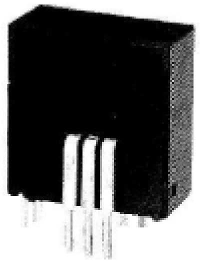
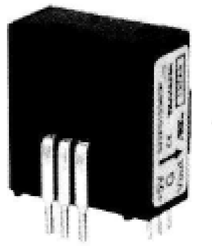
S22P Series

Application Manual





S22P□□□S05M2 Series **S22P□□□S05P Series**

■ Overview

The S22P Series is a closed-loop type and built-in bus bar-type current sensor.

The rated current has variations of 6 A, 15 A, and 25 A, respectively. The mounting structure is the on-board type.

Table 1: Outline of S22P series Ta = 25°C Vcc = +5 V (Unless otherwise specified)

Series name	S22P series	
Model number	S22P□□□S05M2	S22P□□□S05P
Rated current	6 A, 15 A, 25 A	6 A, 15 A, 25 A
Rated output voltage	$Vof + 0.625V$ Vof : Offset voltage (Standard: 2.5 V)	
Bus-bar-pin length	5.5 mm ± 0.5 mm from standoff	3.5 mm ± 0.5 mm from standoff

■Characteristics

- Built-in bus bar-type supply system of the current to be measured.
- The built-in bus bar can be selected from 1 turn to 3 turns depending on the connection method.
- Closed-loop-type circuit configuration.
- Output of on-board-type format with panel mounting structure.
- Single power-supply voltage of +5 V can be used.
- Output in the form of voltage given as output voltage corresponding to the current to be measured.
- Very high accuracy output voltage of within ±1.7%. (When measuring rated current, Ta = 25°C)
- Excellent output linearity of within ±0.2%.
- Fast response: Step response (response speed $\frac{di}{dt}$) of less than 1 μs.
- Withstand voltage: AC 3000 V for 1 minute
- Satisfies conformity safety standard.

■ Use

- General purpose inverter

・UPS

■ Format

S22P □□□ S 05 □□

Suffix M2: Bus-bar pin 5.5 mm
P: Bus-bar pin 3.5 mm
(Each dimension represents the length from the standoff)

Power-supply voltage 05: +5 V

Power-supply type S: Single power supply

Rated current 006: 6 A
015: 15 A
025: 25 A

Series name S22P

■ Standard connection diagram

S22P□□□S05□□

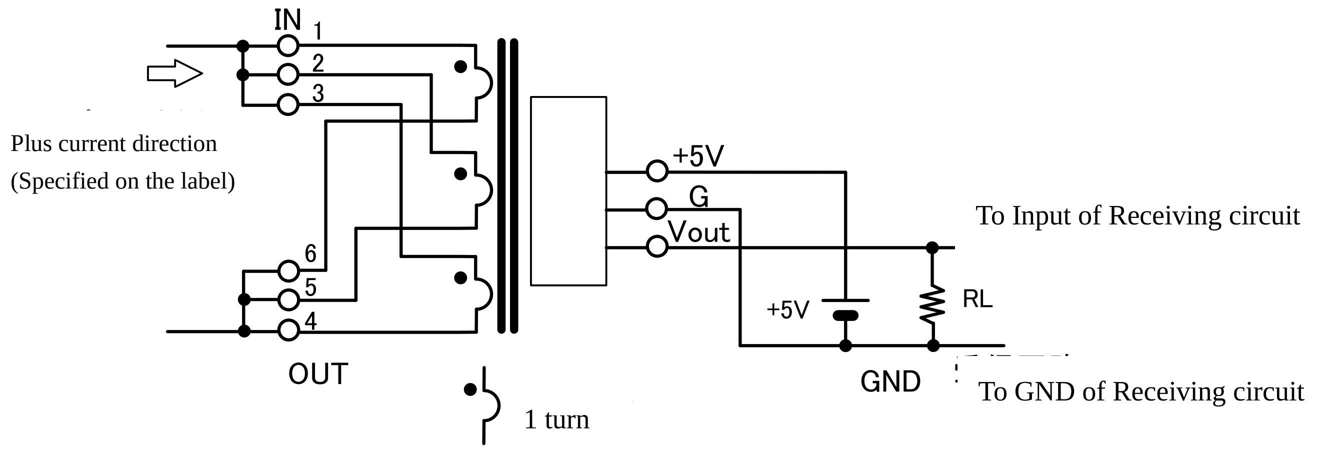


Fig. 1-1: S22P□□□S05□□: Standard connection diagram of 1-turn bus-bar

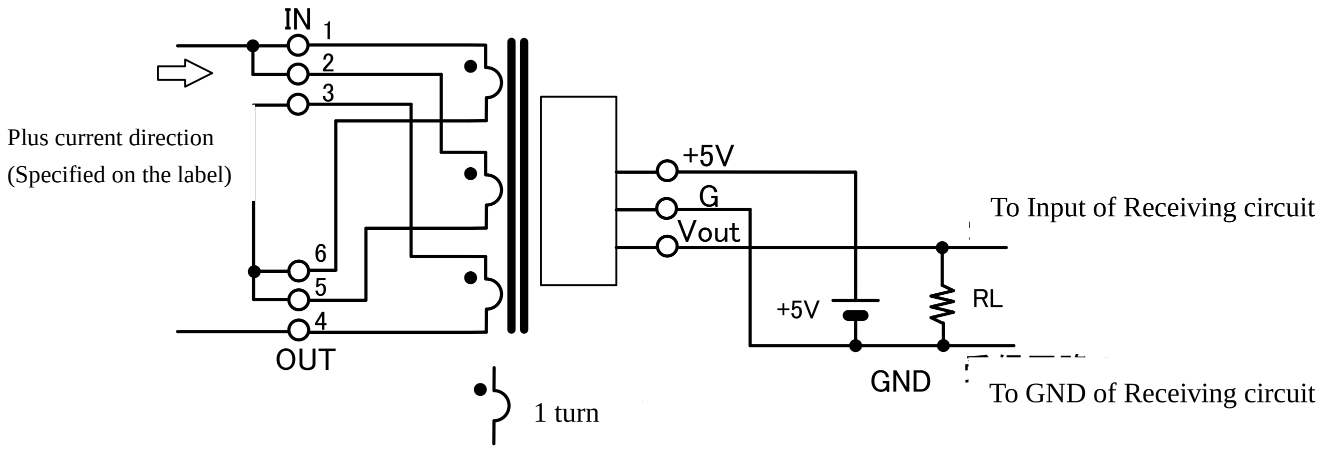


Fig. 1-2: S22P□□□S05□□: Standard connection diagram of 2-turn bus-bar

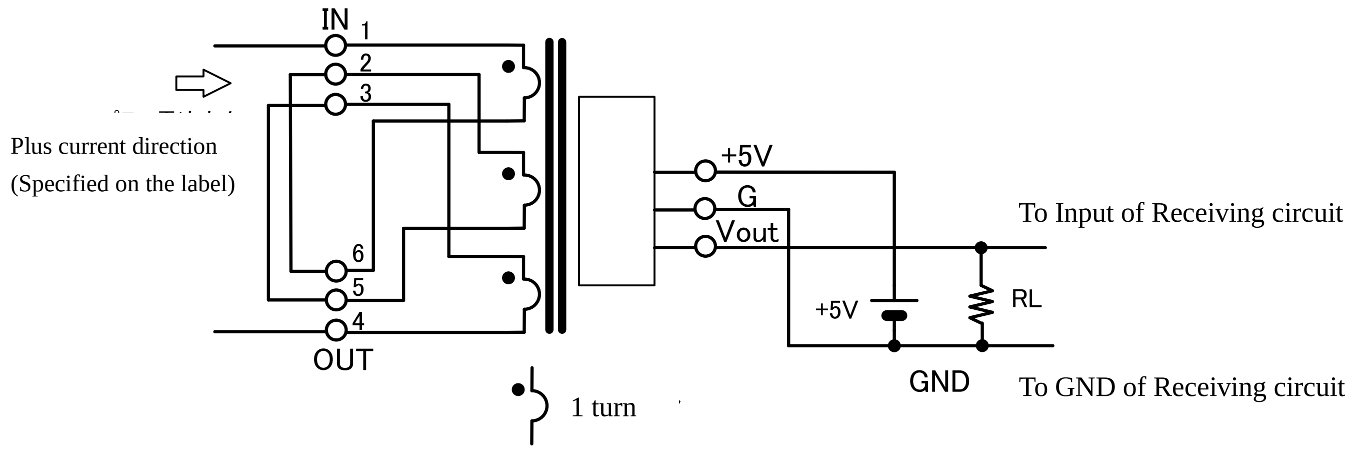


Fig. 1-3: S22P□□□S05□□ Standard connection diagram of 3-turn bus-bar

■ Description of input/output terminals: S22P□□□D05□□

Table 2: Description of input/output terminals

Terminal number	Terminal name	Description	Remarks
1	Bus bar	1 ⇔ 6 for one bus bar.	
2	〃	2 ⇔ 5 for one bus bar.	
3	〃	3 ⇔ 4 for one bus bar.	
4	〃	–	
5	〃	–	
6	〃	–	
7	Vout	Output terminal. Outputs voltage corresponding to the current to be measured.	*
8	GND	Ground terminal. Power supply +5 V and the ground for the output voltage.	
9	+5V	Power supply terminal. Input +5V between the terminal and GND.	

* $V_{OUT} = 0.625 \times \frac{I}{I_f} + Vof$ (Unit: V)

I : Current to be measured (A)

I_f : Rated current (A)

Vo : Offset voltage (V) The standard value is $Vof = 2.5V_{typ}$.

■ Description of basic characteristics

The S22P Series current sensor is used for the measurement of 6 A ~ 25 A class current and outputs the voltage corresponding to the current to be measured from the output terminal. The internal structure is composed of a core (a magnet) penetrating three independent bus bars and an electronic circuit. The electronic circuit is composed of a negative feedback coil constituting a closed loop and a phase compensation circuit for stable operation of the amplifier and the closed loop. A single power-supply voltage of +5 V can be used.

The current to be measured is passed through a bus bar of the sensor. The magnetic flux generated by the current to be measured converges to the built-in core (a magnet), and the built-in amplifier energizes the canceling current to the negative feedback coil in such a way that the generated magnetic flux becomes extremely small, i.e., approximately 0 tesla. That is, a current is supplied to the negative feedback coil so as to cancel the magnetic flux generated by the current to be measured. The magnetic flux of the core (a magnet) is proportional to (current) times (number of turns.) Let the number of turns of the negative feedback coil be N_F. Then, when three bus bars are used as one turn, the magnetic flux at the core (a magnet) is canceled and becomes nearly zero for the current of $\frac{1}{N_F}$ of the measured current passing through the negative feedback coil. The current applied to the negative feedback coil canceling the magnetic flux is converted into voltage by the 2.5 V reference differential amplifier and is output from the output terminal. In this case, therefore, the voltage corresponding to $\frac{1}{N_F}$ of the measured current plus 2.5 V is output. When three bus bars are used as three independent turns, the magnetic flux at the core (a magnet) is canceled and becomes zero for $\frac{3}{N_F}$ of the measured current passing through the negative feedback coil. Similarly, the current applied to the negative feedback coil canceling magnetic flux is converted to voltage by the 2.5 V reference amplifier and is output from the output terminal. A voltage corresponding to $\frac{3}{N_F}$ of the measured current is output. A voltage with a positive polarity is output when the current to be measured is supplied in the direction of the arrow described in the main body.

As described above, the sensitivity, (output voltage – 2.5 V) / (current to be measured), of the closed-loop current sensor is proportional to (number of bus-bar turns)/(number of turns of the negative feedback coil) and is approximately determined by the number of turns of the coil and that of the bus bar. Therefore, it is little affected by fluctuations in the sensitivity of the Hall element. The closed-loop S22P Series current sensor can achieve a high accuracy of within ±1.7% in the output and within ±0.2% in the output linearity.

This current sensor operates in a manner similar to that of a current transformer so that a sharp change in the current can be measured. When the current to be measured changes stepwise, high-speed response is possible. In fact, when the current to be measured rises at the rate of 100 A/µs, the measured value reaches 90% of the target value within 1 µs.

The sensor has an on-board-type structure enabling attachment to a board, and the wiring to the power-supply terminal and the output terminal can be configured in accordance with the pattern on the board.

■Block diagram (+5 V single power-supply type)

S22P□□□S05□□

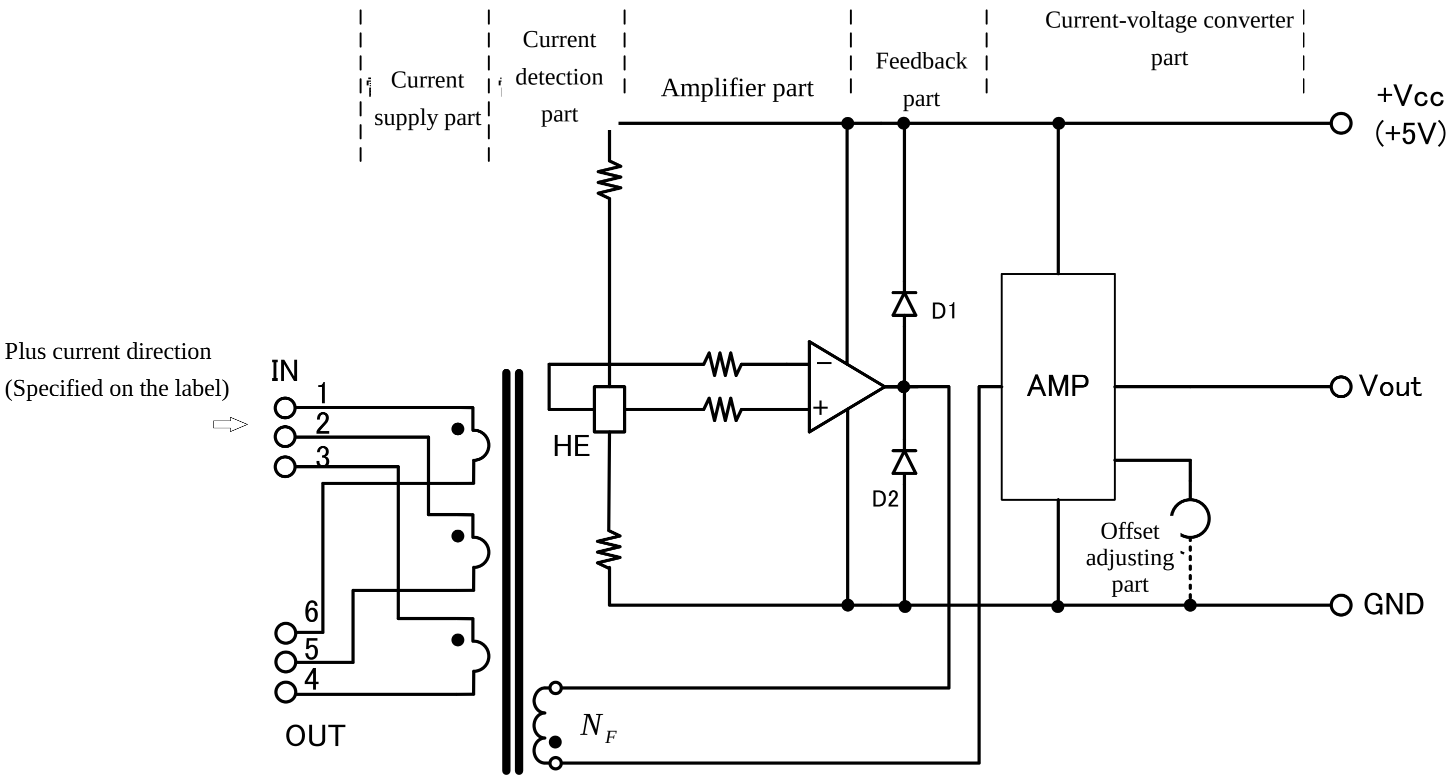


Fig. 2: S22P series: Internal block diagram

■Description of block diagram

Current-flowing unit

The current-flowing part passes the current to be measured through the bus bar built in the main body. Three bus bars are built in and are independent of each other. The three bus bars can be used as one-turn, two-turn, and three-turn bus bars by changing the wiring. The current to be measured is supplied to one bus bar to generate a magnetic flux in the built-in core. The magnetic flux generated by the current to be measured is concentrated on the core of high magnetic permeability. A Hall element, inserted in the core as a magnetic detection element, detects the magnetic flux of the core, and converts the flux into voltage.

The bus bar generates heat due to its own resistance component (copper loss). Even when the ambient temperature is maximum, the maximum value of the current is determined in such a way that the temperature of the sensor does not exceed the specified value.

In addition to the copper loss of the bus bar, heat is generated owing to iron loss (core loss) of the core built into the sensor. Each loss varies depending on various conditions such as the magnitude, frequency, and waveform of the current to be measured. The loss increases with the effective current or with the dominant frequency component of the current to be measured. When the current contains high-frequency components other than those of the fundamental wave, iron loss further increases. Therefore, confirmation using an actual current is necessary.

Current-detection unit

The current to be measured (primary input current) is passed through the bus bar. The generated magnetic flux is focused by the core and applied to the magnetic-detection element (Hall element, HE). When the wiring of the built-in bus bar is one turn, the magnetic flux to be generated in the core by the current to be measured is proportional to the current × 1. On the other hand, approximately $\frac{1}{N_F}$ of the measured current flows through the negative feedback coil and generates a magnetic flux in the direction opposite to the flux generated by the measured current. Because the number of turns of the negative feedback coil is N_F, the magnetic flux of the core is canceled and becomes almost zero. The current flowing through this negative feedback coil is sent to the current-voltage converter.

The magnetic detection element (HE) detects a net minute magnetic flux comprising a small current canceled by the current to be measured and the current of the negative feedback coil and converts it into voltage. The converted voltage is sent to the amplifier.

When the bus bars are used with two-turn wiring, the current of the negative feedback coil canceling the magnetic flux generated by the measured current becomes $\frac{2}{N_F}$ of the measured current. When the bus bars are used with three-turn wiring, the current of the negative feedback coil is proportional to $\frac{3}{N_F}$ of the measured current because of the same mechanism.

The current of the negative feedback coil is sent to the current-voltage conversion circuit, converted into voltage, and then becomes the output voltage.

Feedback section of amplifier unit

The amplifier circuit amplifies the output voltage of the magnetic-detection element (HE). The current from the amplifier circuit is sent to the feedback circuit. The feedback circuit provides current to the feedback coil. As a result, it constitutes a closed loop consisting of the magnetic-detection element ⇒ amplifier circuit ⇒ feedback circuit ⇒ negative feedback coil ⇒ core magnetic flux ⇒ (magnetic-detection element).

See Fig. 3.

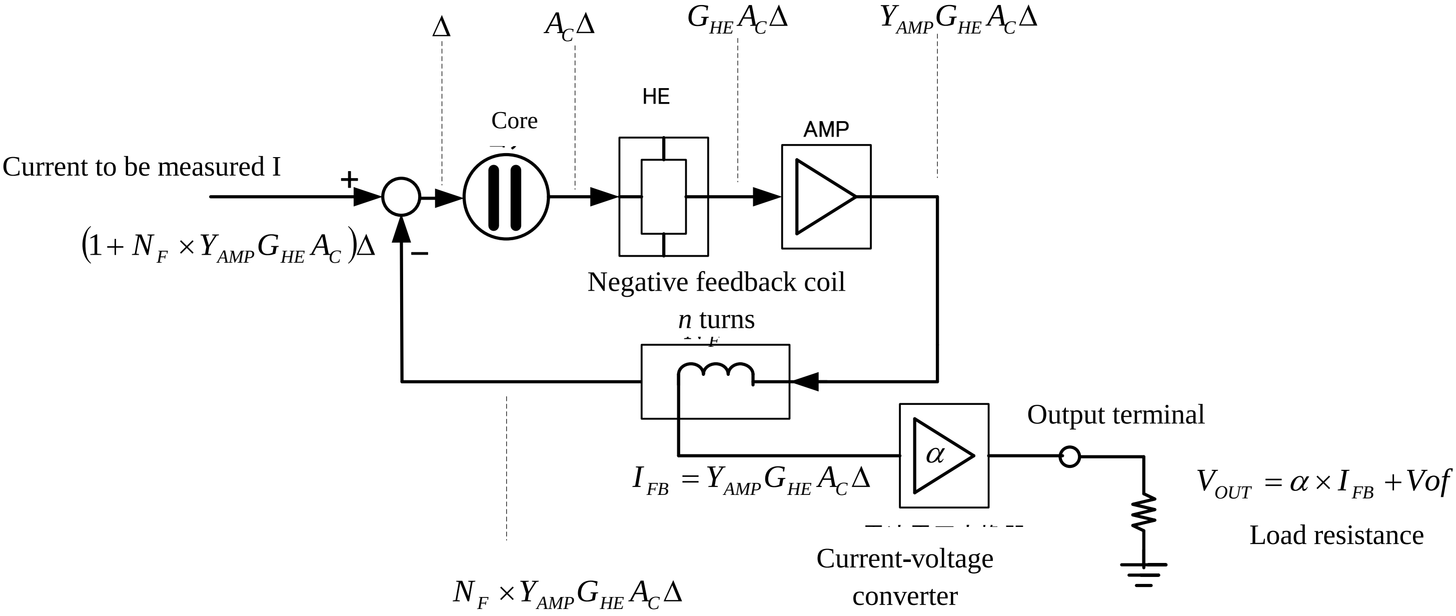


Fig. 3: Closed-loop block diagram (In the case of one-turn bus bar)

The current to be measured, I, is mostly canceled by the current flowing through the negative feedback coil, I_{FB}, and the remaining current Δ becomes a net minute current that excites the core.

The above-mentioned minute current generates a small magnetic flux, $A_C\Delta$, through the core of high magnetic permeability. The small magnetic flux $A_C\Delta$ is detected by the HE and is converted to voltage, $G_{HE}A_C\Delta$. Furthermore, this voltage is amplified by AMP and converted into current $Y_{AMP}G_{HE}A_C\Delta$ that flows through the negative feedback coil and becomes I_{FB}. When the number of turns of the negative feedback coil is N_F, the number of ampere turns is $N_F \times I_{FB}$. Therefore, as a result of subtracting $N_F \times I_{FB}$ from the current I to be measured, the net minute current Δ that excites the core can be written as

$$\Delta = I - N_F \times Y_{AMP}G_{HE}A_C\Delta. \qquad \text{Equation 1}$$

$$I_{FB} = Y_{AMP} G_{HE} A_C \Delta \,. \qquad \text{Equation 2}$$

From Equations 1 and 2, therefore, the relationship between the output current I_{FB} and the current I to be measured is obtained as

$$\frac{I_{FB}}{I} = \frac{Y_{AMP} G_{HE} A_C \Delta}{\Delta + N_F \times Y_{AMP} G_{HE} A_C \Delta} = \frac{1}{N_F + \frac{1}{\mu}} \,, \qquad \text{Equation 3}$$

where $\mu \equiv Y_{AMP} G_{HE} A_C$.

Because μ of the closed-loop current sensor has a very large value, Equation 4 holds while maintaining high accuracy of the output current within ±1.6%.

$$I_{FB} = \frac{1}{N_F} \times I \quad \text{(In the case of one-turn bus bar)} \qquad \text{Equation 4}$$

When the bus bars are wired with n_{BUS} turns, the output current becomes $I_{FB} = \frac{n_{BUS}}{N_F} \times I$.

Current-voltage converter

The current-voltage converter converts the current I_{FB} of the negative feedback coil into voltage. From Equation 4, because I_{FB} is proportional to the current to be measured I, voltage conversion of the current to be measured I is accomplished by the voltage conversion of I_{FB}.

Because the current to be measured flows in both plus and minus directions, the current-voltage converter provides offset voltage V_{of}. That is, the current-voltage converter converts I_{FB} using Equation 5 and outputs the output voltage V_{OUT} from the output terminal.

$$V_{OUT} = \alpha \times I_{FB} + Vof \,, \qquad \text{Equation 5}$$

where Vof is the offset voltage (V) and α is the gain (V/A) in the current-voltage converter.

Equations 4 and 5 give the standard relationship between the current to be measured I and the output voltage V_{OUT}, given by Equation 6.

$$V_{OUT} = \alpha \times \frac{1}{N_F} \times I + Vof \qquad \text{Equation 6-1}$$

$$V_{OUT} = \frac{0.625}{I_f} \times I + 2.5V \quad \text{(In units of V) (Standard value),} \qquad \text{Equation 6-2}$$

where I_f is the rated current (A) and I is the current to be measured (A).

Offset adjustment unit

The offset voltage *Vof* is a reference output voltage where the current to be measured is 0 A. For the S22P Series, the standard value of the offset voltage is 2.5 A.

The main origin of a possible deviation of the offset voltage from the standard value of 2.5 A lies in the fact that the HE, which is the magnetic sensing element, can have an offset voltage. The offset voltage of the HE is a minute voltage output even in the absence of applied magnetic flux. The minute output voltage generated by this offset voltage is the origin of the deviation of the offset voltage. In addition to the HE, deviation of the offset voltage can also be caused by the amplifier section. Before the product is actually shipped, adjustment is made, using the offset-adjusting part, in such a way that the overall offset is comprehensively canceled out and falls within a predetermined deviation.

■Application

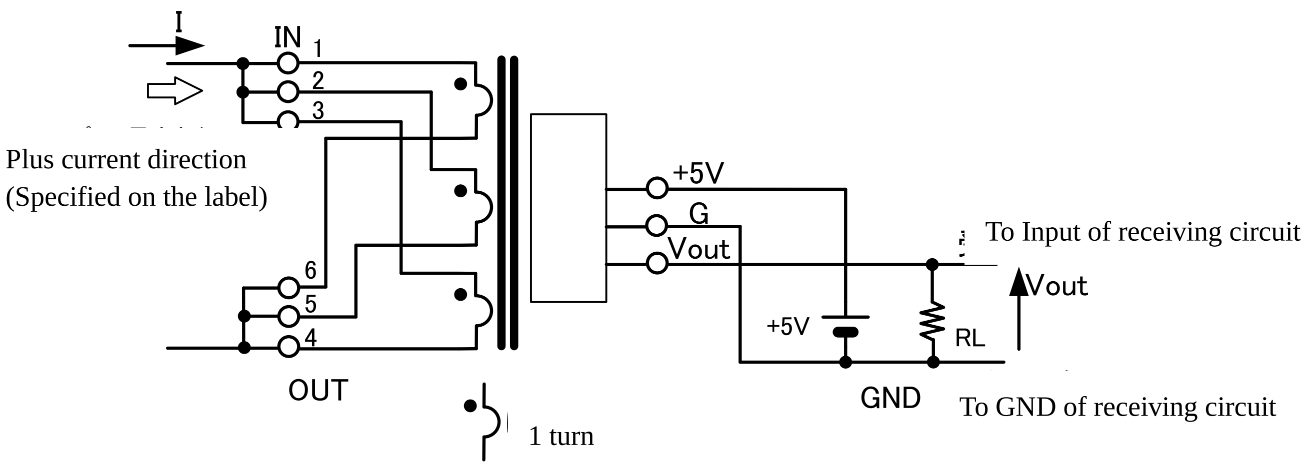


Fig. 4: Application (In the case of one-turn bus bar)

[Note]

The application shown below is not within the assurance standard of the S22P Series current sensor. In other words, the accuracy of the application and the performance corresponding to the parameter values of the parts shown below are not guaranteed. Therefore, when selecting circuits and component parameters during the design of actual products, sufficient evaluation based on careful consideration of safety and the stability of characteristics is necessary.

Basic operation

This current sensor outputs the measured current *I* as the output voltage ($V_{OUT} = \frac{0.625}{I_f} \times I + 2.5V$) in units of V, where I_f is the rated current (A) and 2.5 V is the standard value of the offset voltage. The load resistance *RL* is basically standardized as 10 kΩ. The power supply of +5 V is required to have sufficient capacity to supply the current I_{FB} of the negative feedback coil plus the current consumed by the sensor.

Offset voltage

The offset voltage Vof is the output voltage when the measured current is 0 A. Although the standard value of the offset voltage is 2.5 V, in the case of the S22P series, it has a deviation of ±0.015 V to ±0.05 V (depending on the item). For the offset voltage of 0.015 V, when measuring the current near the rated current, it causes an error within ±2.4%. The influence of the offset voltage when measuring twice the rated current decreases and the error can be compressed to within ±1.2%. On the other hand, when measuring a current of half the rated current, the error due to the offset voltage increases to a value within ±4.8%.

In order to minimize the error, it is necessary to select a sensor with a rated current suitable for the measured current.

If a sensor with a rated current higher than necessary is selected, the measurement error due to the offset current increases.

Output linearity

The output linearity is the difference between a straight line approximating the input/output characteristics of the sensor and the sensor output, and the ratio (%) of the difference to the absolute value is defined as output linearity ε_L. The formula for calculating the output linearity of the measurement point J in Fig. 5 is

$$\varepsilon_L\big|_J = \frac{\Delta_J}{V_O} \times 100 \quad (\%), \qquad \text{Equation 7}$$

where

V_O : Rated output voltage (V),

Δ_J : Difference of sensor output voltage at measured current I_J from approximate linear line (V),

I_f : Rated current (A),

I_J : Measured current at measurement point J (A).

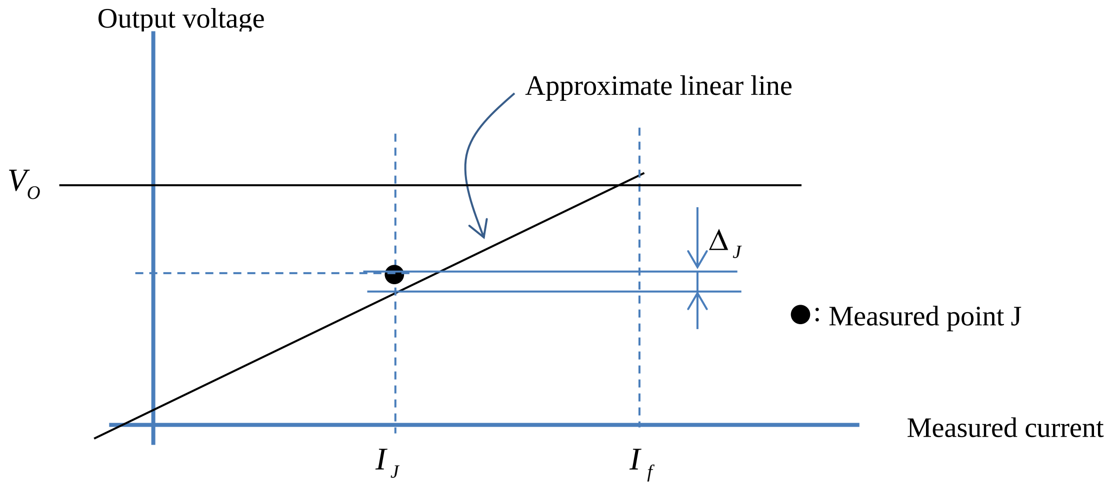


Fig. 5: Output linearity

Hysteresis error

Hysteresis error is caused by the hysteresis characteristic of the core. When the current to be measured is increased from 0 A to the rated current and then returned to 0 A, a maximum difference of ±0.5 mA with respect to the original value arises in the output voltage. This difference is called hysteresis error.

When the current to be measured increases or decreases during operation, this hysteresis error occurs. The amount of error is related to the amount of change of the current to be measured. The hysteresis error becomes larger when the width of the change increases.

Overall detection accuracy $\Delta_{TOTAL}\Big|_{t1\leftrightarrow t2}^{Iin}$

The overall detection accuracy of the current sensor is summarized in Tables 4 and 5.

Table 3: S22P Series: List of deviations determining the accuracy of the output current (Unless otherwise specified) Ta = 25℃

No	Item	Symbol	Standard value (max)			Remarks
			S22P006S05P S22P006S05M2	S22P015S05P S22P015S05M2	S22P025S05P S22P025S05M2	
1	Output voltage accuracy	X_G	Within ±0.01V			When measuring rated current
2	Deviation of offset voltage	ΔVof	Within ±0.05V	Within ±0.02V	Within ±0.015V	
3	Output linearity	ε_L	Within ±0.2%			When measuring rated current
4	Hysteresis error	V_{OH}	Within ±0.0005 V			
5	Temperature coefficient of output voltage	$TcVo$	±0.0000 5 V/℃			Excluding TcVof
6	Temperature coefficient of offset voltage	$TcVof$	-10 ~ +25℃ ±0.0016 V/℃ +25 ~ +85℃ ±0.0008 V/℃	-10 ~ +25℃ ±0.0006V/℃ +25 ~ +85℃ ±0.0003 V/℃	-10 ~ +25℃ ±0.0004 V/℃ +25 ~ +85℃ ±0.0002 V/℃	

(1) Overall detection accuracy for measurement of rated current

Table 4 shows the overall detection accuracy when measuring the rated current I_f, obtained from all items in Table 3.

Table4: Overall detection accuracy for measurement of rated current

Ambient temperature	*Accuracy Δ_{TOTAL}*		
	S22P006S05P S22P006S05M2	*S22P015S05P S22P015S05M2*	*S22P025S05P S22P025S05M2*
25℃	*±1.8%*	*±1.8%*	*±1.8%*
-25℃	*±11.0%*	*±5.4%*	*±4.3%*
+85℃	*±10.0%*	*±5.2%*	*±4.2%*

(2) Overall detection accuracy for measurement of half the rated current $\frac{I_f}{2}$

Table 5 shows the overall detection accuracy when measuring the rated current $\frac{I_f}{2}$, obtained from all items in Table 3.

Table 5: Overall detection accuracy for measuring half the rated current

Ambient temperature	Accuracy Δ_{TOTAL}		
	S22P006S05P S22P006S05M2	S22P015S05P S22P015S05M2	S22P025S05P S22P025S05M2
25°C	±9.9%	±5.1%	±4.3%
-25°C	±31.9%	±12.9%	±9.4%
+85°C	±25.7%	±11.3%	±8.6%

Power supply

The plus and minus power supplies provide the current I_{FB} of the internal negative feedback coil in addition to the current consumed by the sensor, $I_{FB} = \frac{I_{MAX}}{2000}$. Therefore, sufficient capability to supply current is required, including various items, as shown in Equation 8.

$$I_{+5} \geq I_{CC} + \frac{I_{MAX}}{2000} + \frac{Vo\max}{RL} \quad \text{(A)} \qquad \text{Equation 8}$$

I_{CC}: 12.5 mA type

RL : Load resistance (Ω) Standard: 10 kΩ

I_{MAX} : Maximum current to be measured (A)

$Vo\max$: Maximum output voltage (V)