 km.
For the remote-sensing method, see page 9-14.

Technical Memo

Principles of CST Method

The CST (Capacitance Self Tracking) method is the Kyowa developed method of electrically canceling any unbalanced capacitance constantly during measurement with the strain amplifier of AC bridge excitation system, automatically with no switch operation made. As shown in the block diagram below, the unbalanced capacitance detected by the C detecting circuit is inverted in phase by the drive and negation circuits. The inverted capacitance is added to the bridge output to negate the unbalanced capacitance. This method not only eliminates the need for troublesome initial adjustment of unbalanced capacitance of strain amplifiers using AC bridge excitation system but also cancels any unbalanced capacitance during measurement to solve the problem on unstable measurement due to unbalanced capacitance. It also enables use of higher-frequency AC bridge excitation and development of strain amplifiers featuring a frequency response at a maximum 10 kHz. Presently, all Kyowa strain amplifiers of AC bridge excitation system adopt the CST method.



The Reason Why Constant Current Bridge Excitation is Used for Civil Engineering Measurement with Cable Extended

See Fig. 1 at the right and suppose that E is the voltage of the bridge excitation and E' is the voltage applied to the transducer in the constant voltage bridge excitation system. Then,

$$E' = E - 2 \cdot I \cdot r$$

where, "$I \cdot r$" is the voltage decrease due to cable resistance and "$2 \cdot I \cdot r$" is that due to the reciprocating cable resistance.

If the cable is short, $r \fallingdotseq 0$, and thus,

$$E' = E \rightarrow \ e = \frac{E}{4} \cdot Ks \cdot \varepsilon$$

If the cable is extended,

$$E' = E - 2 \cdot I \cdot r$$

$$e = \frac{E'}{4} \cdot Ks \cdot \varepsilon < \frac{E}{4} \cdot Ks \cdot \varepsilon$$

Consequently, the output voltage is lowered.
The input of Fig. 1 may be rewritten to Fig. 2.

In Fig. 2 $E' = \left(\frac{Rg}{Rg+2r}\right) \cdot E$, and thus,

$$e = \frac{E'}{4} \cdot Ks \cdot \varepsilon = \frac{E}{4} \cdot Ks \cdot \varepsilon \left(\frac{Rg}{Rg+2r}\right)$$

This means an output decrease by $\frac{Rg}{Rg+2r}$.

With the constant current system, the current, I, is constant at all times, and thus the bridge output receives no influence from r.

Excitation voltage $E' = I \cdot Rg$

$$e = \frac{I \cdot Rg}{4} \cdot Ks \cdot \varepsilon$$

This means that resistance of the extension cable does not cause any output decrease. However, the input resistance, Rg, of the bridge affects the output. But a difference between the nominal bridge resistance of civil engineering transducer and its actual bridge resistance is extremely small, and thus it need not consider that the input resistance of the bridge affects the accuracy.

Compensation equation: $e \times \frac{\text{Nominal bridge resistance}}{Rg}$

Civil Engineering Transducer

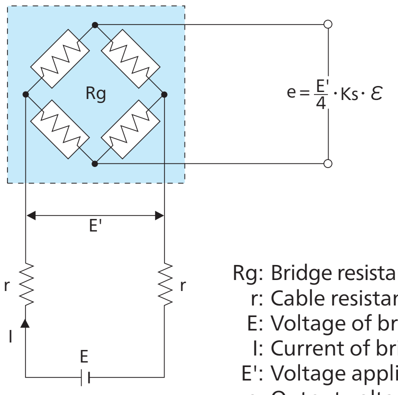


Fig. 1

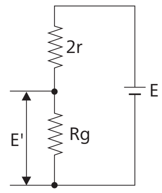


Fig. 2

Rg: Bridge resistance of transducer
r: Cable resistance
E: Voltage of bridge excitation
I: Current of bridge excitation
E': Voltage applied to bridge
e: Output voltage
Ks: Gage factor
ε: Strain

TEDS

TEDS is the acronym of Transducer Electronic Data Sheet, which is incorporated into transducer. By reading the electronic data from the transducer, the measuring instrument is automatically placed in proper measuring conditions without manual adjustment. The format of the transducer electronic data written in the sheet is provided in IEEE 1451.1. The data is roughly classified into the following 3 types:

Common data: Transducer identification data including the manufacturer identification code, model number code and serial number.

Template: Transducer performance data including the type of transducer, detecting physical variable, rated capacity, rated output, input resistance, recommended excitation voltage, date of calibration.
Note: For transducers providing both positive and negative output signals an average of both output signals is written as the rated output.

User data: For maintenance and services by Kyowa engineers. The data is partially open to users and up to 31 alphanumeric characters are written on the sheet by users. However, a dedicated writing device is required.
Inquiries are welcome.