How to Select Metal Foil Strain Gauges (SG)

Overview

Metal foil SG are the most widely used sensing elements to manufacture sensors, e.g., load cells, force sensors, torque sensors, pressure sensors, displacement sensors and so on.

Since the metal foil SG are important elements for sensors, it is crucial to select the right SG for the specific sensor applications. The purpose of this article is to guide users to make the right selection.

The following contents will be covered for this purpose:

1. Ordering Code System of metal foil SG from BCM SENSOR
   The correct understanding and usage of the Ordering Coding System is fundamental to purchase the right SG from BCM SENSOR.

2. Selection procedures of metal foil SG
   Discussed in this section is how to select the right SG according to the application.

Metal Foil for Manufacturing of Strain Gauges from BCM SENSOR

Thanks to the extremely low TCR (temperature coefficient of temperature), both constantan and karma alloy foil are the metal foil selected by BCM SENSOR for manufacturing of metal foil strain gauges (SG).

The key specifications of these two metal foils are shown in Tab. 1.

Tab. 1: Key Specifications of Constantan and Karma Foil

Parameters	**Specifications**	
metal foil	constantan alloy	karma alloy
composition of alloy	Cu(55%), Ni(45%)	Ni(74%), Cr(20%), Al(3%), Fe(3%)
gauge factor of SG made from this foil	2.0, …, 2.2	1.86, …, 2.2
resistivity (Ω•μm)	0.45, …, 0.52	1.24, …, 1.42
TCR (ppm/°C)	±20	±20
linear thermal expansion coefficient (ppm/°C)	~15	~13
max. working temperature for static application	250°C	400°C
max. working temperature for dynamic application	400°C	800°C

For detailed specifications of strain gauges from BCM SENSOR, one can refer to the datasheets of strain gauges.

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Characteristics of Constantan Strain Gauges

Thanks to its excellent linearity, good resistivity and ability to solder the leads or wires easily, the constantan gauge made from constantan foil is the most common SG which are widely used for sensor applications.

Characteristics of Karma Strain Gauges

Comparing to the constantan gauges, the karma gauges from BCM SENSOR have the following advantages and disadvantage.

Advantages of the karma gauges:

- higher resistivity: about 3 times higher than constantan gauges;
- possibility to be EMC (effective modulus compensated) gauges.

Disadvantage:

Due to metallurgic (metallic property) reason it is more difficult to solder leads or wires onto the solder pads of karma gauges.

How to Correctly Select Solder Pad Finishing of Karma Gauges

Two types of solder pad finishing are available for the karma strain gauges from BCM SENSOR: either naked solder pads (SP) or tinned solder dots (SD).

In general, it is always recommended to select the SP finishing for strain gauges so as to keep the strain gauges evenly flexible and facilitate the gauge bonding process.

However, as mentioned above, it is difficult to solder leads or wires onto the karma gauges. Thus, if one does not have any experience having soldered the leads or wires onto the karma gauges, it is highly recommended to choose the SD finishing, rather than the SP finishing, when purchasing the karma gauges from BCM SENSOR.

On the other hand, if one is able to solder the leads or wires onto the karma gauges, it is recommended to select the SP finishing, instead of the SD finishing. This is because the SD finishing makes the strain gauge not only lose its even flexibility but also hurt the operator's thumb during gauge bonding process.

How to Correctly Solder Leads or Wires onto Karma Gauges

In *Installation of Strain Gauges*, the specific techniques of how to correctly solder leads or wires onto the karma gauges will be discussed.

For further engineering advice on how to solder leads or wires onto karma gauges, one can contact BCM SENSOR.

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1. Guidance of Ordering Code System of Metal Foil Strain Gauges

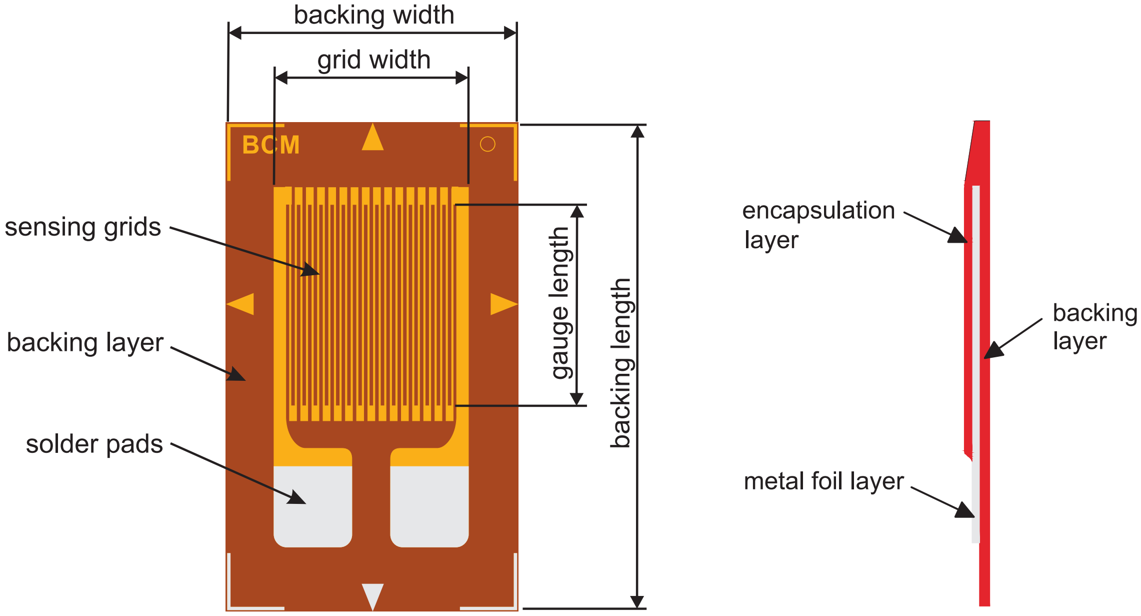
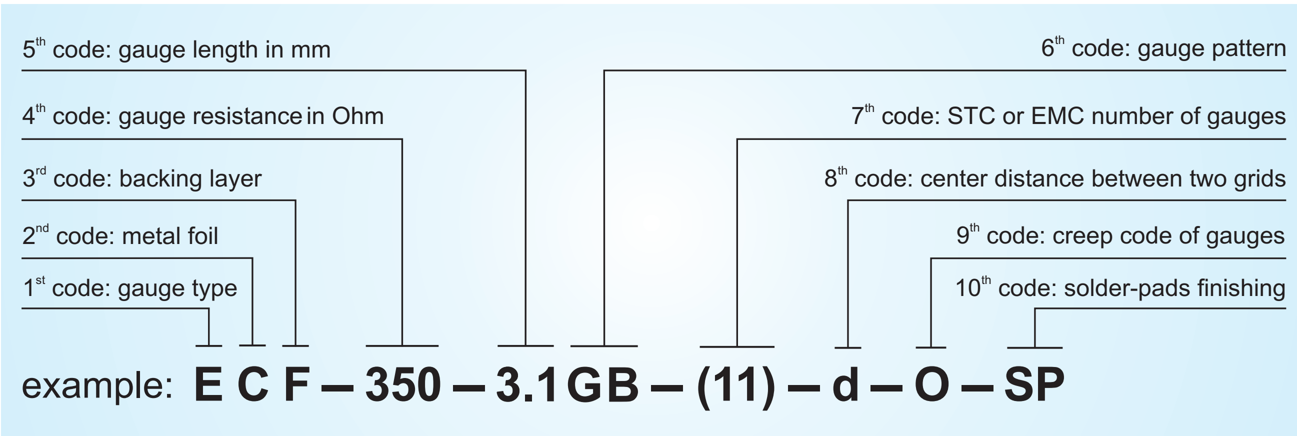


Fig. 1: AA Pattern of Single Linear Strain Gauge

The ordering code system shown below helps users to purchase metal foil strain gauges (SG) from BCM SENSOR. More explanation and advice are given beneath the example of an order code.



1st code: gauge type - it describes whether the sensing grid of the SG is encapsulated or not.

There are 2 types of the SG available:

- E: encapsulated gauge, i.e., the gauge with an encapsulation layer;
- O: open-face gauge, i.e., the gauge without an encapsulation layer.

For sensor applications, the encapsulated SG are most commonly used, while the open-face SG are used much less often. This is because once the open-face gauge is taken out of its package, its sensing grid will be exposed to air (oxygen, humidity and dust) and eventually be oxidized and contaminated during and after the gauge bonding process. Therefore, the open-face gauges may only be selected in case one must trim the gauge resistance after the gauge bonding process, or if one must bond the SG on a surface of small-radius curvature where the encapsulated SG is hard to be bonded due to its encapsulation layer.

The material of the SG encapsulation layer is the same as that of the backing layer of the SG.

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2nd code: metal foil - from which the metal foil SG are made.

There are 2 types of the metal foil available:
- C: constantan alloy,
- K: karma alloy

The karma alloy has a higher resistivity than the constantan alloy, which means that with a same size of sensing grid the karma gauge can have a higher resistance than the constantan gauge.

In addition, the karma alloy can be used to make so-called EMC gauges, but the constantan alloy cannot. However, it is more difficult to solder leads or wires onto the solder-pads of the karma gauges compared to the constantan gauge.

The detailed comparison of these two types of metal foil is discussed on page 2.

3rd code: backing layer - which carries the sensing grid and solder pads of the SG, insulates the SG from sensor body, and transfers strains of the sensor body to the sensing grid of the SG.

There are 5 types of the backing layer (in short, backing) available:
- F: modified phenolic resin;
- I: modified polyimide resin;
- B: laminated polyether-ketone;
- A: advanced laminated polyimide;
- L: laminated polyimide.

BCM SENSOR has been using five different resins to make the SG backing layer, and these five different backing layers have different working temperature ranges. The working temperature range of the backing layer determines the working temperature range of the SG.

As listed above, the codes of these five different resins are F.I.B.A.L.. A guidance showing the relation between these five different backing layers (FIBAL) and their working temperature ranges, is listed below respectively.

Code, Material and Working Temperature Range of FIBAL Backing-Layers:

Code: Material	Working Temperature Range
F: modified phenolic resin	-30 ~ +80°C
I: modified polyimide resin	-85 ~ +150°C
B: laminated polyether-ketone	-45 ~ +150°C
A: advanced laminated polyimide	-195 ~ +200°C
L: laminated polyimide	-55 ~ +150°C

One can select the SG of a right backing layer according to the operating temperature range of his application. For detailed guidance of selection, one can refer to Step 7 in Section 2..

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4th code: gauge resistance - it is measured in ohm between two solder pads of the SG.

The gauge resistance is determined by the resistivity of the metal foil, the thickness of the foil and the total sensing grid length. The total grid length is approximately equal to the gauge length multiplied by the number of loops of the sensing grid over the grid width, as indicated in Fig. 1.

The available gauge resistances for the specific gauge pattern can be found in the datasheets of strain gauges.

The resistance tolerance, the resistance deviation from its nominal value, the resistance difference between the two grids of dual gauges, and the resistance unbalance over the four grids of full-bridge gauges, can also be found in the datasheets for specific SG patterns.

5th code: gauge length (in mm) - it refers to the effective length of the sensing grid sensing the useable strain.

The gauge length is measured excluding so-called end loop of the sensing grid as indicated in Fig. 2. For sensor applications, the gauge length is one of the most important specifications of the SG. Therefore, the step 2 in Section 2. presents practical considerations how to select a right gauge length for a specific sensor application.

One can refer to the available gauge length designed for the specific gauge pattern as presented in each datasheet of strain gauges.

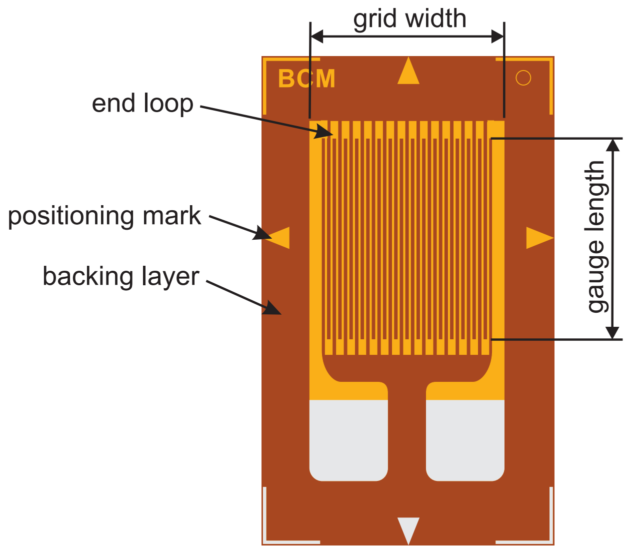

Fig. 2: Gauge Length and Grid Width in Gauge Pattern

In Fig. 2. there are 4 triangle markers, the function of which is to assist precise positioning of the SG at a right place when it is bonded onto a sensor body.

6th code: gauge pattern - it denotes geometrical pattern of the SG and distinguishes it from other SG.

The gauge pattern determines the application of the SG. For details on how to select a right gauge pattern for a specific sensor application, one can refer to step 1 in Section 2..

In the datasheet of every category of SG, one can find all the available gauge patterns in such category.

In Tab. 2 presented is a summary of all the available gauge patterns from BCM SENSOR.

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Tab. 2

Category	Gauge Patterns	Example of Sensor Applications
linear SG	single grid: AA, AA(B) dual-grid: FB	bending beam force sensors
shear SG	single grid: AB, AC dual-grid: HA, HA(A), HA(B), HA(C)	shear beam force sensors and torque sensors
90° SG	BB, BB(A), BB(B)	column load cells, tension and/or compression force sensors
half-bridge linear SG	GB, GB(L), GB(AL), GB(BL), GB(CL)	force sensors of normal-bending beam or reversed-bending beam
full-bridge linear SG	FG(L), FG(BL), FG(CL), FF(L), FF(AL), FF(BL), FF(CL)	bending beam force sensors
	EB, EB(A), EB(B), EB(C), EB(D), EB(E),	force sensors of reversed-bending beam
multi-grid SG	EX, EX(A), QX	multi-axial force and torque sensors
diaphragm full-bridge SG	KA, KA(A), KA(B)	diaphragm pressure sensors
	KC, KC(A), KC(B)	diaphragm force sensors

7th code: STC or EMC number - which is the important number to guarantee a right application of the SG.

The STC (self-temperature compensation) number represents the sensor body material to which the STC-gauges can compensate for its zero-temperature-drift.

The EMC (effective modulus compensation) number indicates the sensor body material to which the EMC-gauges can compensate for its span-temperature-drift.

One can find more information about the STC-gauges and the EMC-gauges in Technical Questions on BCM SENSOR website.

The available STC and EMC numbers from BCM SENSOR are listed in Tab. 3.

Tab. 3

Sensor Body Material	STC Nr.	EMC Nr.
titanium	9	not available (NA)
martensitic stainless steel (SS), mild steel	11	M11
austenitic SS, copper	16	M16
aluminum	23	M23
magnesium	27	not available
plexiglass	65	not available

Regarding the specific SG series made with the available STC or EMC numbers, one can refer to its datasheet.

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8th code: center distance between two grids - it is only applicable to either the half- or full-bridge SG.

For the available center distances between two grids of specific patterns, one can refer to their datasheets.

9th code: creep code - which indicates the SG's creep level to compensate the creep of sensor body.

There are 18 creep codes available to select which are listed according to their negative creep levels:
N10 < N9 < N8 < N7 < N6 < N5 < N4 < N3 < N2 < N1 < O < P1 < P2 < P3 < P4 < P5 < P6 < P7

The smaller the capacity of sensors, the more negative creep the strain gauge must be selected.

A new creep code can be designed for the concerned SG on request for large purchasing orders.

More detailed information on the technique of creep correction can be found on BCM SENSOR website.

10th code: solder-pad finishing - it describes the electrical interface of the SG.

There are 7 types of solder-pad finishing available to select which are listed below:

- SP: naked solder pads, the most recommended option for sensor application with SG;
- SE(1): solder extension which is the extended solder pads from the metal foil of the SG;
- SD(2): tinned solder dots, only necessary to select if one wants to use the karma gauges;
- RL(3): silver-plated round copper leads if one prefers to bonding the SG with round leads;
- EW(4): enamel insulated round copper wires if the SG has to be bonded with enameled wires;
- PW(5): PVC (Polyvinyl chloride) insulated wires, which is rare for sensor applications;
- HW(6): PTFE (polytetrafluoroethylene) insulated wires, not often for sensor applications.

Notes:

(1) Dimensions of SE:
- thickness: same as the metal foil of the SG;
- length: standardized to 30 mm, 45 mm, 50 mm, 70 mm and 90 mm (maximum).
  The longest length of 90 mm is due to limited foil size. The customized length < 90 mm is available on request.

(2) It is recommended to select this option if one wants to use the karma gauges and has no any experience having soldered leads or wires onto the karma gauges.

(3) Dimensions of RL:
- diameter of its cross section: Ø0.15 mm;
- length: standardized to 30±1 mm; other lengths available on request.
  For instance, RL(50) indiactes the length of 50mm.

(4) Specifications and dimensions of EW:
- operating temperature range: -40 ~ +150 °C;
- diameter of its cross section: Ø0.15 mm;
- length: standardized to 30±1 mm; other lengths available on request, e.g., EW(100) indicates 100mm length, but with a limit of 1m, i.e., EW(1000).

(5) Specifications and dimensions of PW:
- operating temperature range: -40 ~ +105 °C;
- outer-diameter of wire: Ø0.6 mm;
- number of conductors: 7;
- diameter of cross section of the single conductor: Ø0.08 mm;
- length: standardized to 30±1 mm; other lengths available on request, but with a limit of 1m,

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(6) Specifications and dimensions of HW:
- operating temperature range: -80~ +250 °C;
- outer-diameter of wire: Ø0.30~0.35 mm;
- number of conductors: 1, i.e., solid conductor;
- diameter of cross section of the single conductor: Ø0.15 mm;
- length: standardized to 30±1 mm; other lengths available on request, but with a limit of 1m, i.e., HW(1000).

3.1.2. Selection Procedure of Metal Foil Strain Gauges

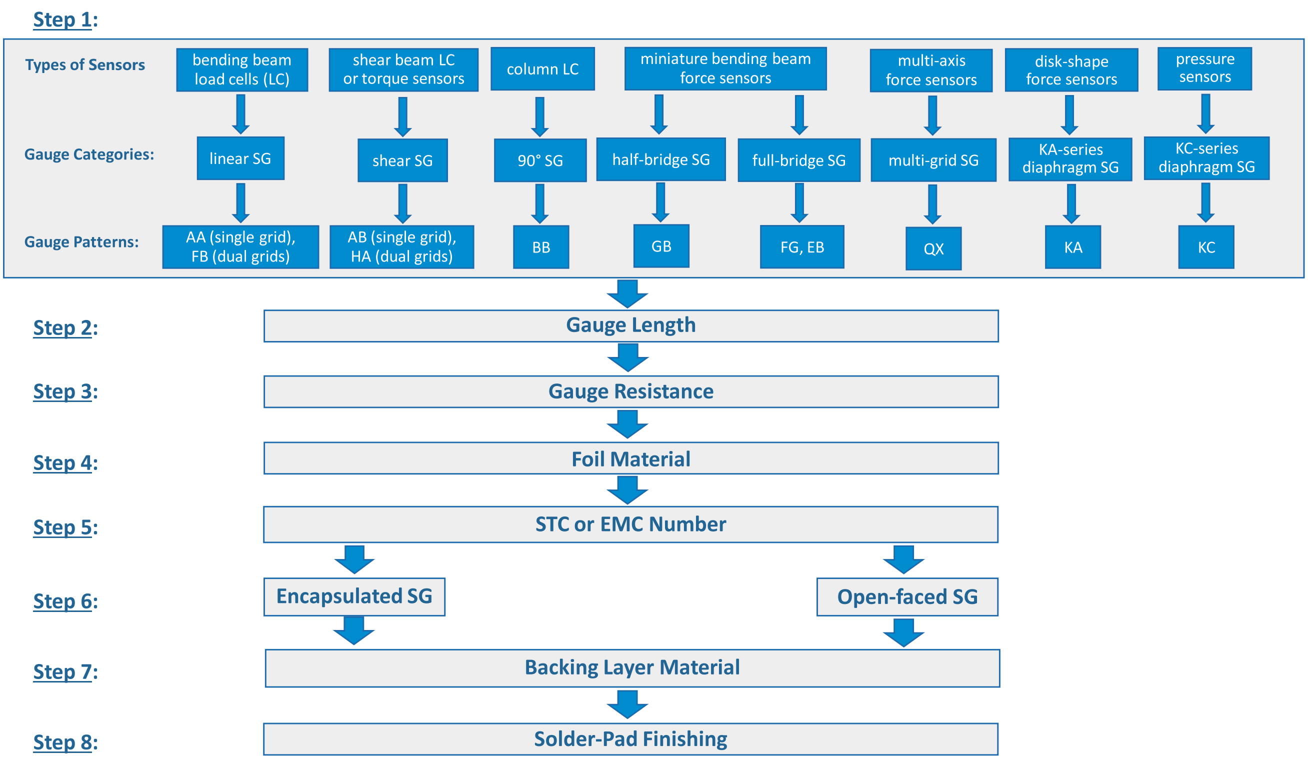
The characteristics of the metal foil strain gauges (SG) may be influenced due to misuse during the sensor production process. For instance, mistakes might be made in one or more of the processes as mentioned below:

- designing of the beam of a sensor body,
- machining of the sensor body,
- bonding and curing of the SG onto the sensor body, and
- soldering of thin leads or wires onto the solder-pads of the SG bonded on the sensor body.

In addition, the characteristics of the SG can be also influenced by the material quality of the sensor body, the quality of the coating and sealant which are used to protect the bonded SG.

To avoid these influences, it is crucial to select a right SG to purchase at the very beginning of the sensor application.

The following chart presents 8 steps which can assist SG users to select a right metal foil SG from BCM SENSOR according to the types of load cells or sensors which the user is going to manufacture. After the chart, the user can find more detailed explanation of each step.



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Step 1: Select a right gauge pattern to fit the type of the sensor one is going to manufacture.

The metal foil SG from BCM SENSOR for sensor applications are classified into seven categories according the gauge patterns, i.e., axial-, shear-, 90°-, half bridge-, full bridge-, diaphragm-, and multi grid-categories. Each category of gauge patterns is suitable for one (or more) specific type(s) of sensor applications, as shown in Tab. 2.

Step 2: Decide the gauge length by considering the strain profile and the effective length of the beam of the specific sensor body, as well as the space available for gauge bonding.

In general, a longer gauge length provides better heat dissipation within the sensor body, while a shorter gauge length offers easier handling and bonding of the SG during its installation process. Nevertheless, if the gauge length is too long, it may result in a lower sensitivity and lesser accuracy of the sensors. When the gauge length is too short, the warm-up time may last longer for the sensor to reach to thermal balance. Therefore, as an optimization it is highly recommended to use the gauge length of about 3mm which could feature a good combination of heat dissipation, sensitivity and accuracy for the sensors.

Step 3: Select the gauge resistance according to the electronics and power supply of sensors.

When sensors are powered by batteries or a low power energy harvesting system, a crucial concern is to save the battery life. To lower the power consumption and save the battery life, it is recommended to use the SG of a higher resistance, e.g., 2000Ω, 3000Ω, or 5000Ω. This is because, for a given excitation voltage, the higher the resistance of the SG, the smaller the working current which leads to a longer battery life of the sensors.

There are two methods to select the SG of a higher resistance:

a. The bigger the grid size of the SG, the higher the resistance of the SG;
b. For a given grid size, the karma-gauge has always a higher resistance compared to the constantan-gauge.

During the selection, one can first employ the method “a.”, that is, if the effective beam length of the sensor body is about 3mm, one can select the constantan-gauge of the gauge length of around 3mm matching the effective beam length. However, one shall take into account the influence of the gauge length as mentioned above in Step 2.

If one still needs a higher resistance after the method “a” was applied, then one can apply the method “b” and select the karma-gauge rather than the constantan-gauge.

Nevertheless, compared to the karma-gauges, it is always easier to solder thin leads or wires onto the solder-pads of the constantan-gauges, which is the advantage of the constantan-gauges for sensor applications.

Step 4: Select the foil material which is available for the selected gauge length and resistance.

As mentioned in Step 3 that, if the constantan-gauges can meet the needs of both the gauge length and the gauge resistance for a specific sensor application, it is always the advantage to select the constantan-gauges rather than the karma-gauges. This is because one can easily solder thin leads or wires onto the SG solder-pads if the constantan-gauges are selected.

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However, for a given gauge length if there is no any suitable constantan-gauge to meet the required gauge resistance, one has to select the karma-gauge. In addition, if one has to use the EMC (effective modulus compensated) gauges for a particular sensor application, one has to also select the SG made from karma foil. This is because, within the SG product range from BCM SNSOR, only the karma foil is used to manufacture the EMC-gauges.

Step 5: Select STC (self-temperature compensated) or EMC code which is corresponding to the sensor body material.

In Tab. 3 the STC and EMC codes are listed for the corresponding sensor body materials.

Regarding the availability of STC and EMC code for the specific gauge series, one can refer to the datasheet. In addition, one can find more detailed explanations about the STC- and the EMC-gauges in Technical Questions on BCM SENSOR website.

Step 6: Decide whether the SG should be encapsulated for particular application of sensors.

For sensor applications all the SG, as a standard of BCM SNSOR, are the encapsulated SG in order to both eliminate the influence of humidity and prevent dust during SG installation process.

Nevertheless, on request the open-face SG are available from BCM SNSOR. The open-face gauges are only required in two cases:

- The gauge resistance of the bonded SG has to be trimmed after the bonding process, or
- The SG has to be bonded onto a curved surface of a small radius of curvature where the encapsulation layer of SG may cause any problem for the gauge curvature during bonding process if the encapsulated SG are used.

If one wants the open-face SG (the first digit of the SG ordering code is “O”), rather than the encapsulated SG (its representing code is “E”), the specifications listed in each datasheet of SG still apply and another nine series will form: OCF-, OCI-, OCB-, OCA-, OCL-, OKF-, OKI-, OKA- and OKL-series.

For instance, the above-listed specifications of the ECF-series metal foil SG are also applicable to the OCF-series metal foil SG.

Nevertheless, for sensor applications the open-face SG are not recommended. Therefore, these nine series of the open-face SG are not listed for discussion in this data book.

Step 7: Select a right backing layer material to meet the required operating temperature range of specific sensor application.

To facilitate the selection, a comparison is illustrated below between the working temperature ranges of SG backing materials and the operating temperature ranges of most typical application sectors.

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Working temperature of FIBAL backing-layers:

F: modified phenolic resin	-30 ~ +80°C
I: modified polyimide resin	-85 ~ +150°C
B: laminated polyether-ketone	-45 ~ +150°C
A: advanced laminated polyimide	-195 ~ +200°C
L: laminated polyimide	-55 ~ +150°C

Application temperature of sensors:		Suggested backing:
commercial application:	0 ~ 70°C	F
weighing application:	-30 ~ +80°C	F
normal industrial application:	-40 ~ +85°C	I B L
automotive:	-40 ~ +125°C	I B L
military:	-55 ~ +125°C	I L
high-temperature application, e.g., engine:	-55 ~ +200°C	A
low-temperature application, e.g., cryogenics:	-195 ~ +25°C	A

For instance, if one is going to manufacture the sensors (or load cells) to be used in either commercial sector or for weighing application, one can select the SG from BCM SENSOR which are made with the backing layer of the advanced phenolic resin (code = F), in order to have a good matching of the operating temperature ranges between the SG and its application. This is because the operating temperature range of SG is determined by the operating temperature range of the backing layer material.

Another example is that, if one is going to manufacture the sensors to be used either for engine application or in a cryogenic environment, one has to purchase the SG from BCM SENSOR which are made with the backing layer of the advanced laminated polyimide resin (code = A).

For normal industry, automotive, or military applications, one can select the SG among the three backing materials, i.e., the modified polyimide resin (code = I), the laminated polyetherketone resin (code = B) or the laminated polyimide resin (code = L), depending on the lower end of the working temperature range of the SG.

<u>**Step 8:** Select the solder pad finishing</u> according to the soldering and wiring requirements in the application.

The most widely used solder pad finishing is the SP (naked solder pads). This is because the option SP always keeps the SG evenly flexible and facilitates the gauge bonding process. Therefore, the SP is always a recommended option when one purchases the SG from BCM SENSOR.

Only if the karma gauges are selected, one may consider selecting the SD (tinned solder dots) as the solder pad finishing, if one has no any experience with soldering leads or wires onto the karma gauges.

The solder pad finishing of RL (silver-plated round copper leads), EW (enamel insulated copper wires), PW (PVC insulated copper wires) and HW (PTFE insulated copper wires) are rarely used in sensor applications. They are more often selected for application of stress analysis. As this data book focuses on the sensor application, there will be no further explanation about these leads and wire finishing.

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The last option of the solder pad finishing is SE (solder extension) which can be selected for one of the following purposes:

a. To ease the gauge wiring in the sensor application;
b. To make the gauge wires neat and nice-looking if the gauge wiring has to be exposed outside of the sensor body and cannot be covered by any sealant;
c. To replace the flat flexible cable.

However, the length of the SE option is limited to maximum 90mm because the SE is made from the same metal foil as the SG.

For detailed engineering advice on utilizing the metal foil strain gauges, one can contact BCM SENSOR.

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