DATA SHEET

General
Rotational speed measurement

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Philips
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PHILIPS

ROTATIONAL SPEED MEASUREMENT

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Principles and standard set-ups

The basic properties of the magnetoresistive technique make it highly suitable for measuring the rotational or angular speed of an object:

- It offers high sensitivity (about 10 to 100 times stronger than the Hall effect), which allows large air gaps (>2.5 mm) to be used between the target and sensor, and produces strong primary signals, making the sensing set-up largely insensitive to disturbances.
- It has a very wide operating frequency range (DC up to >1 MHz), with the sensor still producing a signal down to 0 Hz, allowing its use in very low speed applications (e.g. in car navigation systems).
- As the sensors are metal-based, they can operate up to 190 °C, making them extremely well suited to high temperature situations. These are commonly found in automotive applications such as in braking systems and under the car bonnet, near the engine (cam and crankshaft speed measurement, for example).
- Magnetoresistive sensors are highly insensitive to mechanical stress in comparison to Hall effect sensors, due to the relatively small piezoresistive effect in the permalloy material, so they can be encapsulated simply and cost-effectively.

Since the magnetoresistive effect cannot measure rotational speed directly, a practical set-up uses a magnetic field applied to the sensor from a permanent magnet. Typically, this 'back-biasing' magnet is simply glued to the back of the sensor, so that the sensor sees a uniform parallel field with no component in the sensitive direction and sensor output is zero. Then, if a ferromagnetic target with teeth is brought close to the sensor, the field of the back-biasing magnet is affected by the target and the influence depends on the position of the target in front of the sensor (see Fig.1).

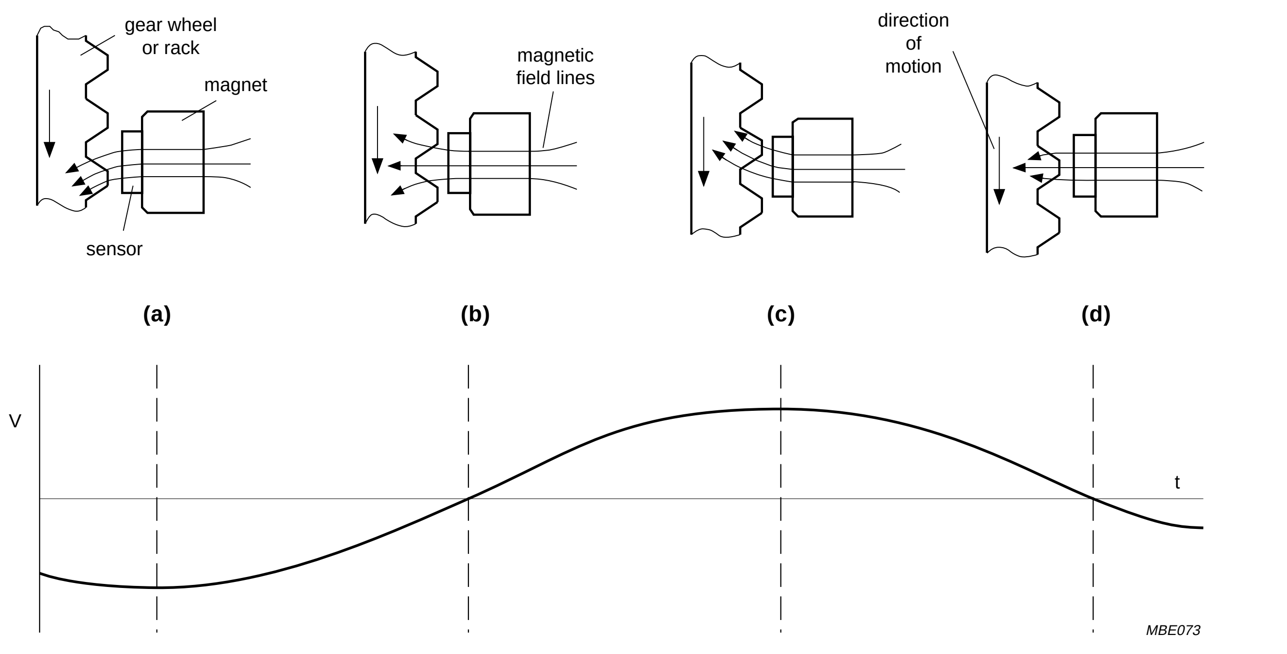


Fig.1 Speed detection using a magnetoresistive sensor.

At a ‘symmetric’ position, where a tooth or valley is exactly in front of the sensor, the target has no effect on the field seen by the sensor, so the sensor still gives a zero output. For a ‘non-symmetric’ position, as the target rotates in front of the target, the effect and thus the amplitude of the sensor output varies according to the actual wheel position.

The peak value of the output, V_{peak}, depends on the magnetic field strength of the biasing magnet, the distance between the sensor and the target and, obviously, the structure of the target. Large, solid targets will give stronger signals at larger distances from the sensor than small targets. In general, the ‘size’ of the structure in this application can be described as a relationship between wheel diameter and the number of teeth, described in Table 1.

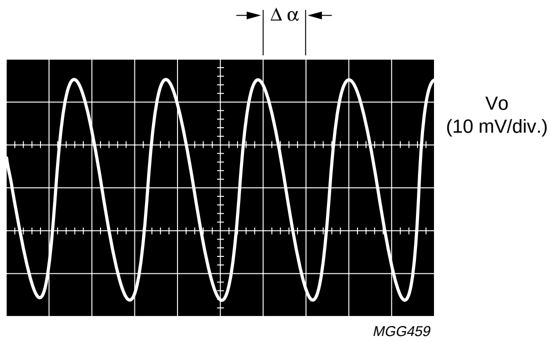


Fig.2 Typical oscilloscope trace for rotational speed measurement.

Table 1 Gear wheel dimensions (see Fig.3)

SYMBOL	DESCRIPTION	UNIT
German DIN		
z	number of teeth	
d	diameter	mm
m	module m = d/z	mm
p	pitch p = π • m	mm
ASA(1)		
PD	pitch diameter (d in inches)	inch
DP	diametric pitch DP = z/PD	$inch^{-1}$
CP	circular pitch CP = π /DP	inch

Note

1. For conversion from ASA to DIN: m = 25.4 mm/DP; p = 25.4 × CP.

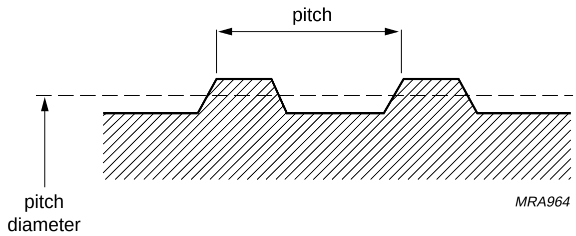


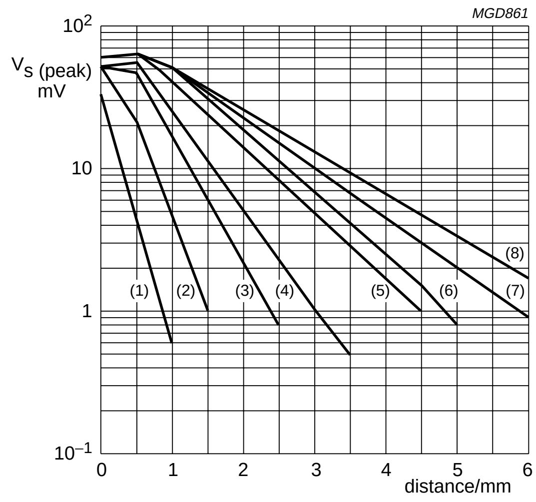
Fig.3 Gear wheel dimensions.

Figure 4 shows a typical relationship between the primary output signal (i.e. with no signal conditioning electronics) of a KMZ10B sensor (with a back biasing magnet) and various target structures, with module ‘m’.

This principle is for so-called ‘passive’ ferrous targets, where the target is not itself magnetized (see Fig.5).

MR sensors are naturally bi-stable devices, with two stable but opposite operating characteristics, so they also need an external magnetic field for stabilization. With a suitably magnetized magnet positioned correctly, a single magnet can perform both stabilization and back-biasing. (For more details on sensor stabilization, please refer to the General Introduction to this handbook and Appendix 2.)

’Active’ targets can also be used, where the target has alternating magnetic poles. In this case, the target itself provides the ‘working’ field, so no back-biasing magnet is required, only a stabilization magnet, which can be smaller than the ones used for both stabilization and back-biasing with passive targets. Also, it should be noted that an active target need not have teeth. An ‘active’ set-up is shown in Fig.6.



(1) m = 0.5; (2) m = 0.75; (3) m = 1; (4) m = 1.25;
(5) m = 2; (6) m = 2.5; (7) m = 3; (8) m = 4.

Fig.4 Typical relationship between the airgap of a KMZ10B sensor, with a back biasing magnet (8 mm x 8 mm x 4.35 m, used eg for KMI15/1), and target module, ‘m’.

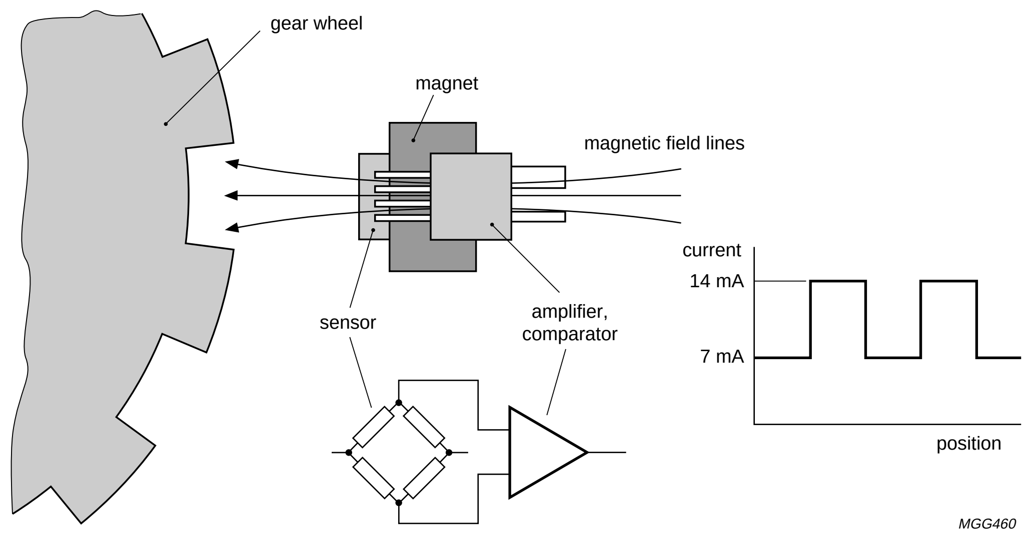


Fig.5 Simple set-up using a passive target.

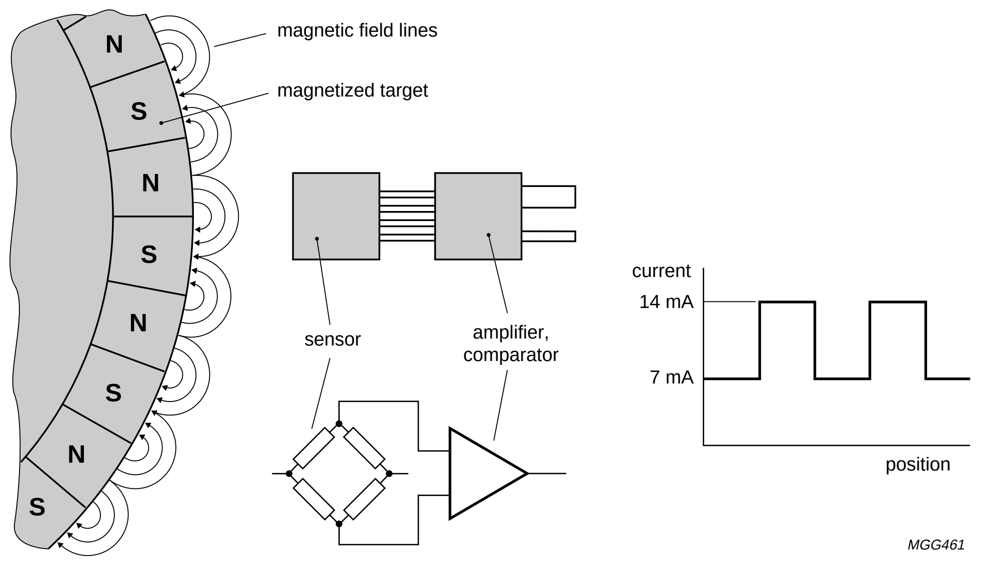


Fig.6 Simple set-up using an active target.

The structure of an active target can be expressed similarly to that for passive targets (Table 1). In this case, a tooth/valley pair is represented by a North-South magnetic pole pair. Figure 7 shows a typical relationship between the primary output signal (i.e. with no signal conditioning electronics) of a KM110B/2 sensor and various active target structures, with module ‘m’.

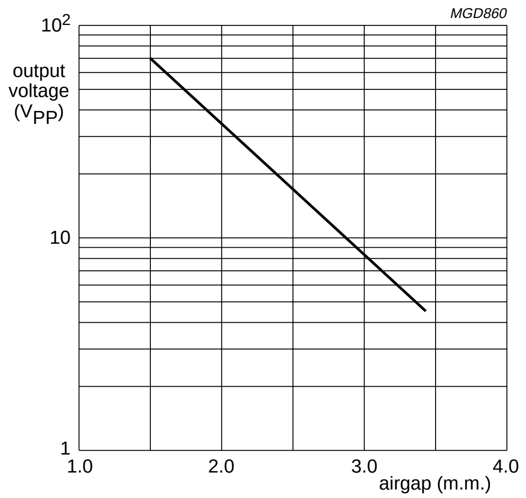


Fig.7 Typical relationship between the airgap of a KM110B/2 sensor and active target module, ‘m’.

Both measurement techniques are inherently accurate, as the frequency of the output is directly proportional to the rotational speed. Although in principle, for a basic application requiring minimal accuracy, the output from the sensor can be used directly, in practice the use of signal conditioning circuitry stabilizes the output from the sensor and ensures accurate speed measurement under varying environmental conditions. Typical conditioning includes EMC filtering, amplification, temperature compensation and switching hysteresis.

Philips’ sensors for rotational speed measurement

Practical rotational speed sensors are always delivered complete with a back biasing magnet, with the signal conditioning circuitry contained in a separate IC, for both active and passive set-ups. To simplify system design, Philips has developed a series of ready to use sensors, the KMI15/X family, which comprises a magnetoresistive sensor (an adapted version of the KMZ10B), a ferrite back-biasing magnet and an advanced bipolar signal conditioning IC, mounted on a single lead frame. The three sensors in the family are the KMI15/1 and KMI15/4 for passive targets, and the KMI15/2 for active targets.

For passive set-ups, the magnets are specially designed to apply a symmetrical magnetic field in the y-z plane of the sensor and a field at 30° relative to the z-axis in the x-z plane. The symmetrical field in the y-z plane (Figs 9 and 10) provides the back-biasing and the component in the x-direction of the sensor plane stabilizes the magnetoresistive element, as described earlier.

For active set-ups, the KMI15/2 comes with a small stabilization magnet (see Fig.11) and needs no back-biasing (the operational field being supplied by the target itself).

These sensors provide a compact design and cost-effective customization possibilities and, as they are simple to design-in, time-to-market is significantly reduced. In addition to the advantages described earlier, these sensors are almost immune to vibration effects (an inherent property of the magnetoresistive effect), can be used with a large variety of gear-tooth structures, are EMC resistant and offer a digital current output signal. The two-wire digital current signal has the advantages of considerably reduced wiring and connections, which can actually be a more significant cost than that of the sensor itself. The IC and sensor are separated physically within the encapsulation, to optimize the KMI15’s high temperature performance (so that the sensor can then be exposed to higher temperatures than the IC and the power dissipation of the IC will not cause inhomogeneous heating of the sensor element).

In the signal conditioning circuit, the sensor output signal is passed through an EMC filter, amplified and then digitized by a comparator which has built-in switching hysteresis, performed by a Schmitt trigger (for more details, refer to the section on switching hysteresis). The voltage control block provides a stabilized 5 V power supply for the sensor, amplifier and comparator and is itself stabilized by a bandgap reference diode.

KMI sensors were developed as magnetoresistive devices with a current output, which has the advantage of using low cost two-wire technology. They use two current sources, integrated into the signal conditioning IC: one supplies a base current output of 7 mA (partly used for the 5 V supply) and a second, switchable 7 mA current source is added when triggered by the amplified and digitized sensor output signal. Thus, during operation the output current, I_{CC}, switches between 7 mA and 14 mA (see Fig.8). A set-up providing a three-wire voltage output is described later and an integrated sensor with three-wire open collector output is under development.

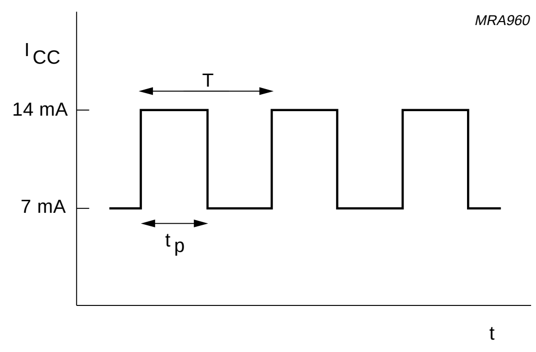


Fig.8 Current output signal.

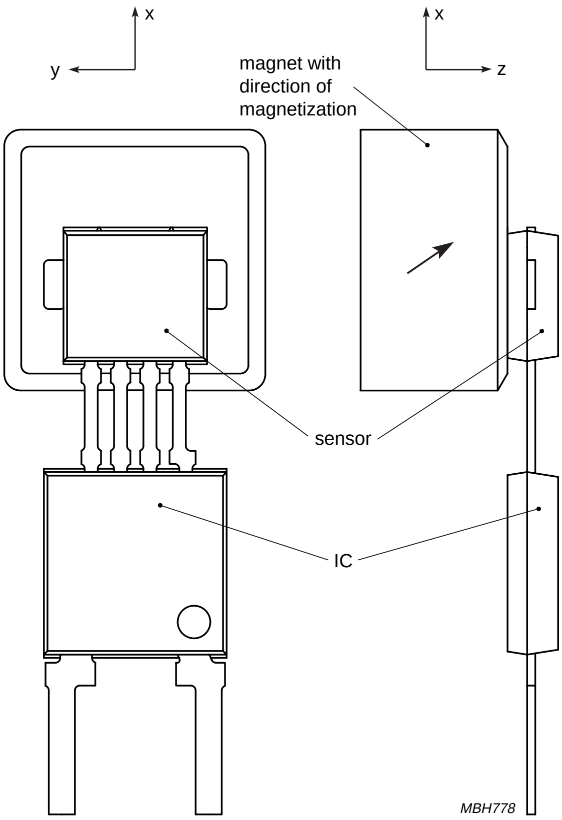


Fig.9 Typical outline of a KMI15/1 rotational sensor module for passive targets.

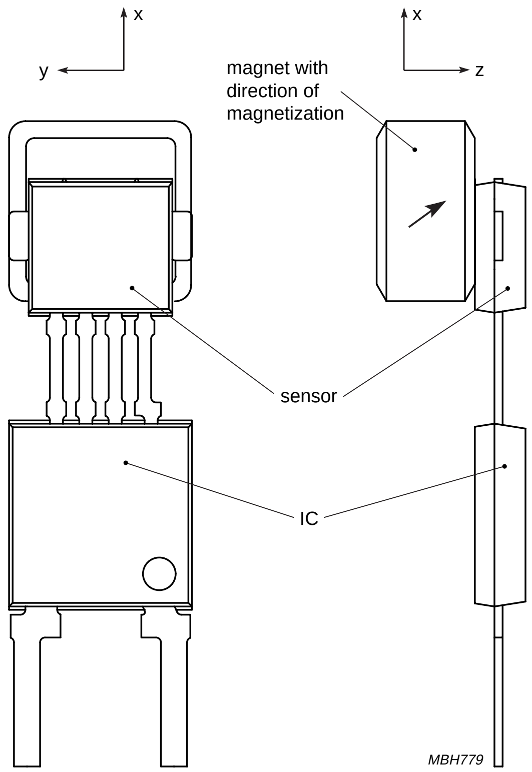


Fig.10 Typical outline of a KMI15/4 rotational sensor module for passive targets.

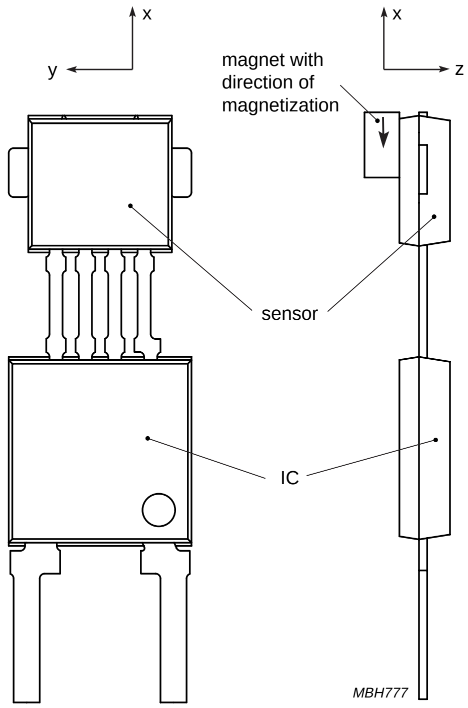


Fig.11 Typical outline of a KMI15/2 rotational sensor module for active targets.

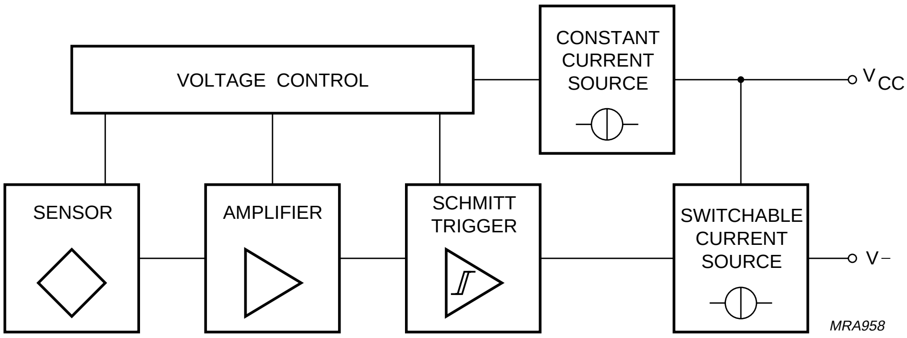


Fig.12 Block diagram of sensor and signal conditioning circuitry.

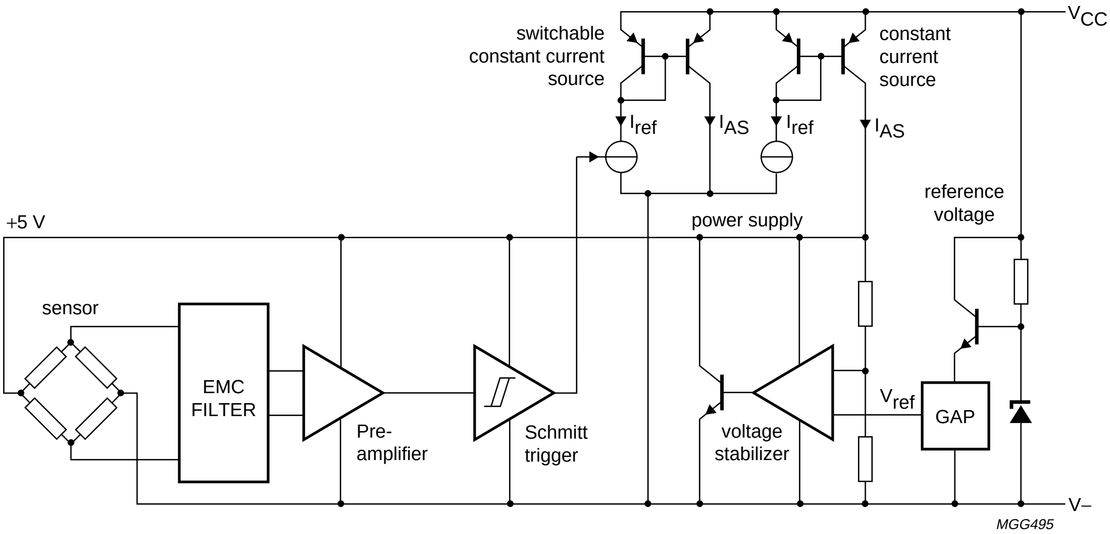


Fig.13 Sensor signal conditioning circuit diagram.

SENSING DISTANCE AND MOUNTING

Sensing distance ‘d’ is defined as the distance between the front of the sensor and the tips of the teeth, measured on the central axis of the magnet (see Fig.14). Above a certain value of ‘d’, I_{CC} ceases to vary between 7 mA and 14 mA and becomes a constant 7 mA. The KMI15 sensors are optimized to deliver a stable digital output signal for a large range of ‘d’ values and have a large switching hysteresis, to avoid unwanted signals arising through vibrations. Variations due to temperature are compensated by the signal conditioning IC; the residual temperature effect is shown in Fig.15.

Movements of the ferromagnetic target wheel in the magnetic field of the sensor system will induce eddy currents in the wheel, generating an offset voltage in the sensor’s output which increases linearly with rotational speed. This reduces the maximum sensing distance slightly at higher frequencies, since this offset is in addition to the static offset, so the available voltage from the switching hysteresis (set to ±3 mV) is reduced, decreasing the maximum airgap at which the sensor operates (switching hysteresis is described in more detail later in this chapter). (Eddy currents can also be used to positive effect in some applications: see the Section on “Information for advanced users and applications” later in this chapter.) Finally, the structure of the wheel itself will affect maximum sensing distance, according to how large and well-defined the teeth are. Figure 16 shows the variation of the maximum distance of ‘d’ with tooth module for a KMI15/1.

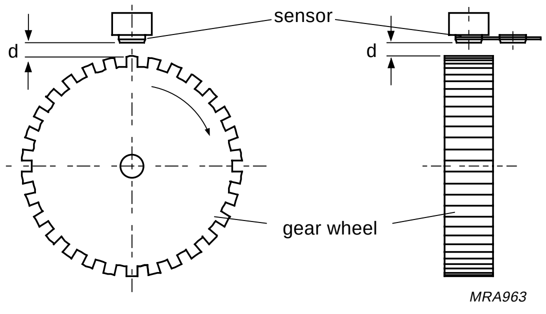


Fig.14 Sensor positioning.

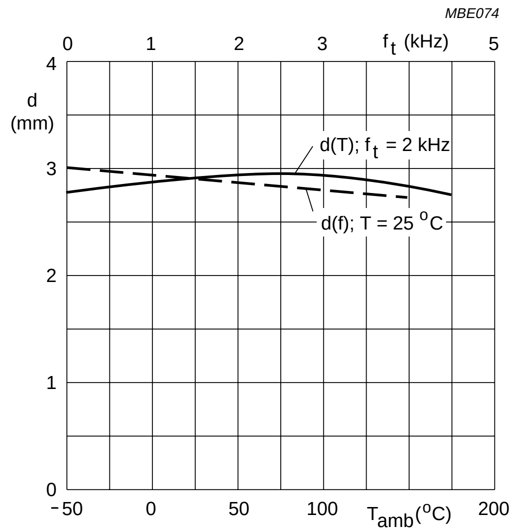


Fig.15 Maximum sensing distance of the KMI15/1 as a function of temperature and tooth frequency.

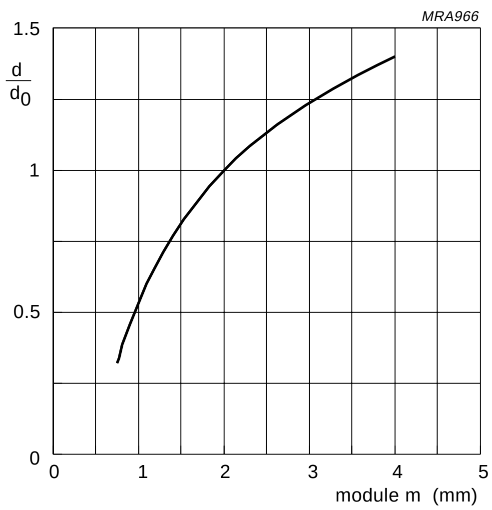


Fig.16 Normalized maximum sensing distance as a function of wheel module.

When mounting the KMI15, there are two important factors to take into consideration:

- The angle between the symmetry axes of the sensor and wheel (in the y-z plane)
- The horizontal shift ‘y’ relative to the optimum sensor position.

Both of these values should be minimized. Recommended tolerances for optimal operating conditions are $|\Theta| < 1°$ and $|y| < 0.5$ mm. Their effect is shown in Figs 17 and 18.

A shift in position in the x-direction is not very critical to the KMI15’s performance, but the magnet’s field component in the x-direction means that an x-shift produces non-symmetrical behaviour (see Fig.19). The optimum position is when x = 0; x should in any case be minimized, especially for small values of ‘d’. A tilt in the x-z plane has negligible influence on the optimum sensing distance for angles <4°.

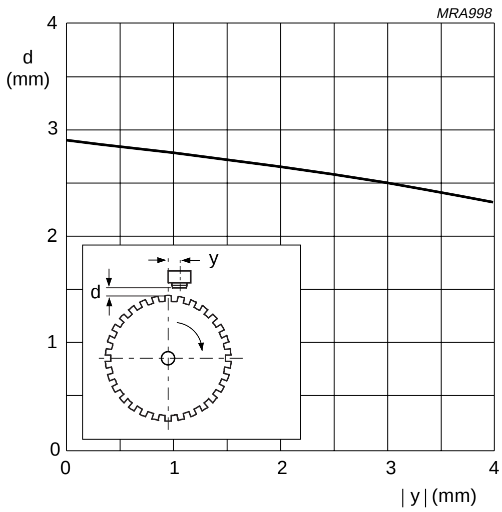


Fig.17 Influence of position tolerance ‘|y|’ on maximum sensing distance ‘d’ for KMI15/1.

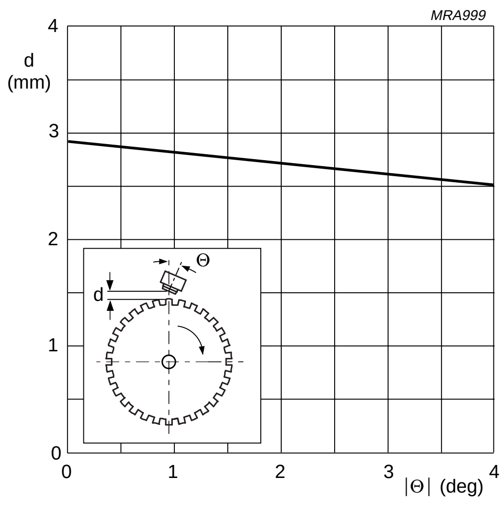


Fig.18 Influence of angular tolerance ‘|Θ|’ on maximum sensing distance ‘d’ for KMI15/1.

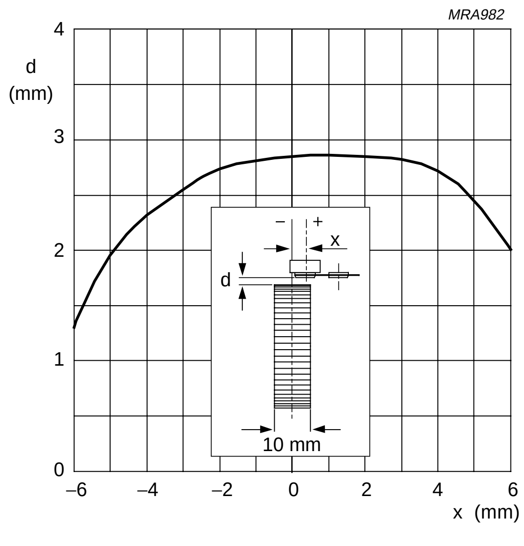


Fig.19 Influence of position tolerance ‘|x|’ on maximum sensing distance ‘d’ for KMI15/1.

SWITCHING HYSTERESIS

Switching hysteresis is included in the signal conditioning circuitry, to prevent unwanted electrical switching of the KMI15 due to:

- Mechanical vibration of the sensor or the gear wheel
- Electrical interference (EMC)
- Circuit oscillation at very low rotational speeds.

Larger hysteresis provides better immunity to disturbances but also reduces sensing distance ‘d’, so a compromise is required between hysteresis and sensing distance. The KMI15 sensors have a hysteresis set to ±3 mV and so the maximum attainable distance ‘d’ will be achieved with a sensor signal level of 6 mV peak-to-peak. Figure 4 shows typical KMZ10B sensor output signal values, with back-biasing magnet), with different target wheel modules and shows clearly that the hysteresis directly determines the usable airgap.

For the KMI15/1, the maximum distance ‘d’ is always >2.5 mm and is typically up to 2.9 mm; for the KMI15/4, the maximum distance ‘d’ is >2.0 mm and is typically 2.3 mm (m = 2 mm).

A hysteresis test set-up is shown in Fig.20, together with its test results as a function of distance. This set-up allows simple testing of products and there is a direct correlation between the test results obtained and the equivalent properties of the most commonly-used gear wheels. In the case of a gear wheel with m = 2 mm and a sensor with d = 1.5 mm, expressed in terms of linear movement of a gear tooth the hysteresis corresponds to 0.3 mm. If the gear wheel diameter is 100 mm, this hysteresis is equivalent to a 0.32° ∞rotation. Obviously, these figures will be different for different gear wheels.

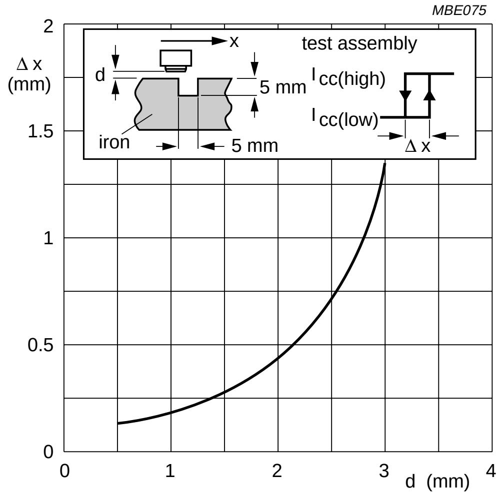


Fig.20 Mechanically measured hysteresis ‘x’ of the KMI15 as a function of sensing distance ‘d’ for the test assembly shown.

CHARACTERISTICS OF THE KMI15/X

To determine sensor characteristics in an actual application, the KMI15/4 was used to measure the rotation of a toothed wheel (m α 0.8).

Sensor output

For these measurements, the output signal of the sensor (KMZ10B with a back biasing magnet) was measured with the sensor placed at a distance of 0.5 mm from the wheel, with no signal conditioning. Figure 21 shows the oscilloscope trace obtained from one full revolution of the wheel and the points where the signal shows a peak correspond to missing teeth, due to an effective change in wheel module at these points. Such a well defined trace at the teeth ‘holes’ demonstrates the intrinsic high sensitivity of the sensor and shows that as well as being able to measure the speed of the wheel, it can also be used to indicate reference marks such as missing teeth (e.g. crankshaft applications) or irregular target structures (e.g. camshaft applications).

Maximum air gap

To be able to define the maximum air gap for a given sensor, it is first necessary to know how the behaviour of the sensor signal changes with measuring distance.

The peak voltage of the output signal, again with no signal conditioning, is shown in Fig.22.

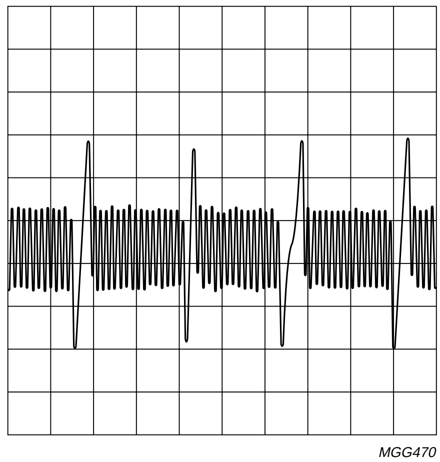


Fig.21 Sensor signal over one revolution.

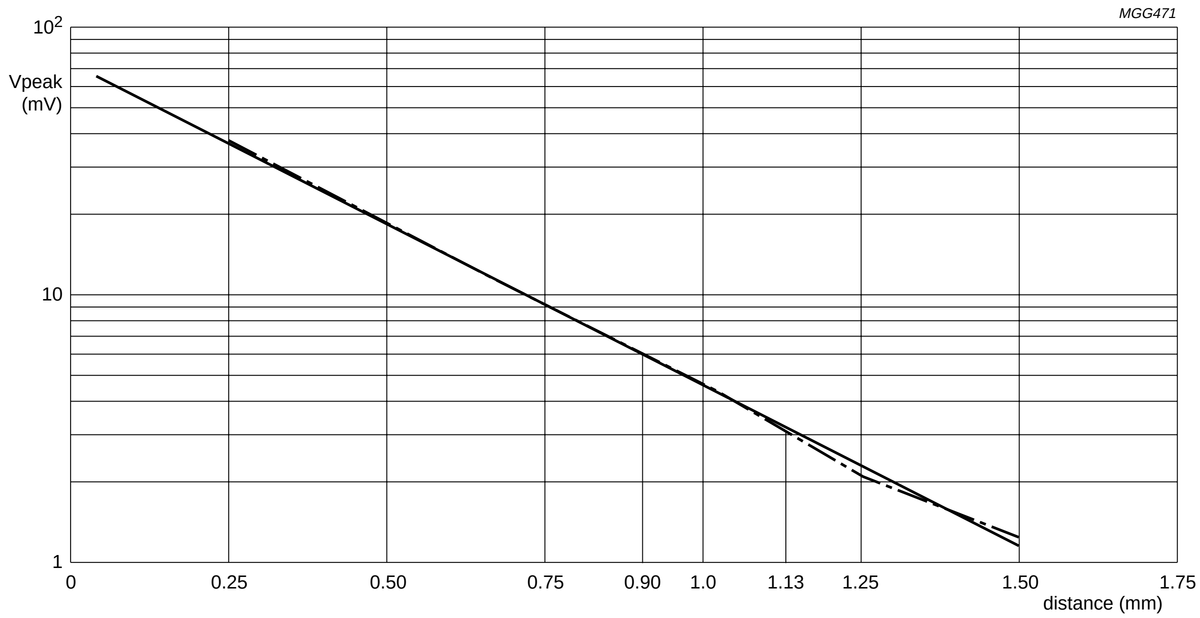


Fig.22 Output signal from a KMZ10B sensor with back-biasing magnet versus distance.

As the hysteresis voltage is set to 6 mV peak-to-peak (3 mV peak), the results show the theoretical maximum air gap is 1.13 mm. However, this does not take into account any eddy currents that may be induced as the wheel rotates, which produce an offset voltage proportional to the speed (for more details, see the section on eddy currents later in this chapter). Taking eddy currents into account, as well as other factors producing offsets such as non-optimal sensor positioning, the maximum permissible air gap is reduced to 0.9 mm.

Eddy currents

The influence of eddy currents was measured by increasing the wheel rotation speed from 500 Hz through to 3000 Hz, with the sensor placed at 0.5 mm from the wheel. From the graph below, the maximum additional speed-dependent offset voltage is determined as approximately ±2.8 mV, with the sign determined by the direction of measurement. If the application requires a large air gap, special attention should be given to the target material and structure to reduce any unwanted influences from eddy currents.

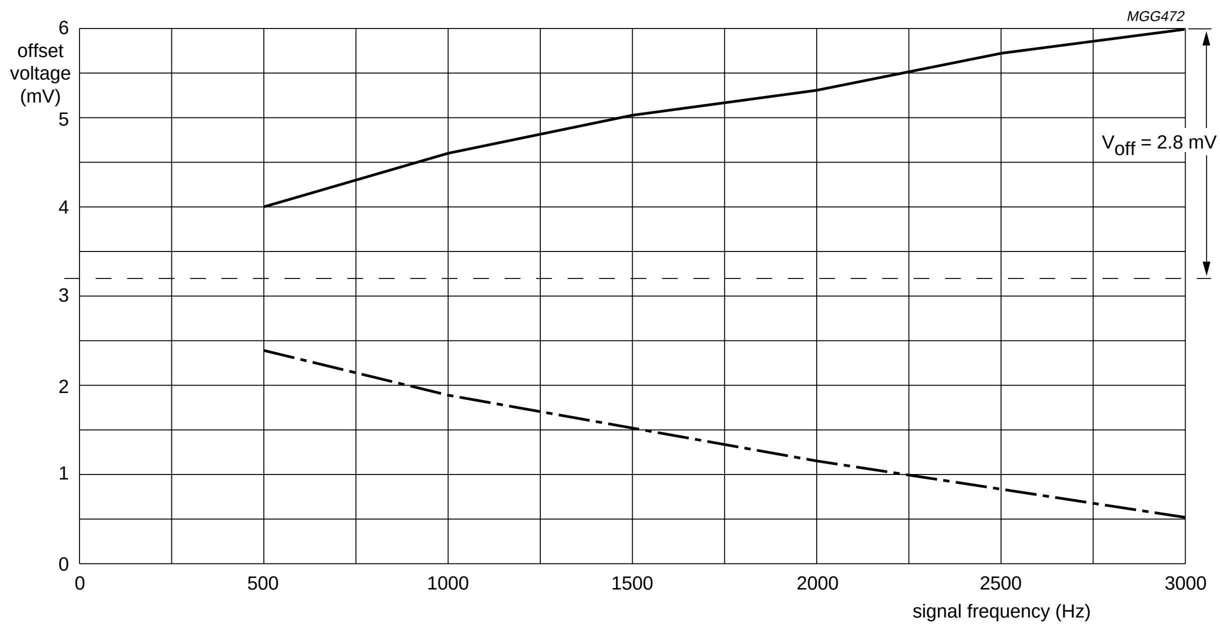


Fig.23 Offset voltage of the KMI15/4 versus frequency, in both directions.

Repeatability

In this test, the speed of the wheel was measured using two sensors: a KMI15/4 in front of the teeth and a reference sensor in front of a small reference (rare earth) magnet placed on the wheel. As it is essential that the measurements are taken on the same tooth, this second sensor is used to trigger the counter at the same moment in every revolution.

One problem in measuring the repeatability of a sensor is that over the length of time taken to make the measurements, the actual velocity of the wheel can vary. This is a basic error within the measurement technique, so the test in fact measures the relative repeatability achievable with the sensor.

Test conditions:

Target RPM (n) = 1000

Sensing distance (d) = 0.5 mm

10 measurements were taken every 4 seconds; the results are tabulated below. From this data an average t_m was calculated.

As shown in the table, during the measurements the motor changed its speed by approximately 0.35%. The result in the last column gives a comparison between the KMI15/4 values and the reference sensor values. The maximum difference between the two sensors is only 0.161‰. This result is also shown in Fig.25.

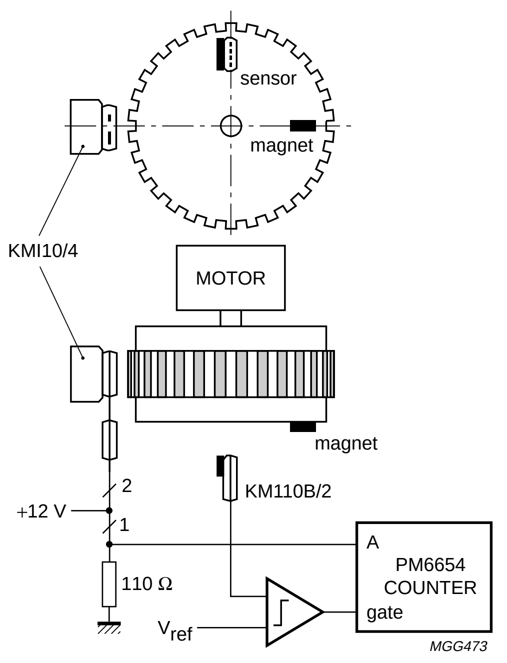


Fig.24 Repeatability measuring arrangement.

Table 2 Repeatability results

MEAS. NO.	KMI 15/4	REFERENCE SENSOR	t/t_m (KMZ) - t/t_m (KM)
	t KMI (µs)	**t/t_m (‰)**	**t KM (ms)**
1	840.7	+2.349	60.4563
2	839.6	+0.918	60.3605
3	842.1	+3.898	60.4036
4	841.4	+3.064	60.4931
5	840.4	+1.872	60.4261
6	836.9	–2.301	60.1753
7	835.9	–3.493	60.1042
8	835.3	–4.208	60.0554
9	836.9	–2.301	60.1851
10	839.0	+0.203	60.3283
t_m	838.83		60.31419

Note: to convert tolerance to degrees, the formula was used:

0.01% 83.883 ns 83.883 ns/60.31419 ms × 360 0.0005.

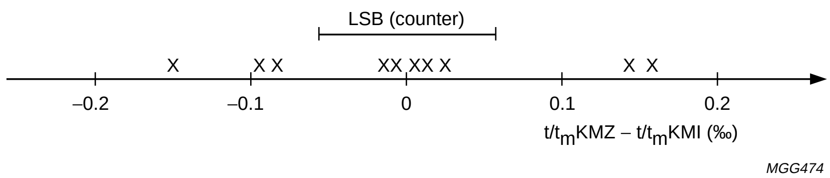


Fig.25 Repeatability of 10 measurements (X).

As shown in the calculation, a tolerance of 0.1‰ equates to 0.005 degrees. So the maximum tolerance and therefore the repeatability of the sensor is better than **0.0008 degrees**.

Due to the effect of the three independent parameters in the test (two sensors and the counter), exact repeatability figures for a single sensor cannot be derived, but what these results clearly show is that the repeatability of the KMI15/4 is much better than the worst result in this particular test.

FUNCTIONAL TESTING OF THE KMI15/1 ROTATIONAL SPEED SENSOR

This was carried out in two steps, testing switching behaviour and sensitivity by electromagnetic stimulation of the device in a Helmholtz coil. The set-up used for the tests, with the direction of the stimulating field parallel to the sensitive direction of the sensor, is shown in Fig.26.

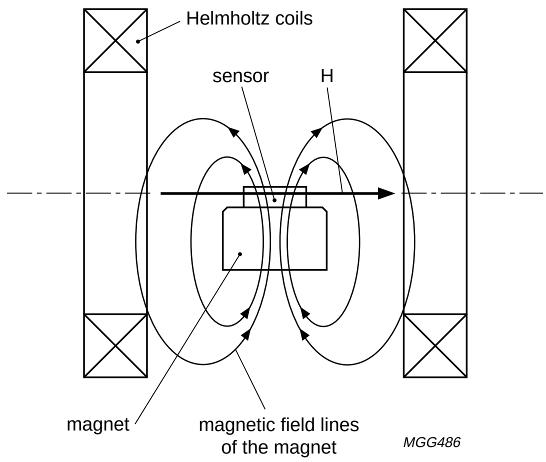


Fig.26 Electromagnetic stimulation of a KMI15/1 sensor.

Control of sensitivity

The measurement of sensitivity (calculating minimum sensing distance) of the KMI15/1 is a more complex operation. Based on the same coil arrangement as shown in Fig.26, the coil and the sensor are linked together as part of an electronic control loop, as shown in Fig.28.

Sensitivity is tested by measuring the minimum magnetic fields (in both the positive and negative rotational directions) required to switch the sensor from a low current state to high and back again. This is done by automatically ramping the magnetic field in the control loop.

The peak-to-peak difference in the minimum magnetic field strength (H_{min}) generates an output voltage when dropped across a magnetoresistive element. This voltage corresponds to the hysteresis voltage V_{hyst} of the Schmitt-trigger circuit in the signal conditioning IC. As the hysteresis voltage is a direct indicator of sensitivity, this test provides a very quick and accurate method for determining the maximum sensing distance (larger distances $H < H_{min}$, smaller distances $H > H_{min}$).

Using a number of gear wheels as test targets, it was found with the samples tested that the maximum sensing distance in rotational directions was d_{max} 2.5 mm (KMI15/1).

Switching behaviour

The magnetic field is switched between H_{low} = –0.84 kA/m and H_{high} = +0.84 kA/m, causing the KMI15/1 output status to switch low or high and by measuring the output current, it is possible to check the switching behaviour.

With the current switching hysteresis set at 7 mA and 14 mA, the final result showed the high and low current levels to be:

I_{low} = 7.0 ±1.4 mA

I_{high} = 14.0 ±2.8 mA,

showing that the switching behaviour is within acceptable parameters for most applications.

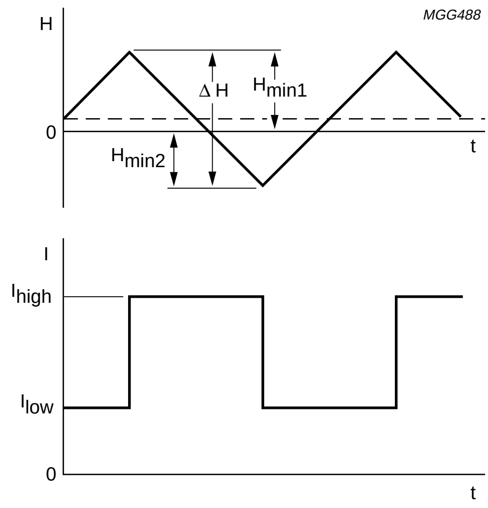


Fig.27 Magnetic field H and current output versus time.

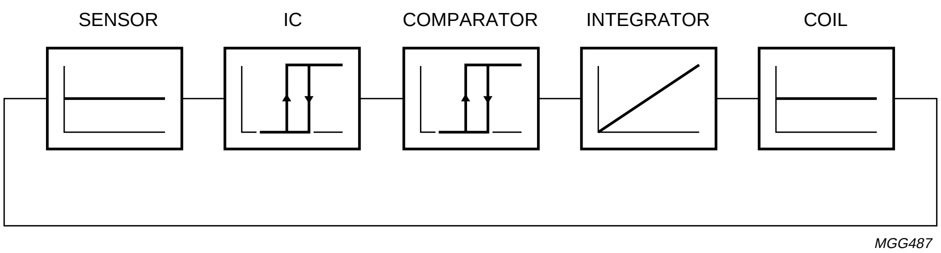


Fig.28 Simplified control loop for sensitivity measurement.

Information for advanced users and applications

DIRECTION DETECTION

All rotational set-ups can be used to measure rotational direction as well as speed, or improve the measurement sensitivity of the set-up, by using two sensors and comparing the phase difference (although the exact set-up will depend on the structure of the target). Three examples are described below:

1. Circuit using two half-bridges of a KMZ10B sensor
2. Dual KMI15/1 with a toothed wheel
3. Dual KMI15/1 with a slotted wheel.

1 "ONE SENSOR SOLUTION"

This concept uses the two magnetoresistive sensor half-bridges in a single KMZ encapsulation. There will be a very small phase difference between the outputs of the two half-bridges when the target wheel turns in front of the sensor and by using separate signal processing for each half, it is possible to indicate direction with only one sensor. As the bridge geometry is fixed within the sensor chip, there is an optimum wheel module but within this constraint, a wide range of wheel pitches is possible. If the target wheel does not have the optimum pitch, the phase difference is not at a maximum and the sensor electronics will have a relatively harder job to produce a clear, well-defined signal. In this case, additional filtering is required. AC coupling is useful, which means the sensor cannot measure down to 0 Hz (as with the dual sensor set-ups described below).

Without filtering, the circuit could indicate zero speed and would be capable of incremental counting, but the operating range would be limited.

2 DUAL KMI15/1 SENSORS WITH A TOOTHED WHEEL

As mentioned, dual sensor set-ups can be used to measure rotational direction as well as speed.

Using two KMI15/1 sensors separated by at least 20 mm and positioned at an angle (not equal to the angle between any two teeth), it is possible to measure the rotational speed and direction of a toothed wheel down to 0 Hz, which cannot be achieved by using two half-bridges. Ideally the phase difference between the outputs should be 90, and the resulting timing of the two output signals indicates direction. This means that the angle between the sensors should be proportional to the angle between two adjacent teeth according to the relationship:

$\alpha = (n + 1/4)\beta$.

If the distance between the sensors is less than 20 mm, the interaction between the magnets will cause an offset voltage in the sensor bridges, which has the effect of reducing the maximum tooth-to-sensor measuring distance.

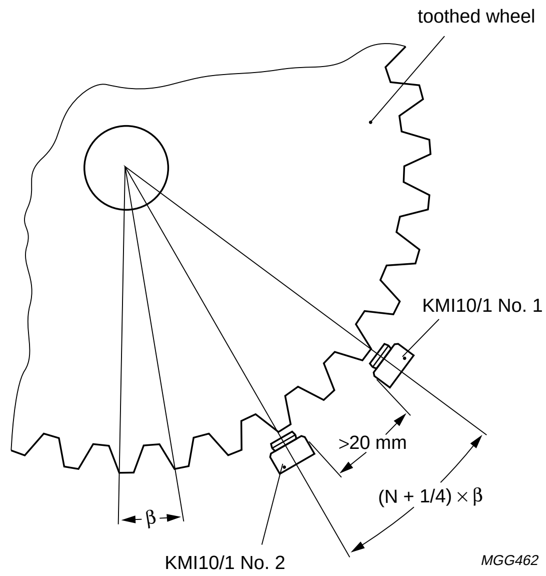


Fig.29 Measurement with toothed wheel.

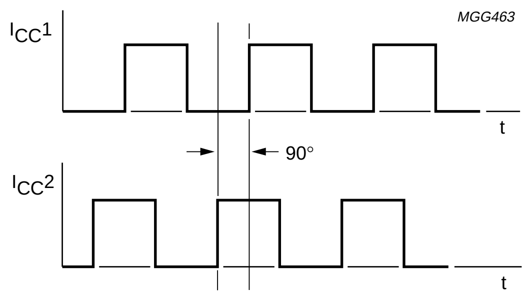


Fig.30 Optimum output signal for clockwise rotation.

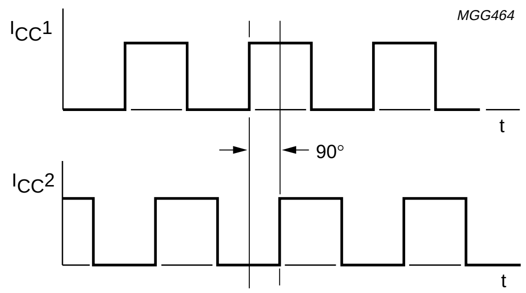


Fig.31 Optimum output signals for anti-clockwise rotation.

3 DUAL KMI15/1 SENSORS WITH A SLOTTED WHEEL

Instead of a toothed wheel, a slotted wheel can be used. In this case the sensors are not mounted in front of the wheel but radially above the surface.

The slotted wheel set-up can be further adapted to allow for sensor-to-sensor distances of less than 20 mm. The sensors are mounted next to each other but with opposite orientations, which reduces the effect of magnetic interaction. With this set-up, tolerances will limit the maximum measuring distance, but it does have the advantage that both sensors could be housed in the same encapsulation, with a single set of conditioning electronics for direction detection, resulting in a simple application design.

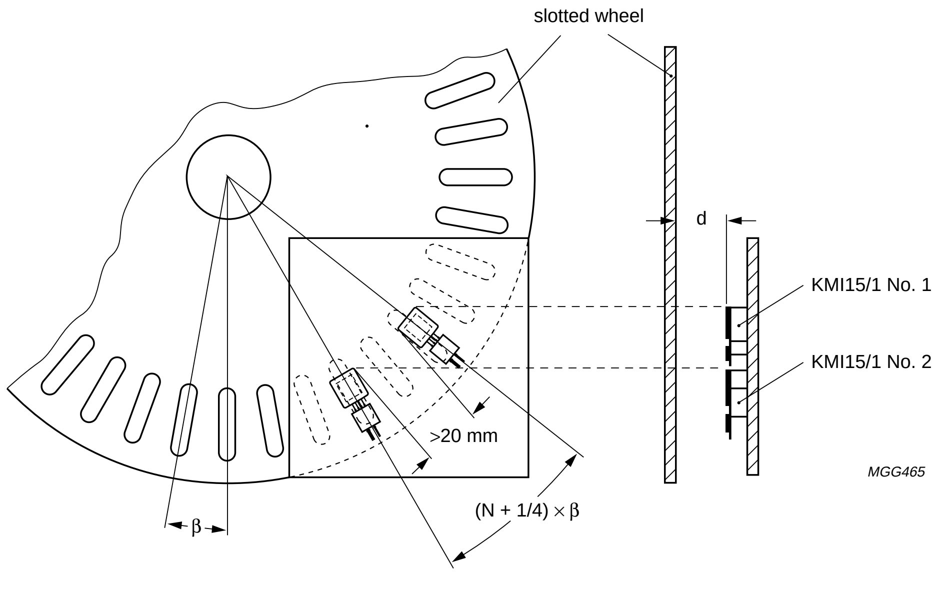


Fig.32 Measurement with slotted wheel.

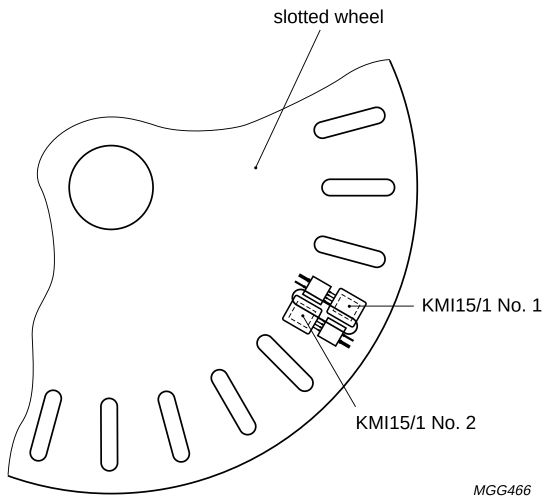


Fig.33 Alternative arrangement with short (<20 mm) sensor-to-sensor distance.

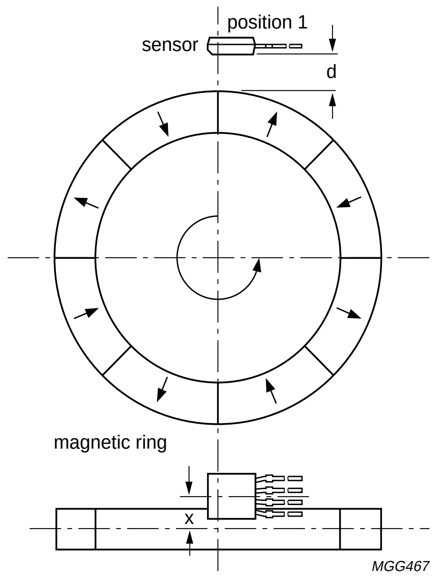


Fig.34 Frequency doubling arrangement using a KMZ10 B sensor.

FREQUENCY DOUBLING

For active targets, magnetic sensors normally output an electrical signal equivalent to the magnetic structure of the multipole rings, with the period of a sensor signal equating to a single magnetic pole pair (N, S). Driving a KMZ10B without an auxiliary magnet and with magnetic fields above about 3 kA/m, effectively doubles the frequency as the magnetic pole pairs deliver two signals in the same period. This is because outside the ‘symmetrical’ position ($x = 0$ in Fig.34), the magnetic field in the sensor plane describes one full rotation for each pole pair (N, S) passing in front of the sensor and as the sensor is saturated, due to the high magnetic field, the basic $\cos^2$ relationship holds true between the sensor output and the angle of the applied field (see Fig.35). For more details on this, please refer to Appendix 1 on the equations for the magnetoresistive effect and Appendix 2 on sensor flipping.

This improves the resolution of measurements and if the resolution is fixed, allows for magnets with reduced pole numbers.

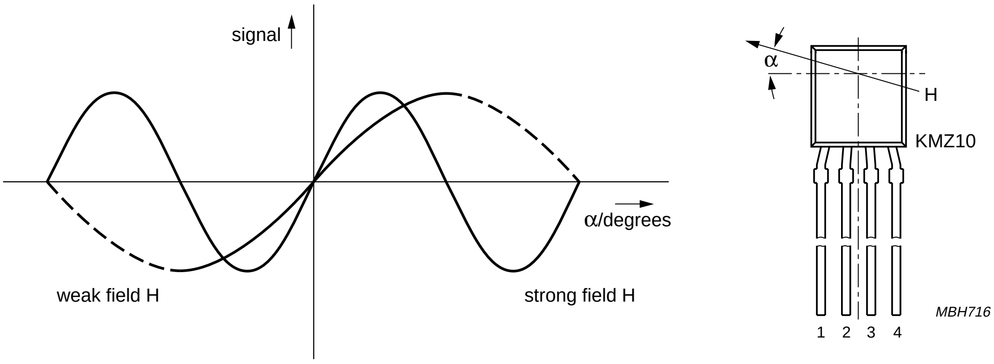


Fig.35 Sensor output with and without bias magnet.

EDDY CURRENTS

As the target rotates in the field of the magnet, eddy currents are induced in the target, according to the target material and rotational speed. These eddy currents themselves generate a magnetic field in addition to the field from the magnet, resulting in an additional offset in sensor output. For standard applications, there is therefore a need for increased hysteresis in the signal conditioning electronics (see Section on “Switching hysteresis” earlier in this chapter). This has an adverse effect on sensor performance in terms of its maximum sensing distance, leading to a reduced airgap, unless it is equipped with a filter.

However, these eddy currents themselves can be used to measure the speed of a metallic, non-ferrous wheel (e.g. copper). The sensor measures the magnetic field produced by the eddy currents induced in the wheel by the auxiliary magnet and increases in the rotational speed are matched by increases in the level of eddy currents. This type of arrangement is suitable for the permanent mounting of a simple tachometer.

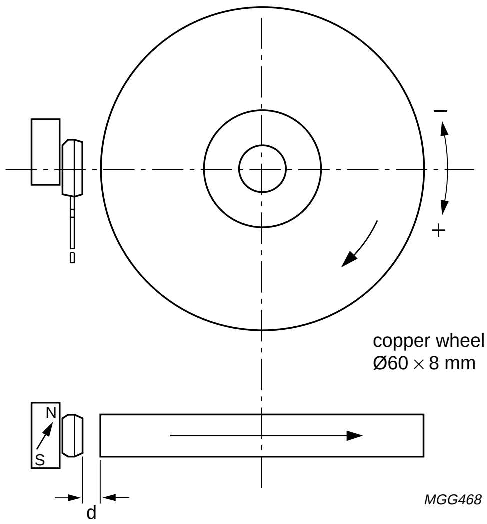


Fig.36 Set-up to measurement RPM using eddy currents.

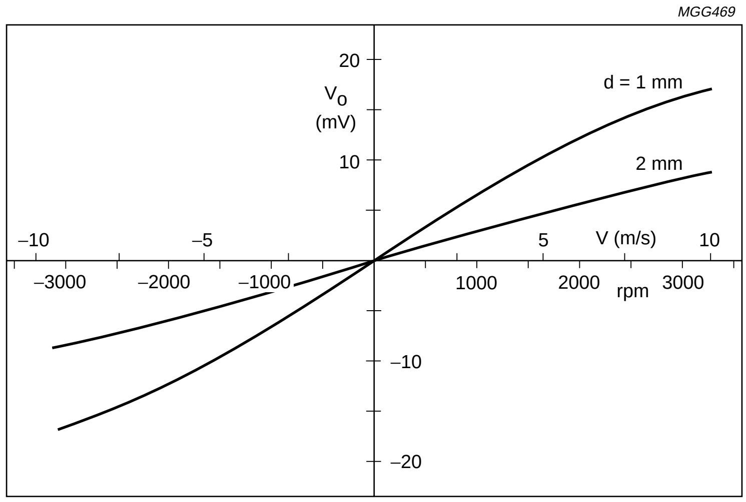


Fig.37 Sensor output versus RPM.

EMC CHARACTERISTICS

Any sensitive electronic system connected to other equipment by unshielded cables, is more susceptible to electromagnetic effects. To determine EM effects on rotational sensors in an ABS system using an unshielded wire 1.5 m in length, two tests were carried out: firstly to determine the influence of the field in a waveguide; and secondly, of a pulse along the cable.

Influence of an electrical field in a waveguide

The unshielded cable is subjected to an electrical field in a waveguide (wave resistance $Z_L = 50\ \Omega$). The sensor (EUT1) is located outside the waveguide and connected via the cable to a second electronic device (EUT2) which in turn, is connected to an oscilloscope to enable a functional check of the sensor. The waveguide is powered by a sweep generator connected to a 3 W amplifier and this test signal is checked and monitored at the waveguide input by the second oscilloscope. The quality of the signal from the first oscilloscope indicates any interference from the electrical field.

The following parameters were used in this test:

Unmodulated

frequency range - 10 MHz to 1 GHz

maximum electrical field intensity - E_{max} = 150 V/m.

Amplitude modulated (AM)

percentage modulation - m = 95%

modulation frequency - f_m = 1 kHz

frequency range - 10 MHz to 1 GHz

maximum electrical field intensity - E_{max} = 150 V/m.

Two set-ups had to be used (see Figs 38 and 39) as with frequencies over 200 MHz, the mismatch could no longer be considered negligible. Also, reflected waves between the waveguide and the amplifier were measured using a disconnected directional coupler and were included in the determination of the actual field intensity in the waveguide.

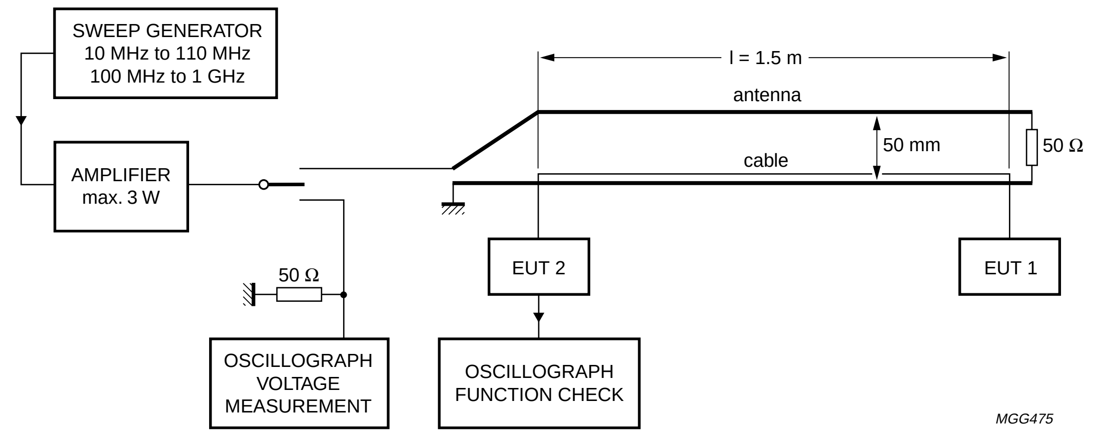


Fig.38 Test set-up with waveguide (antenna) for 10 MHz f 200 MHz.

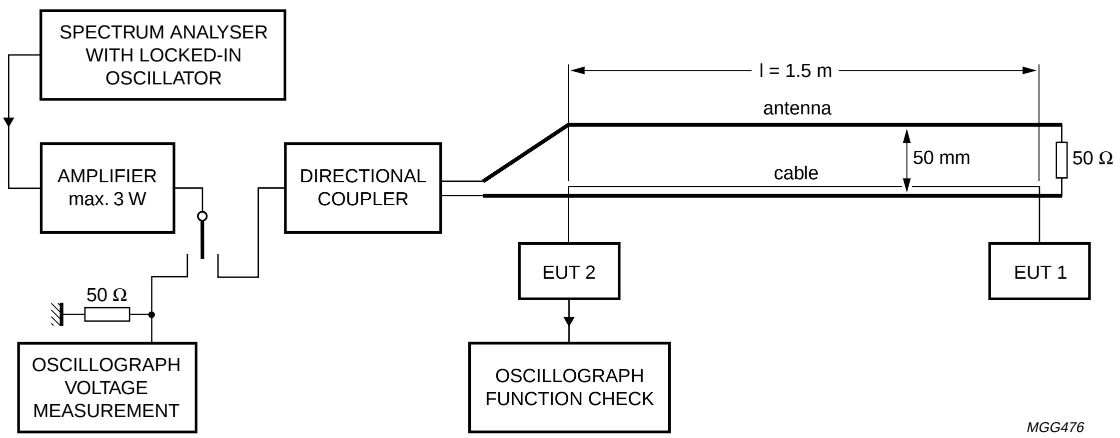


Fig.39 Test set-up with waveguide (antenna) for 200 MHz f 1 GHz.

No undesirable effects were observed on the sensor signal and therefore the system has the required resistance to electromagnetic interference. Also, a destructive test was carried out on the sensor and with field intensities up to E_{max} = 300 V/m throughout the frequency range, no destructive or irreversible changes in the sensor parameters occurred.

Influence of pulse along a cable

Using the following test circuit for the sensor, with the connection points for the test pulse and current measurement points as indicated, the currents i_2, i_3 and i_4 were measured using passive current sensors and a 400 MHz storage oscilloscope. Here the value $i_2(t)$ represents the time variation of the test pulse at the connection point.

The response behaviour to the input test pulse (i_2) is measured under least favourable conditions with low impedance grounding of the earth connection at the sensor output, resulting in higher values of i_{4max} than normally experienced. Figure 41a shows the test pulse $i_2(t)$ with a rise time of approximately 15 ns and a peak value of i_{2max} = 4000 mA.

The currents $i_3(t)$ and $i_4(t)$ clearly show an oscillation where the following peak values were obtained.

i_{3max} = 18 mA

i_{4max} = 2.2 mA

On the basis of i_{4max} = 2.2 mA and R = 115 Ω, then the voltage V_R (see Fig.41) is 253 mV. This voltage is at the input of the RC low-pass filter (R = 1.3 kΩ, C = 47 nF) which has a 3 dB cut-off frequency of f_g = 2.6 kHz. According to Fig.40, the period for i_4 to die away is approximately 16 ns, i.e. a frequency f = 62.5 MHz. This means that the distance between f and f_g is more than four decades and therefore, at 20 dB/decade (ideal low-pass), a distance of approximately 80 dB between V_R and V_T, where V_T represents the input voltage at the trigger unit (Z_T = 100 kΩ).

This clearly gives a value for V_T which is well below the required limit.

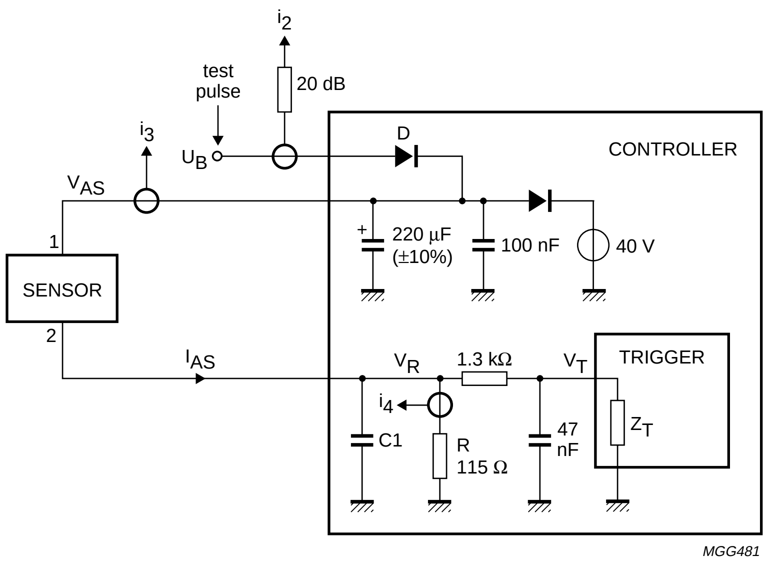
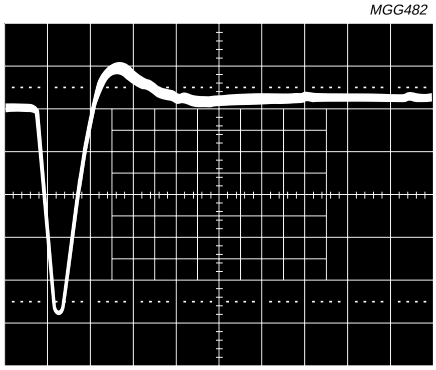
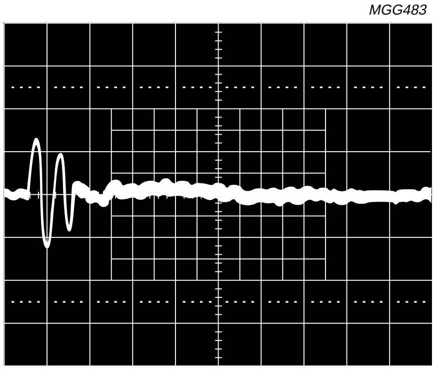


Fig.40 Pulse test circuit diagram for hybrid sensor.



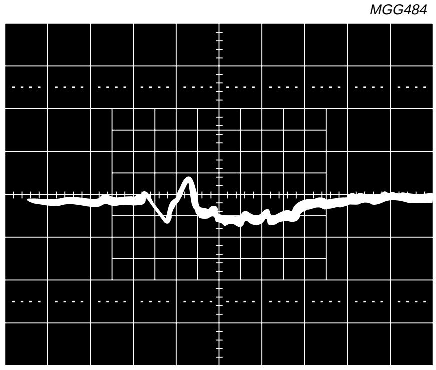
(a)

a. Test pulse I_2.



(b)

b. Test pulse I_3.



(c)

c. Test pulse I_4.

Fig.41 Oscilloscope traces showing.