1. Application of resistors for industrial use

Nikkohm Co., Ltd is a manufacturer of resistors for industrial use that feature the world's first class performance. Resistors for industrial use are not those which are incorporated in consumable electronic equipment such as mass-produced TV sets, PCs, mobile phones and digital cameras but those categorized in production properties and applied to IC testers which are used in production process of high quality ICs to be mounted into electronic devices, IC production facilities, board testers which are used for inspecting boards to be mounted into electronic devices, fixed transmitting and receiving stations for mobile communication networks and electronic measuring instruments used for their development. Resistors for industrial use also include those incorporated in semi-mass-produced equipment used in power generating facilities, transforming facilities, air conditioning/blast facilities, water supply and sewerage systems, industrial machines for motor control and others, machine tools and transportation control systems for CTC, ATC and others. The performance requirements for industrial resistors are not only high accuracy, stability and long life but also low failure rate, and as a matter of course, secured traceability of components and environmental measures are also strongly required.

2. Unit and range of resistance value

The unit of resistance value used by resistors is ohm. Roughly speaking, the minimum resistance is 0.1 milliohm and the maximum resistance is 100 G ohms. The resistance values of Nikkohm's resistors range from 0.1 milliohm to 10 M ohms.

3. Accuracy and tolerance of resistance value

Since resistors are industrial products, their resistance values show some deviation. When referring to the accuracy of a resistor, an expression: "this resistor is guaranteed to be within the range of ±0.1%" is often used. The highest accuracy level of the resistors manufactured by Nikkohm is 0.01%. It is easy to maintain stable production and stable distribution of 1000-ohm resistors because ±0.01% of 1000 ohms means a range from 999.9 ohms to 1000.1 ohms. 1milliohm resistors, however, are difficult to maintain stable distribution using the current technology because ±0.01% of 1 milliohm is a range from 9.9999 milliohms to 1.0001 milliohms, which means the measurement and control capability for 0.1 microohm is required. As understood from the above description, guaranteed resistance accuracy tends to vary in accordance with the target resistance value.

In addition, the temperature coefficient of resistance to be described below is a key element to determine the accuracy.

4. Accuracy of resistor and temperature coefficient of resistance

The primary material of a resistor is metal and the resistor utilizes electric conduction of a metallic material, which tends to cause fluctuation in resistance values due to the temperature of a resistive element and the ambient temperature around a resistor. For example, if the ambient temperature of a highly accuracy 1000 ohms ± 0.000 ohm resistance values, its resistance value deviates from 1000 ohms. As for a precision resistor, the deviation rate of resistance value against a change of 1°C is represented by a temperature coefficient of 0.0001%/°C or 1ppm/°C as an example.

Although resistance tolerance and temperature coefficient of resistance are both expressed in proportion, resistance tolerance is generally expressed in % and temperature coefficient of resistance is in ppm in order to prevent erroneous indication due to long digit number of a value.

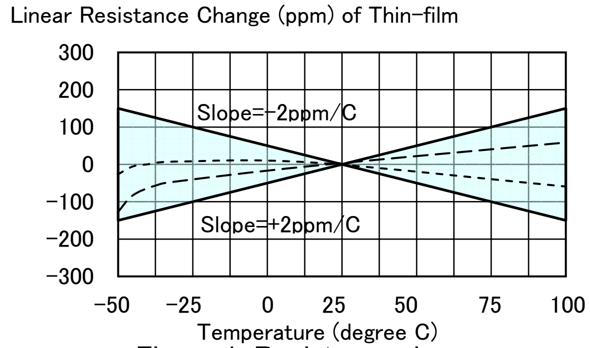

Figure 1. Resistance change.

5. Relation between resistance accuracy and temperature coefficient of resistance

Resistance tolerance and temperature coefficient of resistance are related to each other because the accuracy of resistance is determined based on the worst case design which is developed through temperature simulation tests for securing the accuracy of each electronic device. For example, in the case where the design temperature range of an electronic device is set to be from -25°C to +75°C, taking a room temperature of 25°C as its central value, this difference in temperature, ±50° C, can be effectively balanced with a resistance tolerance of ±0.01% and a temperature coefficient of ±2ppm/K for the circuit accuracy of ±0.02% as shown in the following table:

Requirement	±0.02%	
As Tolerance of resistor	±0.01%	
As TCR	±2ppm/℃	
Error from temp.	±100ppm=±0.01%	-50℃,+50℃
Accumulated error	0.01%+0.01%=0.02%	

Table 1 .Tolerance estimation from -25C to 75C

Requirement	Resistance tolerance	TC of resistance
±0.02%	±0.01%(X)	±2ppm/℃(Q)
±0.2%	±0.1%(B)	±25ppm/℃(E)
±2%	±1%(F)	±100ppm/℃(A)

Table 2. Combination tolerance and TCR, -25C to +75C

6. Long-term stability

Resistance of a precision resistor tends to slightly vary (increase) while it is left unused or energized. It is necessary to prevent this change in resistance value from deviating from the required accuracy range as described earlier. To show the stability performance of a resistor, the data book includes test results of natural standing (per year), load life (1,000 hours), moisture resistance (1,000 hours), PCT (100 hours), etc. A well-controlled super precision thin film resistor shows a natural standing property at around 35ppm/year.

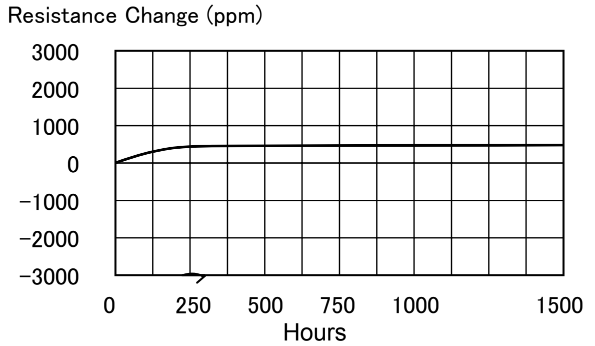

Figure 2. Stability

7. Heat generation and rated power

When an electric current of I is applied to a resistor with a resistance R, a joule loss P (W) is generated.

$$P = I^2 R \qquad \text{(W)}$$

This generated heat warms the air of the inner space of an electronic device mainly with the help of conductivity through resistor terminals as well as convection and radiation through air flow from the surface of a resistor, and the temperature of the resistor will reach to the level of equilibrium state.

The data book includes the increases in resistor temperature which are measured while its power is gradually increased. (Usually a room temperature is deducted and only an increased portion of the measured temperature is recorded.) Since the temperature rise curve typically indicates a change either in temperature of an inner resistive element material or temperature of resistor's outer surface, it is necessary to confirm which temperature is indicated when the data is referred to. Temperature of Nikkohm's resistors with through hole terminals and metal clad resistors shows a curved increase while that of resistors which release heat by heat conduction such as a T220 resistor shows a linear increase. The rated power and load derating curve of a resistor are determined based on this curve of temperature rise.

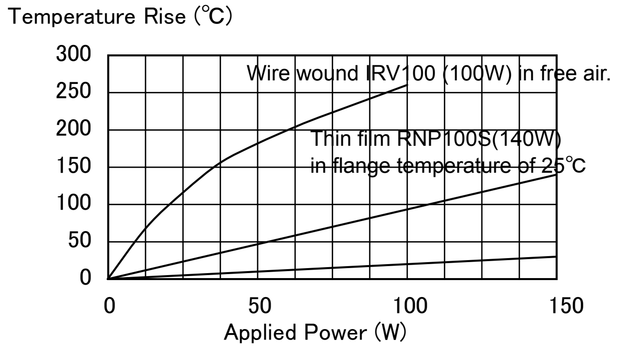

Figure 3. Temperature rise

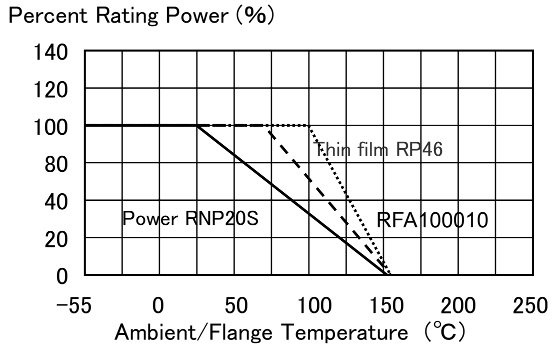

Figure 4. Derating curve

8. Use of impulse of resistor and rated power

Resistors retain stable operation without failure for a long time of period when used with rated power. Power resistances and those which are used in circuits for switching power sources, AC motor control and others are almost always subject to receiving impulse current. In such cases, some may use resistors based on the assumption that they could normally operate as long as the average value of a pulse current waveform or average power is within the range of the rated power. This assumption should be avoided. The many combustion loss accidents related to resistors are derived from this erroneous assumption.

To safely operate resistors, it is important to use them within their rated power. Even if they are wire wound resistors which are said to have greater bearing capability against impulse, they must be used under the condition that the peak value of the impulse power is kept within 5 times of the rated power. Of course, there is a case that a resistor sufficiently supports the peak pulse power which is 5000 times of the rated power and offers intact performance if used in the area where the pulse width is 1 microsecond or less. To make this type of application feasible, meticulous preliminary evaluation must be conducted on a relevant resistor in the designing phase.

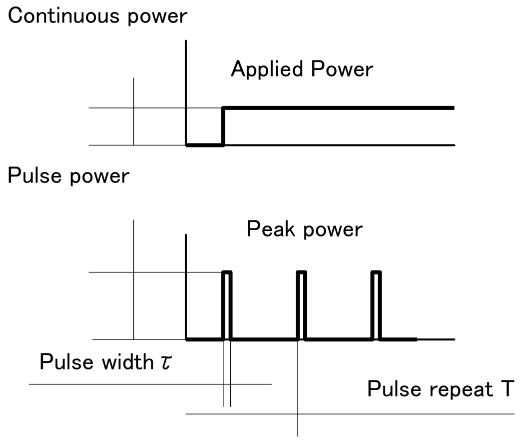

Figure 5. Pulse applicayion

Fig. 5 shows impulse waveforms. As for impulse, there is a misunderstanding that a resistor safely operates if peak power of Pa is equal to or less than the rated power of the resistor where Pa = Pp (t/T) is applied. Due to a physical property of resistors, a minute damage starts under peak power and leads to a failure in a due course. Therefore, cautions must be exercised when a resistor is used beyond its rated power. It is necessary to note here that resistors may be damaged by heating of the entire unit, however, for the application to an impulse circuit, it also can be damaged by burnout at a limited small part of a material of the resistive element that is a component of a resistor without a rise in temperature of the entire unit of the resistor.

9. Impedance of resistor

When DC voltage V is applied to a resistor and DC current I passes through it, the relation between voltage and current is linear, or they are said to be in proportional relation. In this case with a slope R, the relation between voltage and current is defined by the resistance value R. On the other hand, when AC voltage is applied, the relation between voltage v and current i is, technically speaking, affected by the time lag and phase lag of its sine wave form, and therefore, impedance Z of complex number must be incorporated in addition to a real number R. This means that the relation between voltage and current is represented not by Ohm's law of a scalar expression but by a vector expression.

The impedance of a resistor is approximately expressed as a phenomenon (vector relation between voltage and current) in an equivalent circuit. As for an equivalent circuit, it is necessary to select an optimum circuit in the relevant AC frequency area.

As shown in Fig. 6, at the commercial frequency (50 Hz/60 Hz), commonly used resistors can be expressed only by R, a real number of impedance. However, in accordance with increase in frequency, resistors must be expressed by a RLC typed lamped parameter equivalent circuit and for 1 GHZ or over by the combination between a RLC lamped parameter equivalent circuit and an equivalent distributed constant circuit such as a transmission circuit as shown in Fig. 6.

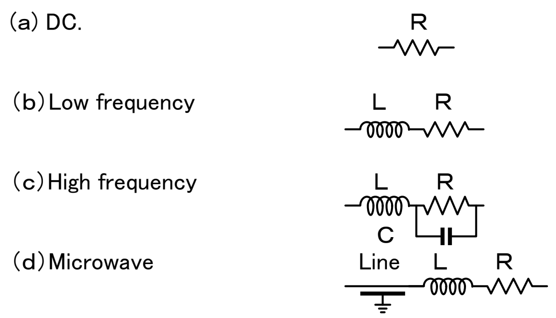

Figure 6. Equivalent circuit of resistor.

It is almost impossible to measure the value of capacitance C of the equivalent lamped parameter circuit (C) in Fig. 6 for small resistors such as one with a chip of 5 mm or shorter in length or Nikkohm's rectangular flat metal film resistors. The expression of "almost impossible" is used for a value equivalent to 0.1 pF or less. Since L of a small chip resistor is about 1 nH, the RLC type equivalent circuit of (c) in Fig. 6 is seldom taken into consideration.

10. Types of resistors classified by appearance

10-1 Rectangular chip resistor

Viewing from the front, resistors of this type are square without a lead wire. These mainstream resistors are classified into thick film chip (sintered resistive element), thin film chip (metal thin film resistive element) and metal foil chip (bulk metal foil resistive element) by materials of their resistive elements.

10-2 Axial lead resistor

Resistors of this type are produced by sputtering a thin film resistive element on the round ceramic surface and others, fitting metal caps with the both ends and coating the surface. Thin film, carbon film, metal oxide film and others are used for the resistive elements.

10-3 Radial lead resistor

Rectangular metal film resistors and some others belong to this group.

10-4 Cement resistor

Resistors which are composed of an axial lead resistor in a ceramic case sealed with cement, and used for electric power systems.

10-5 Metal clad resistor

Resistors which are produced by placing a wire wound element or others in an aluminum metal case and molded with silica powder featuring high heat conductivity and cement, or silicon resin, and used for electric power systems.

10-6 Flanged resistor

The flanged resistors has a resistor in a transistor package of T126, TO220, TO247, etc. There are many other shaped power resistors welded with a resistive element on a metal plate fixed with screws.

10-7 Resistor for electric power system

Although there are groups of high power resistors and power resistors, there is no clear-cut definition for rated power to draw a line between high power and others. Nikkohm calls resistors with a rated power of 5 W or over as high power resistors. The import and export statistics, however, classify resistors with 20 W or over as power resistors for their calculation.

11. Structure of resistor

11-1. Thin film resistor

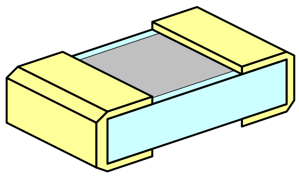

Figure 7. Thin film

11-2. Thick film resistor

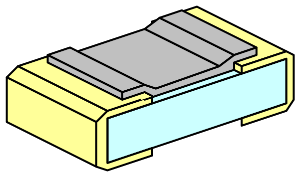

Figure 8. Thick film

11-3. Metal plate resistor

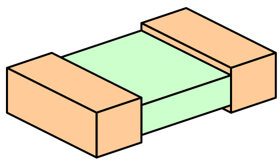

Figure 9. Metal plate

11-4. Wire wound resistor

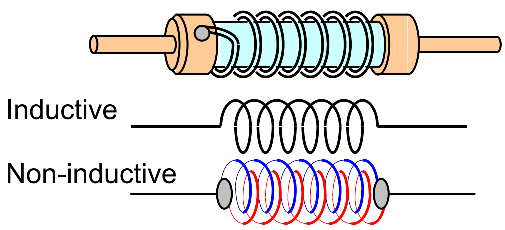

Figure 10. Wire wound

12. Name of resistor

The type names of Nikkohm products are comprised of 2 or 4 alphabet letters representing type of resistor, a number representing electric power or size, an alphabet representing TCR, a resistance value, and an alphabet representing tolerance and 3 alphabets representing additional treatment. The TCR symbols and tolerance symbols are listed in the following tables. The tolerance symbols are often used. The reason why Nikkohm affixes TCR symbols to their products is that TCR values are important to precision resistors and that Nikkohm which has been diversified and expanded from a precision resistance manufacturer has its own regulations which require TCR symbols even for high frequency resistors and power resistors.

13. TCR symbol and tolerance symbol

The TCR symbols and the tolerance symbols are listed in the following tables:

TCR	
X	+/- 1ppm/C
Y	+/- 2ppm/C
W	+/- 2.5ppm/C
Z	+/- 5ppm/C
N	+/- 10ppm/C
L	+/- 15ppm/C
E	+/- 25ppm/C
C	+/- 50ppm/C
A	+/-100ppm/C
H	+/-250ppm/C

Tolerance	
T	+/-0.01%
Q	+/0.02%
A	+/0.05%
B	+/0.10%
C	+/0.25%
D	+/0.50%
F	+/1.00%
G	+/2.00%
J	+/5.00%
K	+/-10.0%
M	+/-20.0%

Table 3. TCR and Tolerance

14. Nominal resistance value

Since it is not economical to prepare all the resistance values required by electronic/electric circuits and standardize their use in the electronic component market, standardization organizations such as IEC and JIS have established discrete resistance values as nominal resistance values. The resistance values of the products manufactured by Nikkohm range from 1 milliohm to 10 M ohms. E6 and E12 series are resistors of 1 ohm or less and ultra-precision resistors adopt the resistance values of E24 and E96 series. If a mass order is received, resistors of any intermediate values among those of E series products will be manufactured.

As for resistors at precision levels (0.05%, 0.02% and 0.01%), customized resistors of specified resistance values from 4 to 6 effective digits will be manufactured so as to ensure superb performance.

Nikkohm incorporates additional values including 2.5 and 5.0 into its in-house standards as well as using values defined by the established organizations such as IEC.

15 Production lot symbol

To ensure the traceability of the production process of each product, a lot symbol representing its production date is marked on the product or on the surface of the package. The traceability of some products is controlled by production S/N numbers. The symbols for production dates are listed in the following table.

E6+
1.0
1.5
2.2
3.3
4.7
6.8

E12+
1.0
1.2
1.5
1.8
2.2
2.7
3.3
3.9
4.7
(5.0)
5.6
6.8
8.2

E24+	
1.0	3.3
1.1	3.6
1.2	3.9
1.3	4.3
1.5	4.7
1.6	(5.0)
1.8	5.1
2.0	5.6
2.2	6.2
2.4	6.8
(2.5)	7.5
2.7	8.2
3.0	9.1

Table 4. Resistance value, E6+, E12+, E24+

1.00	1.43	2.05	2.94	4.22	6.04	8.66
1.02	1.47	2.10	3.01	4.32	6.19	8.87
1.05	1.50	2.15	3.09	4.42	6.34	9.09
1.07	1.54	2.21	3.16	4.53	6.49	9.31
1.10	1.58	2.26	3.24	4.64	6.65	9.53
1.13	1.62	2.32	3.32	4.75	6.81	9.76
1.15	1.65	2.37	3.40	4.87	6.98	
1.18	1.69	2.43	3.48	4.99	7.15	
1.21	1.74	2.49	3.57	5.11	7.32	
1.24	1.78	2.55	3.65	5.23	7.50	
1.27	1.82	2.61	3.74	5.36	7.68	
1.30	1.87	2.67	3.83	5.49	7.87	
1.33	1.91	2.74	3.92	5.62	8.06	
1.37	1.96	2.80	4.02	5.76	8.25	
1.40	2.00	2.87	4.12	5.90	8.45	

Table 5. E96+

Year	Month	Date code
2006	JAN	61
2006	FEB	62
2006	MAR	63
2006	APR	64
2006	MAY	65
2006	JUN	66
2006	JUL	67
2006	AUG	68
2006	SEP	69
2006	OCT	6X
2006	NOV	6Y
2006	DEC	6Z

Table 6. Date code

16. Message from Nikkohm, management policies and features of technologies and products

We are committed to running the company under the corporate philosophies of articulating customer oriented services, challenge to be the best in the world, and development of human resources as well as the policies of pursuing high quality, development of new products, and improvement of production processes.

We are focused on creating innovative, the world's first level industrial resistors of Nikkohm brand, employing the technologies and processes of sputtering and vacuum deposition for forming thin films, heat treatment of thin films, precision patterning, printing and annealing for forming thick films, precision treatment of metal plates and laser machining.

In addition to availing ourselves to these treatment technologies, we are engaged in research and development of academic level in regard to electric conduction of metals, electric conduction of thin films, designs for heat generation and heat transfer, thermal strain, optimization of high-frequency properties, control of heat bond electromotive force, precision measurement, etc. as well as high level technology development, component designing and reliability assurance control in order to continuously provide with reliable electronic components and contribute to the society.

Nikkohm brand products have played key roles in the fields related to social infrastructure such as electric power service, electric power generation and transformation, transportation control, measuring equipment, semi-conductor production facilities, machine tools and major communication networks for 40 years. ■

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