Rocoil®
PRECISION ROGOWSKI COILS

THE 7000 SERIES ROGOWSKI COIL INTEGRATORS

FEATURES

- Three channel or single-channel integrator.
- Internal rechargeable battery.
- Powered from either 230V or 120V mains supply.
- Can measure up to hundreds of kA.
- Sensitivity can be specified by the user.
- Switch selection of up to four sensitivity values.
- Input and output protection against surges.
- Excellent low frequency response.
- Bandwidth to greater than 60kHz.
- Withstands very large overloads for an indefinite time.
- Sensing coils can be replaced without the need for recalibration.
- Flexible Rogowski coils can be fitted without 'breaking' the conductor.
- True RMS, Channel Summing and Overload Indication available as special options.

1. INTRODUCTION

The **Rocoil**® 7000 series integrators can be used in conjunction with both flexible and rigid Rogowski coils to provide accurate current measurement over a range from less than 1 amp to over 1 million amps in a compact and portable measuring system which is simple to use. Type 7000 integrators are available in single-channel and three-channel versions

The Rogowski coil sensors provide complete isolation from the circuit being measured and have no effect on the current even for very low-impedance circuits. The output from the integrator is a voltage wave-form which accurately reproduces the current wave-form. This includes complex wave-forms, which have a high harmonic content, and transients.

The measuring system cannot be harmed by current overloads. Also, unlike a current transformer there is no danger from high voltages if the output from the coil is open-circuited.

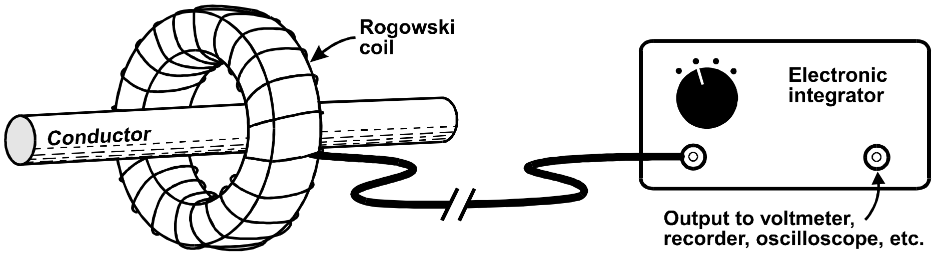
There are other devices that measure electric current without making electrical contact with the conductor. Many of these, including the conventional current transformer, use a ferromagnetic core and are subject to magnetic saturation effects that limit the range of currents that they can measure. A 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.
3. They respond accurately to transient currents, including asymmetrical transients which makes them an excellent choice for use in protection systems and for measuring current pulses.

2. 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 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 electronic indicating device such as a voltmeter, oscilloscope, protection system or metering equipment.



3. COIL SENSORS (Rogowski Coils)

Two types of Rogowski coil sensors are available; Flexible coils and Rigid coils.

3.1 Flexible Coils (for example Type 1000 series, Type 4022): Flexible Rogowski coils can be used for measuring electric current in large or awkwardly-shaped conductors, where space round the conductor is limited, for high frequency measurements in excess of 20kHz and for the measurement of very large currents.

Flexible coils are suitable for measurements requiring an accuracy of about 1%.

The coil is fitted by wrapping it round the conductor to be measured and bringing the ends together. The ends are fitted with a locating system to ensure that they are aligned correctly. Electrical connection to the coil is at one end only. The other end is 'free' to be threaded round awkwardly-shaped conductors or conductors in confined spaces.

It is not necessary to mount the coil so that it is circular nor is it necessary to have the conductor exactly in the centre of the loop. Off-centre operation does not normally introduce errors of more than I - 2%. If the coil is long enough it can be wrapped more than once round the conductor provided the ends are brought together correctly. The output is proportional to the number of wraps.

3.2 Rigid Coils (type 2100): Rigid Rogowski coils have a greater accuracy and stability than flexible coils and excellent rejection of interference caused by external magnetic fields. They are more suitable for low current and low frequency operation than flexible coils.

3.3 Phasing: If several coils are being used they should be mounted in the same sense (i.e. with all the output leads coming off all clockwise or all anticlockwise) and the outputs will then be in phase.

3.4 Insulation: Unless otherwise specified it should not be assumed that the coils are insulated against high voltages. Additional insulation should be used with conductors carrying dangerous voltages.

3.5 Interchangeable Coils: Some systems are provided with interchangeable coils. This means that any coil can be plugged into any input of the integrator. Coils can be replaced if they become damaged or they can be changed for coils of a different length without the need to re-calibrate the whole system. Integrators are marked to indicate the interchangeable system being used (e.g. '820R') and the coils are also marked, usually at the connector. Interchangeable coils are sometimes colour coded red, yellow, blue. This is just for convenience and it is not essential for a coil to be plugged into the matching colour input of the integrator.

The interchangeable system used depends mainly on the length of the output lead between the coil and the integrator including any extension leads. The system number is 820R for lead lengths up to 5m, 430R for lengths 5 - 30m and 270R for lengths greater than 30m. The system number refers to the input impedance of the integrator.

4. INTEGRATOR POWER SUPPLY

4.1 Description: The instrument is driven from a mains supply with battery back-up. A linear supply is used rather than a switch-mode type to minimise circuit noise. There is a switch on the rear panel to select between nominal 230V and nominal 120 V mains supplies. The mains supply is connected via an IEC connector at the rear. When the integrator is connected to the mains a green LED lights on the front panel and battery charging starts automatically. There is no switch on the integrator to turn off the mains.

The integrator is turned on by a switch on the rear panel. When the integrator is switched on a red LED lights on the front panel. The integrator automatically selects between battery power or mains power depending on which supply gives the higher voltage.

4.2 Power Supply Specification

Mains input: 120 or 240V, 50/60Hz: Mains voltage is selected by a switch on the rear panel.

Battery: NiMH 12V / 1600mAH
Battery Charge Time: 24 hours approximately.

Battery life: The table gives typical battery life for a fully charged battery in good condition (Serial IG-1186 onwards)

Integrator Type	Single Channel	Three Channel
Standard	100 hours	40 hours

Where additional options are fitted (RMS, overload indication, sum output) the battery life will be shortened.

Low Battery Indicator: The red LED indicating that the integrator is on will start to flash when the battery charge is low. The low-battery indication is only reliable when the mains supply is not connected.

5 INTEGRATOR PERFORMANCE

5.1 Description The integrator converts the output from the coil to a voltage which accurately reproduces the current wave-form. Sensitivity is defined in Amperes/Volt (A/V) and is selected by a switch on the front panel. The current is equal to the instantaneous voltage at the output multiplied by the A/V value. For example at 100A/V a 1V output means an instantaneous current of 100A . This is the same as if the measurement were made using a 10mΩ shunt only there is no direct connection with the circuit being measured and the system does not respond down to DC.

For some coil/integrator combinations each coil is 'dedicated' to a particular integrator channel. In this case the coil inputs are colour coded and the serial numbers of the coils to be used with that particular integrator are given on a label at the back of the integrator. In most cases, however the coils are interchangeable so that any coil can be used with any integrator. This means that a coil or integrator can be replaced without the need for re-calibrating the whole system. (Section 3.5)

5.2 Specification

(i) Output Voltage (AC Output): 1V output for the nominal sensitivity.

(ii) Overload Capability: When the instrument is mains powered the output is linear up to at least 10 x the nominal sensitivity and 9 x on a fully-charged battery. (Note: this refers to the peak current not the RMS). At the end of the battery life as defined in the table above the peak overload capability will be about 8 x nominal sensitivity.

(iii) Noise: Typically less than 1mV peak to peak referred to the output. For example at 100A/V, the noise is equivalent to less than 100mA p/p. On high-sensitivity versions (e.g with a 10 A range) there may be a low-frequency noise component that exceeds 1mV.

(iv) Output Impedance: 51 ohms. For best accuracy the integrator should be used with high-impedance recording / monitoring equipment having an input impedance preferably greater than 50kΩ.

(v) Measurement accuracy: For flexible coils ±1%. For rigid coils ±0.1%

(vi) Effect of Temperature on Accuracy: The output is affected by both the temperature of the coil and the temperature of the integrator. These are considered separately.

The temperature coefficient due to the coil depends on the type of coil used and on the input impedance of the integrator (see section 3.5) and it is impossible to give an accurate general figure for this. A typical value is -0.05% /°C. Long flexible coils and low input impedance give the largest temperature coefficients.

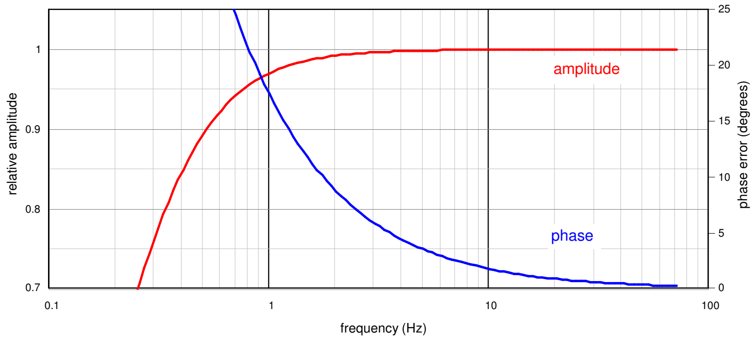
With rigid coils there is an option to design either for best frequency response or best temperature response. Contact Rocoil for further details.

A typical temperature coefficient for an integrator is < 0.01%/°C . The integrator can become quite warm when the battery is charging. For best accuracy the integrator should be used battery powered.

(vii) Frequency Response (Standard Version): Stated accuracy applies in the range 20Hz to 2kHz

(viii) High frequency -3dB point (Standard Version): Typically 30kHz for rigid coils and >60kHz for flexible coils. The high-frequency roll-off will be at a lower frequency for long flexible coils and with long output leads.

(ix) Low frequency -3dB point (Standard Version): Typically less than 1Hz. A typical low-frequency response curve is shown in the figure.
For integrators which have a 'sensitive' range (e.g. 10A/V) the response will not extend to such low frequencies.



One consequence of the limited low frequency response is 'droop' which occurs with some asymmetric transient wave-forms. See the appendix for more information about droop

(x) Earthing: The output of the integrator is earthed to the metal case of the integrator. If the integrator is connected to the mains the output will be earthed to the local mains earth. If the equipment used to monitor the output is some distance away there could be an earth conflict if the input to the monitoring equipment is also earthed. Ideally the measurement system should be arranged so that it is earthed in only one place. If the integrator is earthed through the mains lead it may be necessary to use monitoring equipment with differential inputs. Alternatively, if the input to the monitoring equipment is earthed it may be necessary to use the integrator battery powered.

6 INTEGRATOR OPTIONS

A number of options is offered in addition to the standard design

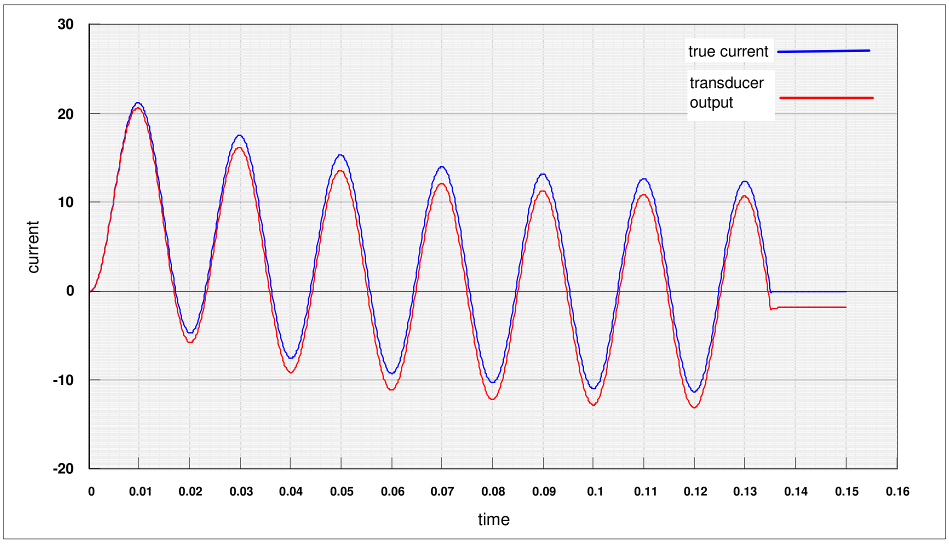
6.1 RMS Output: An additional output for each channel equal to the true RMS value of the AC output.

6.2 Overload Indication: An indicator for each channel which shows when the output voltage is close to the maximum for the integrator. With a transient overload the light will remain on for about 1 second.

6.3 Summing Option: An output at the rear of the integrator which provides an instantaneous sum of the three outputs. Each channel has a sum switch which can be set to +, 0, or - depending on whether the channel output is to be added to the sum, not included in the sum or subtracted from the sum.

APPENDIX: Dealing With Droop.

The figure shows an example of a wave-form that shows the droop effect. This is a calculated wave-form. The blue trace is the true current, the red trace is the wave-form measured using the Rogowski coil transducer. The most obvious feature on the measured wave-form is that the output of the integrator is non-zero at the end of the transient.



The amount of droop is determined by the integrator time constants. The example given above was calculated for time constants T1 = 0.2s, T2 = 1.0s which is typical for a system having a 10A/V range using flexible coils. With rigid coils or with less sensitive ranges the time constants can be made longer and the droop will be smaller. However, if the time constants are made too long there is the disadvantage that the integrator takes a long time to settle when it is switched on and the output becomes more noisy with low frequency components but it may be useful in some situations.

The droop effect is not only a problem with Rogowski coil transducers. It will occur with any 'AC only' current measuring equipment including current transformers. The advantage of Rogowski Coil transducers is that the droop can be predicted accurately and compensated for.

It is also possible to apply a simple algorithm to the recorded wave-form to remove the droop. The low-frequency response is characterised by two time constants. The algorithm makes use of the known time constants of the integrator and is very accurate. More information about this technique can be obtained from Rocoil.