Rocoil® 2100 SERIES RIGID ROGOWSKI COILS

FEATURES

- Rigid Rogowski Coil for precision measurements.
- Construction provides a highly stable coil.
- Each coil individually 'tuned' to minimise interference from adjacent conductors.
- Typical measurement accuracy 0.1%.
- Excellent rejection of external magnetic fields.
- Very low sensitivity to the position of the conductor within the coil.
- Can be designed for almost zero temperature sensitivity.
- Rugged light-weight construction.
- Two-layer insulation.
- Internal Electrostatic screen.
- Available with internal diameters from 73mm to 217mm
- Can be used to measure at frequencies from less than 1Hz to more than 10kHz.

INTRODUCTION

The Rocoil® Type 2100 Rigid Rogowski coils are available in a range of internal diameters. They are supplied with electrostatic screens as standard. The construction of the coils ensures that the mutual inductance is stable so that when it is calibrated the calibration has a long term stability. These coils are carefully made to ensure that they have a low pick-up of external magnetic fields. The formers are precision machined. Each coil is tested during manufacture and we make small adjustments to the winding to reduce the pick-up. We can measure the mutual inductance of the coil to an accuracy better than 0.1%.

With a suitable electronic integrator these coils can be used to measure low currents with a resolution as low as 1mA and high currents of greater than 100kA. Rogowski coil sensors provide complete isolation from the circuit being measured and have no effect on the current being measured even for very low-impedance circuits.

There are other devices that measure electric current without making electrical contact with the conductor. Many of these, including the conventional current transformer, use a ferromagnetic core and are subject to magnetic saturation effects that limit the range of currents that they can measure. A Rogowski coil, on the other hand, is 'linear'; it does not saturate and the mutual inductance between the coil and the conductor is independent of the current. Many of the useful features of Rogowski coil systems result from their linearity.

1. They have a wide dynamic range so that the same coil can be used to measure both very small and very large currents.
2. Calibration is easier because the coil may be calibrated at any convenient current level and the calibration will be accurate for all currents including very large ones.

INSTALLATION: The coil is fitted by sliding it over the conductor. For best accuracy it should preferably be centred on the conductor although off-centre operation results in only a minimal reduction in accuracy. If it is not possible to disconnect the conductor to fit the coil a 'split ' version of the coil is available. The coil is not as heavy as a conventional current transformer and in most cases a simpler mounting arrangement is possible.

The output of the coil is along a cable attached to the coil which can be several metres long if necessary.

It is not recommended that coils are installed or removed from conductors that can carry dangerous voltages whilst they are live.

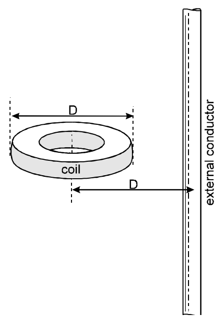
COIL CALIBRATION: The coil calibration is defined by its mutual inductance. Coils that are supplied without integrators are individually calibrated and the calibration values can be provided to the user. The calibrations are done to an accuracy better than 0.1% using a mutual inductance bridge designed by Rocoil especially for use with Rogowski Coils. Typical mutual inductance values are given in the table. Exact values cannot be guaranteed and for a batch of coils made at the same time there could be a spread in mutual inductances of about 1%.

NOTE: The mutual inductance is for a coil working into a high impedance. If a load resistance is fitted across the coil the 'effective' mutual inductance will be reduced because the load resistance and the coil resistance form a potential divider.

CONNECTIONS: The coils are connected to the integrator by a 'twinax' cable (twisted pair with overall screen) which is permanently attached to the coil. The cable normally fitted is sheathed in a single layer of PVC. The standard cable length is 2m but the length can be at least 100m if required. One disadvantage of using a long cable length is that the extra capacitance of the cable can affect the high-frequency performance of the coil. This is not normally a problem for measurements at power frequencies.

INSULATION: Coils are normally insulated in a double layer of polyester tape with an outer layer of black rayon tape. Although this provides a good level of insulation no claims are made about the ability of the coils to be used on uninsulated conductors which carry dangerous voltages. **Additional insulation should be used with conductors carrying dangerous voltages.**

INFLUENCE OF EXTERNAL MAGNETIC FIELDS: We test the coils for pick up of external magnetic fields by placing them close to a current-carrying conductor. Real magnetic fields have a very complex geometry and the best we can do is to choose two orthogonal positions in relation to the conductor, ie with the conductor perpendicular to the plane of the coil, as in the illustration, and with it parallel to the plane of the coil. For each position the coil is rotated to determine the pick-up at different angular positions of the coil.



These tests are carried out on each coil at several stages during its construction. The information is used to make small adjustments to the winding to 'fine-tune' it for minimum pick-up. After the winding has been adjusted satisfactorily it is fixed in place with a conformal lacquer which is baked on. For coils at the 'standard' distance shown in the figure the pick-up for any orientation of the coil is less than 0.1% compared with the output of the coil if it was mounted round the conductor.

INFLUENCE OF CONDUCTOR POSITION: If the conductor is moved from the central position by a distance equal to 0.5 x the inner coil radius the output will change by less than 0.1%.

PHASING: If two coils are being used for current summing they should be mounted in the same sense (i.e. with both the output leads coming off clockwise or both anti-clockwise) and the outputs will then add. If the coils are mounted in the opposite sense the outputs will subtract.

FREQUENCY RESPONSE:
Low Frequencies: The low-frequency performance is determined by the design of the integrator. With a suitable integrator the rigid coils can be used to measure at frequencies below 0.2Hz (-3dB).

High Frequencies: The upper frequency limit depends on the resonance properties of the coil. and the length of the output lead. For rigid coils resonant frequencies are in the range from about 20 - 95kHz depending on the size of the coil with smaller coils having the higher resonant frequency. To get the flattest frequency response the coil must be terminated with a resistor of the correct value to damp out self-resonance effects. With a correctly-damped coil the frequency response will roll-off to -3dB at about the same frequency as the resonant frequency.

EFFECT OF TEMPERATURE ON THE COIL OUTPUT: The effect of a temperature rise is to cause the coil former to expand which increases the mutual inductance. However, a temperature rise also causes the resistance of the winding to increase.

When the coil is used with an integrator the increase in resistance will cause the output of the integrator to be reduced. With careful design the expansion effect and the resistance effect can be made to cancel each other out giving a temperature variation which is essentially zero over a wide temperature range. This requires the integrator to have the correct input impedance.

TEMPERATURE RESPONSE VS. FREQUENCY RESPONSE: As described above coils can be optimised to have either very low temperature coefficient or have a flat frequency response depending on the impedance used to terminate the coil output. Unfortunately the resistor values needed to satisfy the two criteria are widely different. A coil which is terminated to have a flat frequency response will have a large temperature coefficient and vice-versa. The following tables give approximate figures for two coil types, SX-76 (small coil) and SX-150 (large coil) for illustration.

Coils Optimised for Flat Frequency Response

coil type	frequency for 1% variation	temperature coefficient
SX-76	34kHz	0.018%/°C
SX-150	15kHz	0.029%/°C

Coils Optimised for Flat Temperature Response

coil type	frequency for 1% variation	temperature coefficient
SX-76	8kHz	<0.001%/°C
SX-150	4kHz	<0.002%/°C

For systems where 0.1% accuracy is important the constant-frequency option may not be practicable because the output of the coil changes by more than 0.1% for a small temperature rise of only a few degrees.

TEMPERATURE OF OPERATION: There is not much practical experience of high-temperature operation of these coils. The coils are heat treated at 70°C during manufacture so it is assumed that they should survive operation at this temperature.

SPLIT COILS: All the coil sizes can be manufactured in split form to enable them to be installed without breaking the conductor. Split coils have similar stability and good rejection of external magnetic fields provided that they are fitted carefully and that the mating surfaces are free of contaminants that can cause misalignment.

Rogowski Coils are much less sensitive to misalignment than conventional split current transformers. With an SX-76 coil, for example, a gap error of 0.3mm would introduce an output error of less than 0.1%. The phase is not affected even by a much larger gap.

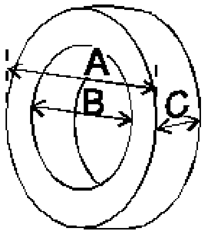
PRODUCT DESCRIPTION: Except for some special constructions the 2100 series of rigid coils all have the same winding cross-section which is a 'barrel -shaped' cross-section 22 x 38mm with rounded corners and edges. This gives a maximum cross-section but ensures that the winding remains accurately in contact with the surface of the former.

The coils are defined by the inner diameter of the finished coil. Thus 2100/147 has an inner diameter of 147mm. For historical reasons the coils are often referred to by the former dimensions. For example SX-150 refers to '**S**tandard **X**-section, **150**mm ID' which is, effectively, a 2100/147. In addition each coil is given a unique serial number which also begins with S + (another letter) + (a number).

The following table lists the coil sizes we have supplied so far.

Coil Type	Former size	A (mm)	B (mm)	C (mm)	Mutual ind. (μH)	Volts/kA @50Hz	Resistance (Ω)	Resonant frequency
2100/73	SX-76	122	73	42	3.14	0.99	45	78kHz
2100/97	SX-100	146	97	42	3.25	1.02	62	64kHz
2100/117	SX-120	166	117	42	3.40	1.07	73	no data
2100/147	SX-150	196	147	42	3.50	1.10	92	59kHz
2100/167	SX-170	216	167	42	3.60	1.13	109	41kHz
2100/197	SX-200	246	197	42	3.61	1.13	123	41kHz
2100/217	SX-220	266	217	42	3.61	1.13	133	no data

NOTE: The Mutual Inductance, Resistance and Resonant Frequency data are approximate and will vary for individual coils of the same nominal design. The resonant frequency also depends on the length of the coil output lead. The values given in the table are for an output lead length of 2m. For a longer lead the resonant frequency will be lower.



THE ROGOWSKI COIL PRINCIPLE

The coil is an ‘air cored’ toroidal winding placed round the conductor such that the alternating magnetic field produced by the current induces a voltage in the coil. The coil is effectively a mutual inductor coupled to the conductor being measured and the voltage output direct from the coil is proportional to the rate of change of current. The special design of the coil ensures that its output is not influenced significantly if the conductor is positioned ‘off-centre’. The design also ensures that the influence from currents and magnetic fields external to the coil is minimal.

To complete the transducer the coil output voltage is integrated electronically to provide an output that reproduces the current wave-form. This combination of coil and integrator provides a system where the output is independent of frequency, which has an accurate phase response and which can measure complex current wave-forms. By varying the integration parameters (C and R) the sensitivity of the complete measuring system, measured in Amperes per Volt, can be varied over about five orders of magnitude. The output from the integrator can be used with any form of high-impedance electronic indicating device such as a voltmeter, oscilloscope, protection system or metering equipment.