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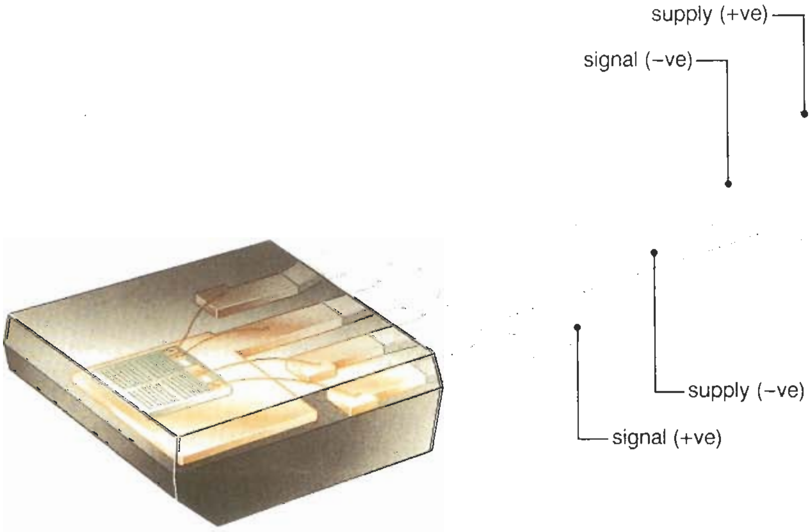
The magnetoresistive sensor

a sensitive device for detecting magnetic-field variations

Magnetic-field sensors provide a highly effective means of measuring both linear and angular displacement. This is because even quite small movement of actuating components in machinery (metal rods, gears, cams etc.) can create measurable changes in magnetic field. Examples where this property is put to good effect can be found in instrumentation and control equipment, which often requires position sensors capable of detecting displacements in the region of tenths of a millimetre, and in electronic ignition systems, which must be able to determine the firing positions of an internal-combustion engine with great accuracy.

Formerly, many of these measuring systems were based on Hall-effect sensors, which make use of the property of a current-carrying semiconductor membrane (Hall element) of generating a voltage perpendicular to the direction of current flow when subjected to a magnetic field normal to its surface.

A more recent development for detecting magnetic-field variations, however, is the KMZ10 magnetoresistive sensor which, in many applications, provides an attractive alternative to the Hall-effect sensor. The KMZ10, for example, is more sensitive than the Hall-effect sensor and can operate over an extremely wide temperature range. What's more, its frequency range is much wider: from DC up to several megahertz.



The KMZ10 magnetoresistive sensor – a recent development for detecting magnetic-field variations

The KMZ10 makes use of the **magnetoresistive effect**: the well known property of a current-carrying magnetic material to change its resistivity in the presence of an external magnetic field. This change is brought about by rotation of the magnetization relative to the current direction. In the case of permalloy, for example (a ferromagnetic alloy containing 20% iron and 80% nickel), a 90° rotation of the magnetization (due to the application of a magnetic field normal to the current direction) will produce a 2 to 3% change in resistivity.

In the KMZ10, four permalloy strips are arranged in a meander pattern on a silicon substrate (Fig.1), and connected to form the four arms of a Wheatstone bridge. The degree of bridge imbalance is then used to indicate the magnetic field strength, or more precisely, the variation in magnetic field in the plane of the permalloy strips normal to the direction of current. A proprietary 'barber-pole' configuration, comprising aluminium stripes deposited on the permalloy strips at 45° to their axes, assures a linear characteristic of the bridge (see box).

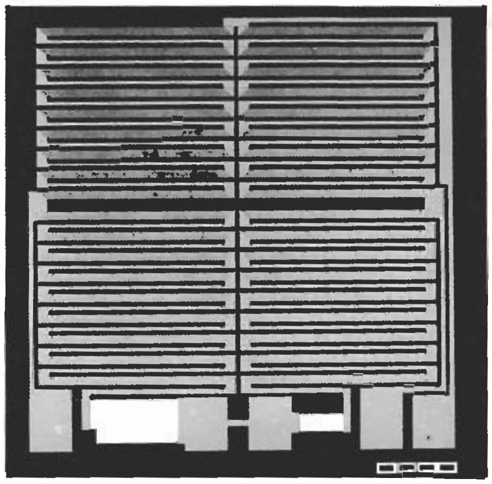


Fig.1 The KMZ10 chip is made up of four permalloy strips arranged in a meander pattern and connected to form the four arms of a Wheatstone bridge. The chip incorporates special resistors that are trimmed during manufacture to give zero offset at 25 °C

LINEAR BEHAVIOUR THANKS TO SPECIAL 'BARBER-POLE' CONFIGURATION

The resistivity of a polycrystalline ferromagnetic alloy such as permalloy is related to the angle θ that the magnetization makes with the current direction by

$$\rho = \rho_o + \Delta\rho_{max}\cos^2\theta \qquad (3)$$

where ρ_o is the isotropic resistivity and $\Delta\rho_{max}$ is the change in resistivity resulting from a 90° rotation of the magnetization (from the direction of current flow).

If this rotation is caused by a magnetic field H normal to the direction of current, and if the field tending to align the magnetization with the current is H_o (comprising the demagnetizing and anisotropic fields), then $\sin\theta = H/H_o$ and

$$\rho = \rho_o + \Delta\rho_{max}(1 - H^2/H_o^2) \qquad \text{for } H < H_o$$

and (2)

$$\rho = \rho_o \qquad \text{for } H \geqslant H_o$$

It's obvious from this quadratic expression that the resistivity/magnetic-field characteristic is non-linear, and what's more, that each value of ρ is not necessarily associated with a unique value of H.

Fortunately, there are several ways to linearize the characteristic. One is to provide a uniform biasing field H_{bias} in the direction of the field H. Then, provided $H \ll H_{bias}$, ρ will be proportional to H. The KMZ10, however, employs another method that uses aluminium stripes secured to the top of each permalloy strip at an angle of 45° to its axis (Fig.A). This has been called the 'barber-pole' configuration because of its resemblance to the poles traditionally seen outside barber shops.

Since aluminium has a much higher conductivity than permalloy, the effect of these stripes is to rotate the net current direction through 45°, that is, to reduce θ to θ – 45°. Relation (1) then becomes:

$$\rho = \rho_o + \frac{\Delta\rho_{max}}{2} + \Delta\rho_{max}\frac{H}{H_o}\sqrt{1 - \frac{H^2}{H_o^2}}$$

As Fig.B illustrates, for small values of H (relative to H_o), ρ increases linearly with H.

With the complementary barber-pole configuration to that shown in Fig.2, that is, with the aluminium stripes inclined at – 45° to the axis of the permalloy strip, θ increases to θ + 45° and (1) becomes:

$$\rho = \rho_o + \frac{\rho_{max}}{2} - \Delta\rho_{max}\frac{H}{H_o}\sqrt{1 - \frac{H^2}{H_o^2}}$$

and ρ decreases linearly with H.

The KMZ10 itself comprises two (diagonally opposed) elements in which ρ increases with H, and two in which it decreases. This largely eliminates the effects of ambient variations (temperature etc.) on the individual elements, and moreover, magnifies the degree of bridge imbalance, so increasing the sensitivity of the device.

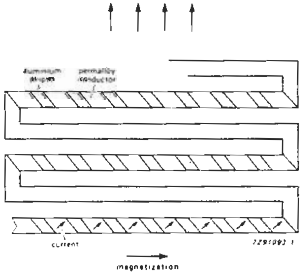


Fig.A

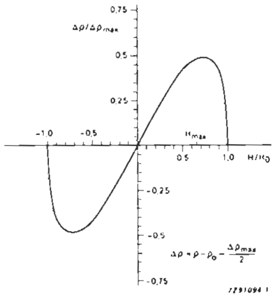


Fig.B

SENSITIVITY – GOVERNING FACTORS

One of the major advantages that the KMZ10 has over other devices like the Hall-effect sensor is the ease with which its sensitivity can be set during manufacture. For small field variations, the sensitivity of the KMZ10 is, from equ (3), given by $\varrho/H = \varrho_{max}/H_o$. The value of ϱ_{max} is determined by the material properties; H_o by, among other things, the strip geometry.

Figure 2 shows how strip geometry governs sensitivity. For a given field strength, the thicker the permalloy strip, the less the magnetization is rotated. So by using different strip geometries, it's possible to produce a range of devices with different sensitivities and measuring ranges. At present, three types are produced: designated types A to C (Table 1).

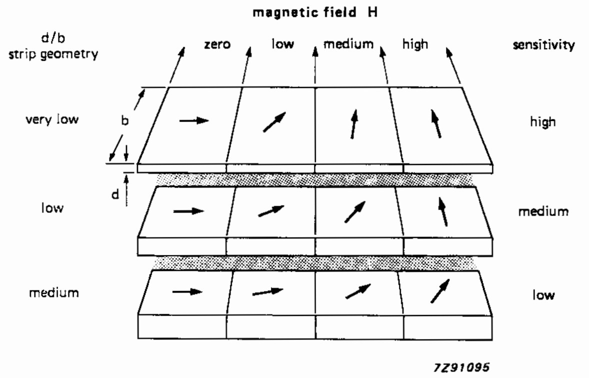


Fig.2 Factors affecting sensitivity. The higher the d/b (depth/breadth) ratio of the aluminium stripes, the less the magnetization will be rotated by a given magnetic field and the lower will be the sensitivity

Table 1
KMZ10 magnetic-field sensors

	KMZ10A	KMZ10B	KMZ10C	units
H_{max}	500	2000	7500	A/m
open-circuit sensitivity (typ)	14.0	4.0	1.5	(mV/V)/(kA/m)

Note: in air, 1 kA/m corresponds to 12.56 G

KMZ10 CHARACTERISTIC BEHAVIOUR

During deposition of the strip material (by sputtering), a strong magnetic field is applied parallel to the strip axis. This serves to accentuate the inherent magnetic anisotropy of the strips, so that even in the absence of an external magnetic field, the magnetization will always tend to align with the strips.

The internal magnetization of the sensor strips therefore has two stable positions, so that if the sensor for any reason should come under the influence of a powerful magnetic field opposing the internal aligning field, the magnetization may flip from one position to the other, and the strips become magnetized in the opposite direction (from say the +x to the −x direction). As Fig.3 shows, this can lead to changes in sensor characteristics.

In Fig.3, the unbroken line shows the characteristics of a normal sensor (with the sensor magnetization oriented in the +x direction), and the broken line shows the characteristics of a 'flipped' sensor.

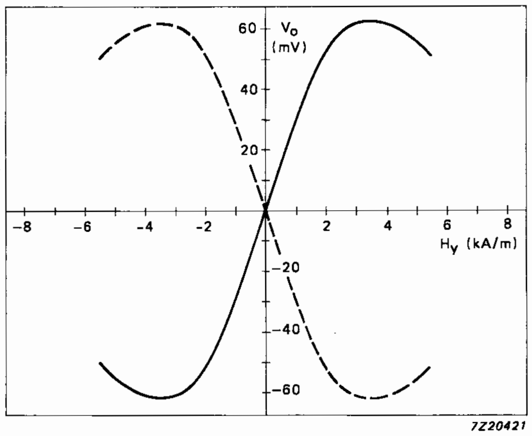


Fig.3 Sensor characteristic. The unbroken line shows the characteristic of a 'normal' sensor (with the magnetization oriented in the +x direction), and the broken line shows the characteristic of a 'flipped' sensor

The field, H_{-x} say, needed to flip the sensor magnetization (and hence the characteristic) depends on the magnitude of the transverse field H_y: the greater the field H_y, the smaller the field H_{-x}. This is quite reasonable since the greater the field H_y, the closer the magnetization's rotation approaches 90°, and hence the easier it will be to flip it into a corresponding stable position in the −x direction.

This is illustrated in Fig.4, which shows sensor output signal V_o versus H_x for several values of H_y. Take the curve for H_y = 0.5 kA/m. For such a low transverse field, sensor characteristic is stable for all positive values of H_x, and a reverse field of around 1 kA/m is required before flipping occurs.

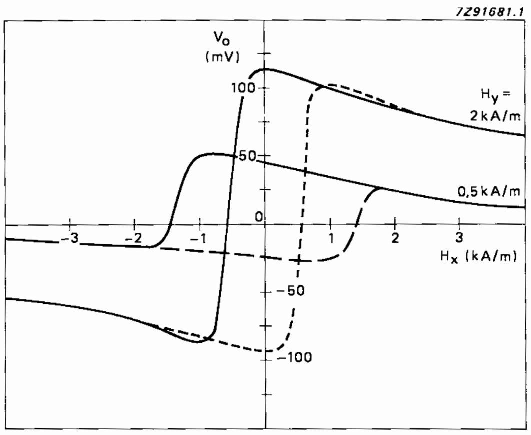


Fig.4 Sensor output V_o versus H_x for several values of H_y (sensor KMZ10B). The curves illustrate several things: first, that the sensor exhibits hysteresis, second, that the flipping is not instantaneous, and third, that sensitivity falls with increasing H_x.

Figure 4 also shows that the flipping itself is not instantaneous; this is because not all the permalloy strips flip at the same rate. Also in Fig.4 you can see the hysteresis effect exhibited by the sensor.

Finally, Figs 3 and 4 show that the sensitivity of the sensor falls with increasing H_x. This again is reasonable since the moment imposed on the magnetization by H_x directly opposes that imposed by H_y, thereby reducing the degree of bridge imbalance and hence the output signal for a given value of H_y.

Internal magnetization

As a precaution against the sensor flipping, it can be provided with a stabilizing magnetic field parallel to the internal aligning field. This stabilizing field will, however, reduce sensitivity slightly, but since it need not be too strong, the effect is only slight. The stabilizing field may be provided by an auxiliary magnet close to or even glued to the sensor with its axis parallel with the x-axis of the sensor. In some applications, especially where the sensor is used to measure the field of say a moving permanent magnet (as in linear position sensors), the magnet itself may be oriented to provide the auxiliary field.

This field should not be confused with the linearizing field H_{bias} (see box), which is unnecessary with the KMZ10 owing to its barber-pole configuration, and which anyway is applied perpendicular to the internal aligning field.

Effect of temperature on behaviour

Figure 5 shows that the bridge resistance increases linearly with temperature. This variation comes, of course, from the fact that the resistance of the bridge resistors themselves (i.e. the permalloy strips) varies with temperature. Figure 5 shows only the variation for a typical KMZ10B sensor. The data sheets show also the spread in this variation due to manufacturing tolerances, and this should be taken into account when incorporating the sensor into practical circuits.

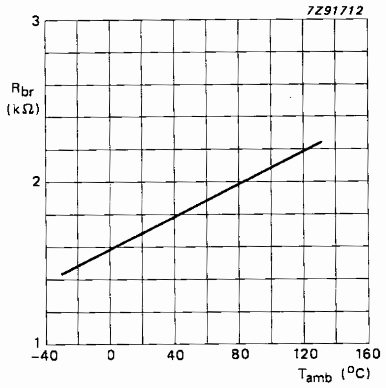


Fig.5 Bridge resistance as a function of temperature (KMZ10B)

Not just the bridge resistance but the sensitivity too varies with temperature. This can be seen from Fig.6 which plots output voltage against transverse field H_y for various temperatures. The figure shows that sensitivity falls with increasing temperature. The reason for this is rather complicated and is connected with the energy-band structure of the permalloy strips.

In general, temperature dependence of sensor characteristics presents no problem since it's relatively easy to incorporate effective compensating networks in the operating circuitry.

Figure 7 is similar to Fig.6 but with the sensor powered by a constant-current supply. The figure shows that with a constant-current supply, the temperature dependence of sensitivity is significantly lower. This is a direct result of the increase of bridge resistance with temperature (Fig.5) which partially compensates the fall in sensitivity by increasing the voltage across the bridge and hence the output voltage. The figure, therefore, adequately demonstrates the advantages of operating with constant current.

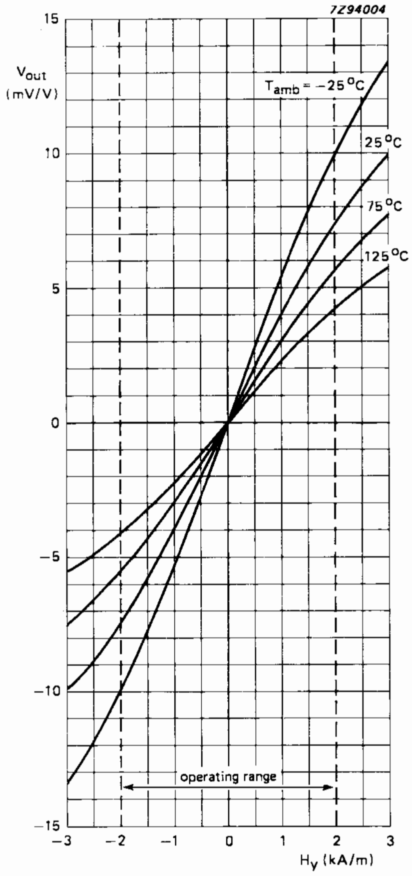


Fig.6 Output voltage V_o versus transverse field H_y for several temperatures (sensor KMZ10B). The figure illustrates that, for a constant supply voltage, sensitivity falls with increasing temperature

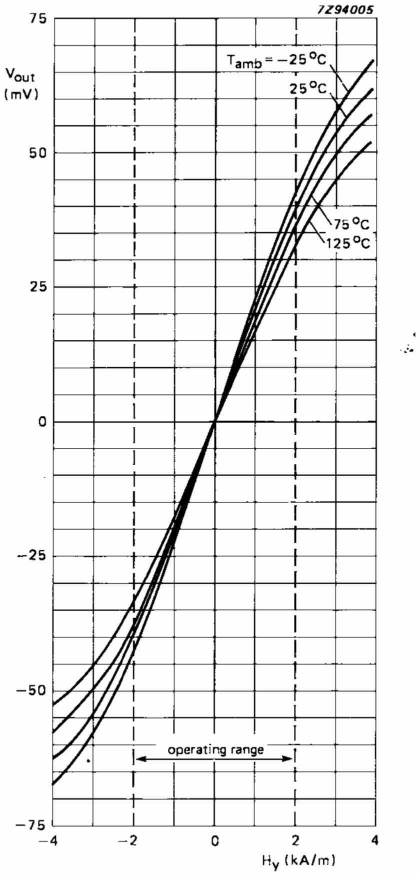


Fig.7 Output voltage V_o versus transverse field H_y for several temperatures, with the sensor powered by a constant-current supply (KMZ10B, current 3 mA). The reduction in temperature dependence of sensitivity is a result of the increase of bridge resistance with temperature, which increases the bridge voltage to partially compensate the fall in sensitivity

KMZ10 VERSUS THE OTHERS – HOW DOES IT COMPARE?

With the broad range of magnetic-field sensors currently available, the question of which to use for a particular application is often a confusing one. In many instances the choice is dictated by familiarity – designers familiar with say, the Hall-effect sensor, will quite naturally choose it for their system even when other sensors, like, for example, the magnetoresistive sensor, might prove more appropriate. Table 2 lists the essential features of some of the more common magnetic-field sensors and should help in choosing the right sensor for a given application.

From Table 2 it can be seen that for applications requiring high sensitivity and low drift, and where mechanical stresses may be high, the KMZ10 magnetoresistive sensors are clear favourites.

We'll now look at some typical application examples to find areas where the KMZ10 can be used to advantage.

Automotive navigation systems

This is an area currently generating a lot of interest, particularly with the imminent introduction of compact-disc based navigation systems (such as the Philips

Table 2
Essential characteristics of some magnetic-field sensors

	operating temp range (°C)	supply voltage (V)	sensitivity at 1 kA/m (mV)	offset (mV)	offset drift (μV/K)	frequency range (Hz)	sensitivity to mechanical stress
magnetoresistive							
KMZ10A	–40 – 150*	10	140	+ 15	+ 20	0 – 1 M	low
KMZ10B	–40 – 150*	10	40	+ 15	+ 10	0 – 1 M	low
KMZ10C	–40 – 150*	10	15	+ 15	+ 10	0 – 1 M	low
Hall-effect							
In	–40 – 100	1	7			0 – 1 M	high
GaAs	–40 – 150*	5	1.2	± 25		0 – 1 M	high
Si (with signal conditioning)	–40 – 150	12	94	6000	± 1600	0 – 100 k	high
flux-gate	–40 – 100					0 – 1 k	
Wiegand-effect	–40 – 125					0 – 25 k	insensitive
induction coil	–40 – 190					1 – 50 k	insensitive
‘magnetic’ transistor	–40 – 150**	20	up to 20				
‘magnetic’ diode	–40 – 90	6	12.5	± 1000	± 80	0 – 4 kHz	

*175 °C possible **estimated

CARIN system) into top-end domestic motor cars. The requirement here is for robust compass systems with an accuracy of around 1°. Likely candidates for this application are the magnetoresistive sensor and the flux-gate sensor. The former, however, is significantly cheaper and is currently attracting a lot of attention from automotive system designers.

Current sensors

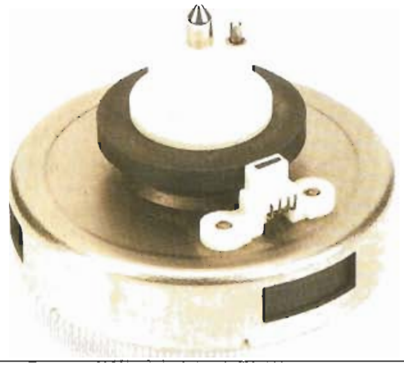
This is an area in which Hall-effect sensors have been prominent for some time, generally because of their small size which compensates, to some extent, their low sensitivity. Typical Hall-effect current sensors use the current to be measured to energize an electromagnet, and the strength of the resulting magnetic field, measured by the Hall-effect sensor, provides a measure of the current. A disadvantage of such systems, of course, is that they inevitably affect the current they are measuring. The magnetoresistive sensors, on the other hand, thanks to its high sensitivity, can measure the magnetic field of a current-carrying wire directly, so its use has no effect on the current to be measured. It could, therefore, be a powerful rival in this area.

Angular and linear displacement measurement.

Again this is an area where the high sensitivity of the magnetoresistive sensor makes it a clear favourite, allowing it to operate in the far-field region of a magnetic system, giving better linearity and reproducibility than its main rival – the Hall-effect sensor. It's also a cheaper solution since its high sensitivity allows the use of relatively cheap ferrite magnets. It is, however, more sensitive to disturbing magnetic fields (the earth's field for example), so care must be taken to avoid or compensate for these.

Movement detectors

For detecting moving magnets or iron parts in hydraulic systems, or flywheels, the magnetoresistive sensor is an excellent candidate. Its high sensitivity means that it can detect these moving objects at relatively large distances (compared with other sensing systems), and even through (non-ferrous) walls. The sensor can also be easily combined with a comparator to provide digital outputs provided operating temperatures don't exceed say 150 °C.



This speed control, based on a rotating magnet and a magnetic-field sensor, is used in some of the latest VCR systems. The KMZ10 is an excellent candidate for the sensor in such applications

Table 3
Magnetoresistive sensors – advantages and main application areas

advantages	
high sensitivity	– simplifying magnetic circuits for lower costs – allowing operation over relative great distances – allowing the use of cheaper magnetic circuits and ferrite-based magnets instead of metal magnets
low source resistance	– giving low sensitivity to electrical interference
high-temperature operation	– 150 °C continuous, 175 °C peak (chip alone can withstand 175 °C continuous)
operation over a wide frequency range	– from DC up to several MHz
metal-film technology	– giving excellent long-term stability
low sensitivity to mechanical stress	– facilitating mounting of the sensor and allowing its use in relatively rough environments
application areas	
traffic control	– detection of vehicles
low-cost navigation	– allowing the production of simple compass systems with an accuracy of around 1°, ideal for automotive applications
long-distance metal detection	– for the detection of, for example military vehicles (tanks etc.) by measuring disturbances in the earth's magnetic field
motion detectors	– by measuring position changes relative to the earth's magnetic field
current detection	– for example, earth-leakage switches
general magnetic-field measurement	– from 10 A/m to 10 kA/m
direct-current measurement	– starting currents in motor vehicles (in engine-management system for example), where they afford simplicity since the high currents involved eliminate the need for magnetic circuits
angular or position measurement	– sensing of accelerator pedal or throttle position (again in engine-management systems) – position sensing in industrial automation systems (commercial sensor arrays that can measure positions with an accuracy of ± 30 μm) – force/acceleration/pressure measurement using a moving magnet, for example: engine-intake-manifold pressure sensors, fluid-level sensors, low-cost weighing systems, geosonic (seismic) sensors, accelerometers
mark detection and counting	– camshaft or flywheel position sensors for engine ignition systems – end-point sensors – wheel-speed sensors for anti-blocking systems – rpm counters (0 to 20 kHz) for engine tachometers and for electronic synchromesh systems – flow meters – zero speed detectors (for spin dryers or drum washing machines) – rpm control in electric motors – general instrumentation

USING THE KMZ10

The MRS in circuit

For some applications it's not necessary to compensate for temperature dependence of bridge characteristics, and it's sufficient to operate the KMZ10 from a simple constant-voltage source. For many applications, however, temperature compensation is essential and Fig.8(a) shows a simple set-up for doing this using just a single opamp (an NE5230N).

The circuit provides the following facilities:

- **compensation of sensitivity drift with temperature** via a negative feedback loop incorporating a KTY83-110 silicon temperature sensor
- **offset adjustment** by means of potentiometer R7
- **gain adjustment**

Figure 8(b) shows the output of this circuit for various temperatures and clearly demonstrates the effectiveness of the temperature compensation. The circuit does not compensate for spread of sensitivity drift and offset. What's more, in this circuit, the temperature sensor draws relatively high current so self-heating effects may result in incomplete temperature compensation.

Figure 9 shows a more elaborate circuit, embodying the functions of Fig.8. The circuit provides for adjustment of gain (P2) and of offset voltage (P1) from the magnetic-field sensor, and although it largely compensates for the sensor's temperature coefficient of sensitivity, it provides no compensation for the (relatively small) temperature variation of offset voltage. Compared with the circuit of Fig.8, however, it does allow the use of higher supply voltages and hence can generate higher output signals.

The circuit can be divided into two stages: an amplification stage that produces a symmetrical output signal derived from the magnetoresistive sensor, and an output stage that also provides a reference to ground for the amplification stage.

The magnetoresistive sensor has a negative temperature coefficient of sensitivity, the precise value of which can be obtained from its data sheet. To compensate this the amplification stage is given an equal but positive temperature coefficient by means of a KTY81 (or KTY85) silicon temperature sensor in the feedback loop of opamp OP1.

The gain A of the amplification stage is:

$$A = 1 + \frac{R6(T) + R10}{R_A}$$

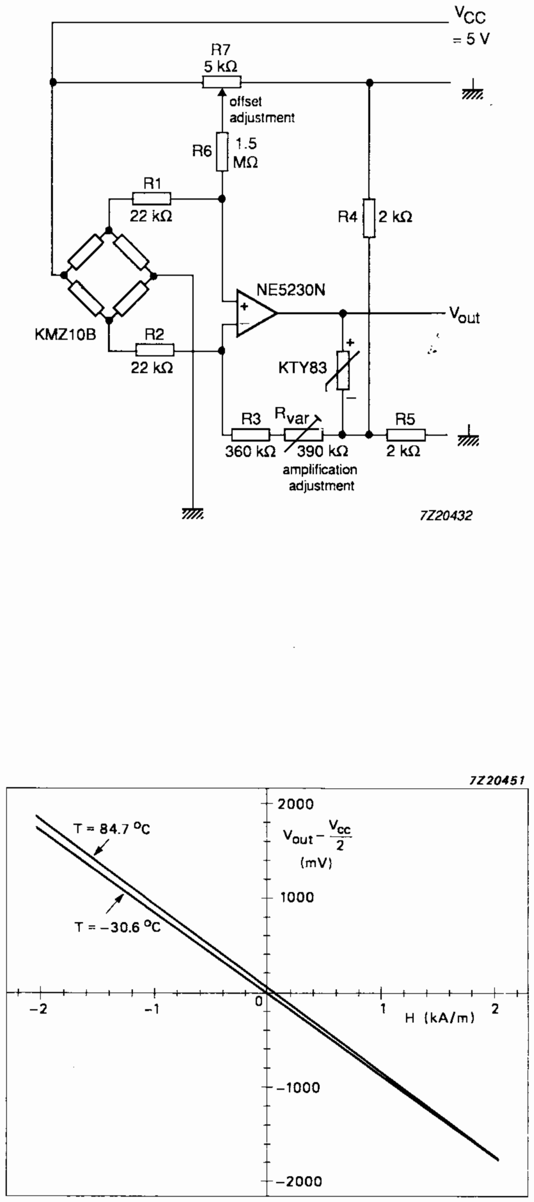


Fig.8 (a) Simple drive circuitry for the KMZ10 incorporating temperature compensation;
(b) output [V_{out} - $V_{cc}/2$] of circuit of Fig.8(a) for two temperatures, clearly demonstrating the effectiveness of the temperature compensation

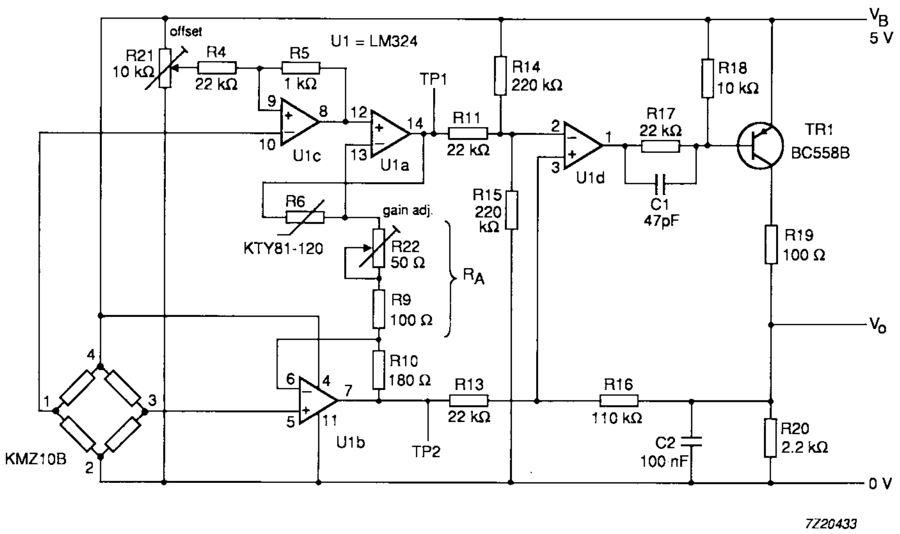


Fig.9 KMZ10 drive circuitry with a quad opamp.
The circuit provides for adjustment of gain, offset voltage and temperature coefficient of sensor sensitivity

and its temperature coefficient of amplification TC_A (equal and opposite to the magnetoresistive sensor's temperature coefficient of sensitivity) is:

$$TC_A = \frac{R6(T)\,TC_{KTY}}{R_A + R6(T) + R10}$$

in which TC_{KTY} is the temperature coefficient of the silicon temperature sensor (0.0078/K for the KTY81 and 0.0075/K for the KTY85).

For a given gain A, resistances R_A and R10 can then be calculated from:

$$R10 = R6(T)\left\{\frac{TC_{KTY}}{TC_A}\left(1-\frac{1}{A}\right)-1\right\}$$

$$R_A = \frac{R6(T) + R10}{A-1}$$

In Fig.9, the output stage has a maximum gain of 5 and gives an output voltage of half the supply voltage V_B for zero differential output voltage of the amplification stage (between test points TP1 and TP2). Output voltage will vary from zero to slightly less than V_B.

One point position measurement with the KMZ10

Figure 10(a) shows how a KMZ10B may be used to make position measurements of a metal object, a steel plate for instance. The sensor is located between the plate and a permanent magnet oriented with its magnetic axis normal to the axis of the plate. A discontinuity in the plate's structure, such as a hole or region of non-magnetic material, will disturb the magnetic field and produce a variation in the output signal from the sensor.

This is shown in Fig.10(b) which gives the sensor output signal versus hole/sensor offset x, for two values of magnet/plate spacing d. The interesting point of this figure is that the crossover point, i.e. the point where the hole and sensor precisely coincide, is independent of d. The obvious advantage of this set-up is that precise location of the sensor/magnet combination is unimportant for one-point position measurements, so adjustment procedures in a practical device would be greatly simplified. Although not shown in Fig.10(b), the crossover point is also independent of temperature. This is not surprising since it is effectively a null measurement, and it could be a major advantage in practical applications.

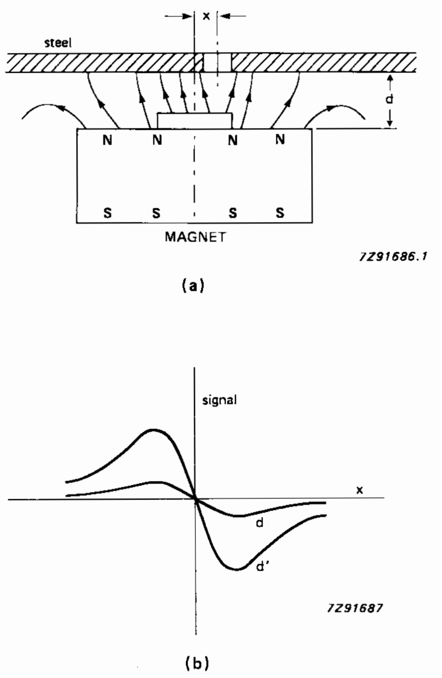


Fig.10 One-point measurement with the KMZ10.
(a) The sensor is located between a metal plate and a permanent magnet oriented with its magnetic axis normal to the axis of the plate. A discontinuity in the plate's structure, such as a hole or region of non-magnetic material, will disturb the magnetic field and produce a variation in the output signal from the sensor.(b) Output signal versus hole/sensor offset x for two values of magnet/plate spacing d. The figure shows that the crossover point is independent of d, which greatly simplifies adjustment procedures

Linear position measurement

Figure 11 shows probably one of the simplest arrangements for measuring linear displacement using a KMZ10 sensor and a permanent magnet.

When the sensor is placed in the field of a permanent magnet, it's exposed to magnetic fields in both the x and y directions. If the magnet is oriented with its axis parallel to the sensor strips (that is, in the x direction) as shown in Fig.11(a), H_x then provides the auxiliary field and the variation in H_y can be used as a measure of x displacement. Figure 11(b) shows how both H_x and H_y vary with x, and Fig.11(c) shows the corresponding output signal as a function of x.

An excellent example of how this arrangement can be put to practical use, making use of the circuit of Fig.9, is shown in Fig.12(a). Here, the linear displacement of the magnet provides a measure of the movement of a pressure-sensing membrane. Figure 12(b) shows that the

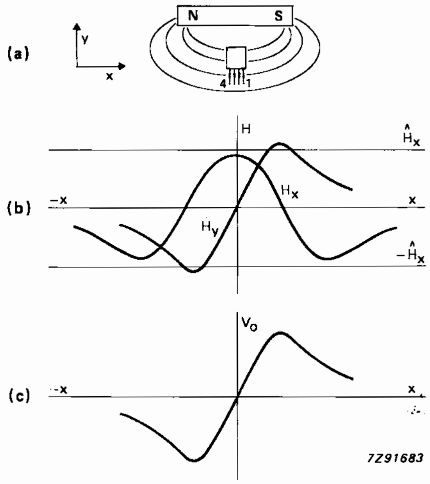


Fig.11 Sensor output in the field of a permanent magnet as a function of its displacement x parallel to the magnetic axis. The magnet provides both the auxiliary and transverse fields. In the example shown, the auxiliary field is always less than the field H_x that will cause flipping. Note the pinning arrangement in this figure, which indicates that the sensor is viewed from the rear.
Reversal of the sensor relative to the permanent magnet will reverse the characteristic

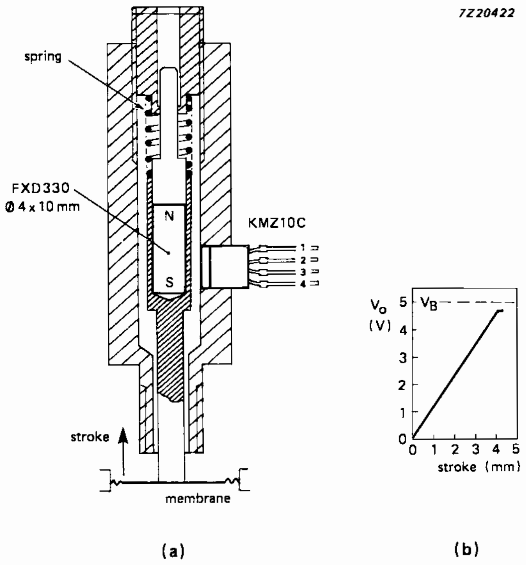


Fig.12 (a) Pressure sensor in which the movement of a membrane is transmitted to a permanent magnet from which it can be detected by a KMZ10C magnetoresistive sensor
(b) Amplified bridge output voltage versus membrane displacement (using the circuit of Fig.9)

(amplified) bridge output voltage V_o is substantially a linear function of membrane displacement. A typical application for such an arrangement would be for sensing inlet manifold pressure in engine-management systems.

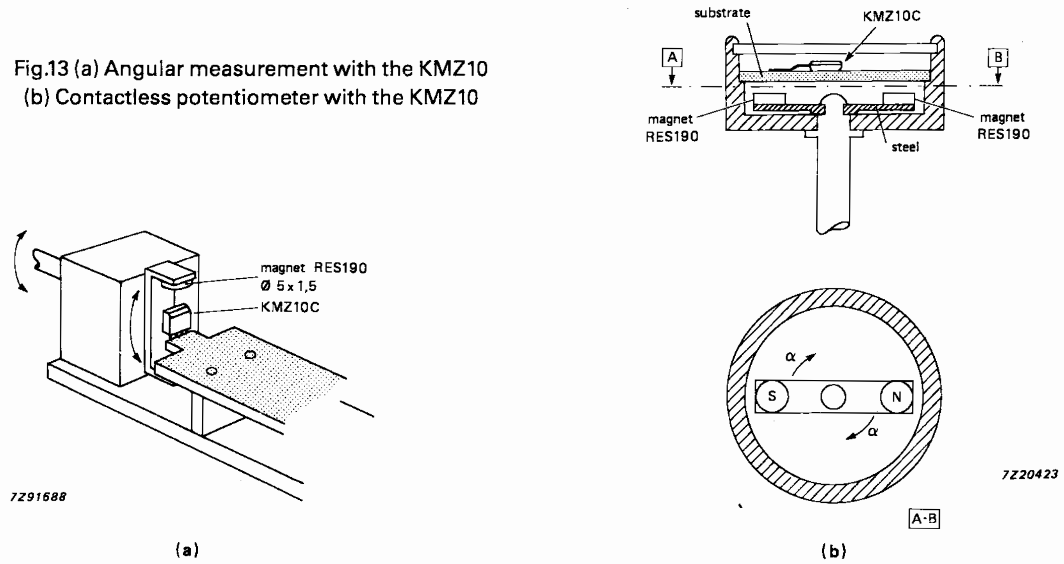
Angular position measurement with the KMZ10

Figure 13(a) shows a set-up for measuring angular position using a KMZ10C. The sensor itself is located in the magnetic field produced by two RES190 permanent magnets fixed to a rotatable frame. The output of the sensor will then be a measure of the rotation of the frame (Fig.15). Taking the zero position for measurement to be parallel to the x axis of the sensor (that is with the magnetic field in the H_x direction), then the device can measure angular rotation up to around +85 °. Beyond that the sensor is in danger of flipping.

Figure 14 shows a circuit for measuring the sensor output in the set-up of Fig.13. The output signal of the sensor bridge is amplified by opamps A_1 and A_2. A KTY81 silicon temperature sensor in the feedback loop of A_2 varies the gain of the opamp to provide temperature compensation for the output signal. Figure 15 shows the effectiveness of this temperature compensation by comparing the output V_2 of A_2 with the direct output V_1 from opamp A_1 for a range of temperatures.

Figure 13(b) shows a more practical arrangement for measuring angular position. This arrangement is, in effect, a contactless potentiometer and could be used, for example, as a throttle or accelerator pedal position detector in engine management systems.

Fig.13 (a) Angular measurement with the KMZ10
(b) Contactless potentiometer with the KMZ10



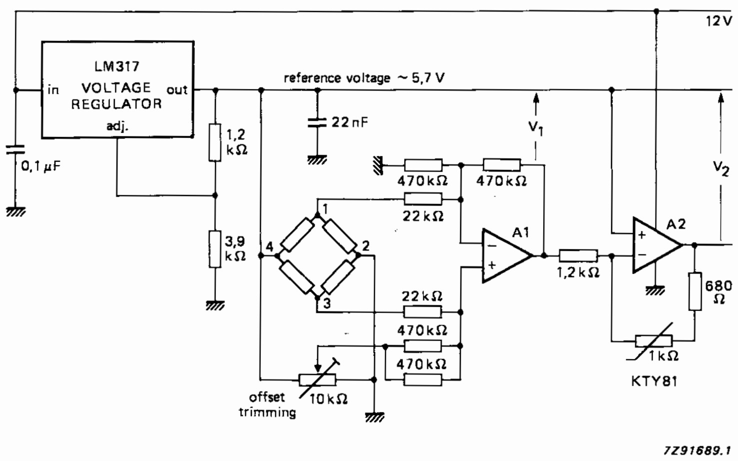


Fig.14 Circuit for measuring sensor output in the setup of Fig.13.

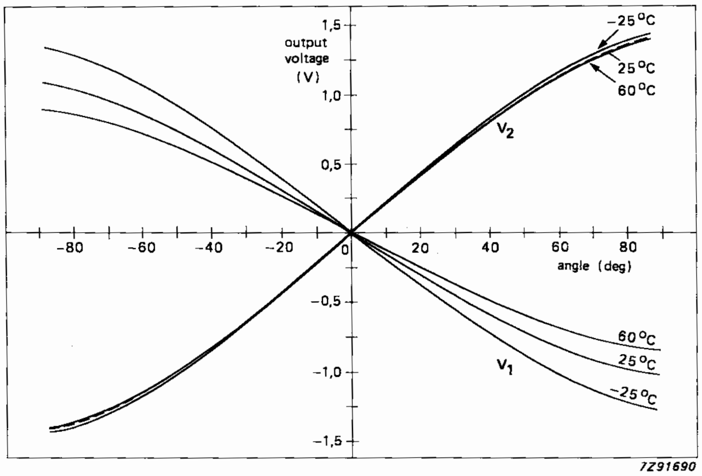


Fig.15 Effect of temperature compensation in the circuit of Fig.14. The figure compares the uncompensated output V_1 of opamp A_1 with the compensated output V_2 of opamp A_2.

Current measurement with the KMZ10

Figures 16 and 17 show two ways in which the KMZ10B can be used to measure electric current. This could be useful, for example, in headlamp-failure detection systems in motor vehicles or in clamp-on (non-contacting) meters as used in the power industry.

Figure 16 is a rather simple set-up in which the sensor measures the magnetic field generated by the current-carrying wire. Figure 17(a) shows how the sensitivity of the sensor varies with distance d from the wire and Fig.17(b) shows sensor output versus current for various values of d.

Not surprisingly, sensor sensitivity rises as d decreases. For relatively large values of d (say 5 mm), the increase in sensitivity is substantially linear, but at closer spacings, when the magnetic field generated by the current is no longer uniform over the sensor, the rate of increase drops off. For higher currents, a similar drop off from linearity would be observed at quite large distances, but this is due to the magnetic field generated by the current saturating the sensor.

The sensor can also be laid directly onto a conductor of a printed-circuit board, and Fig 17(a) also shows the sensitivity of the sensor for three PCB conductor widths.

Figure 18 is a more sophisticated arrangement in which the magnetic field generated by the current-carrying wire is compensated by a secondary circuit wrapped around a ferrite core. At the null-field point, detected by a KMZ10 sensor located in the air gap between the ends of the core, the magnitude of the current in the secondary circuit is a measure of the current in the main circuit. This arrangement provides a more accurate means of measuring current and lends itself more to precision applications.

What's important to bear in mind in both these examples is that they allow current measurement without any break in or interference with the circuit.

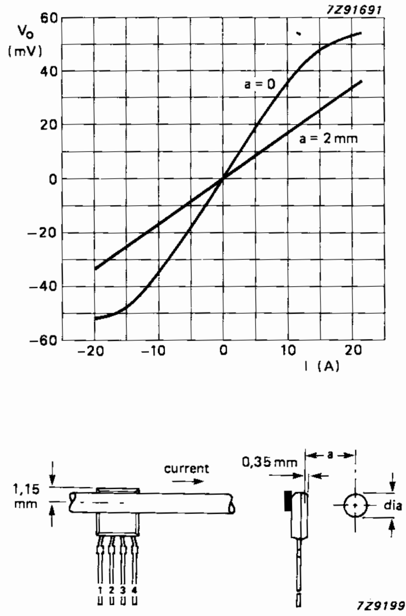


Fig.16 Simple setup for measuring current with a KMZ10B sensor plus auxiliary magnet. The sensor simply measures the magnetic field generated by a current- carrying wire.

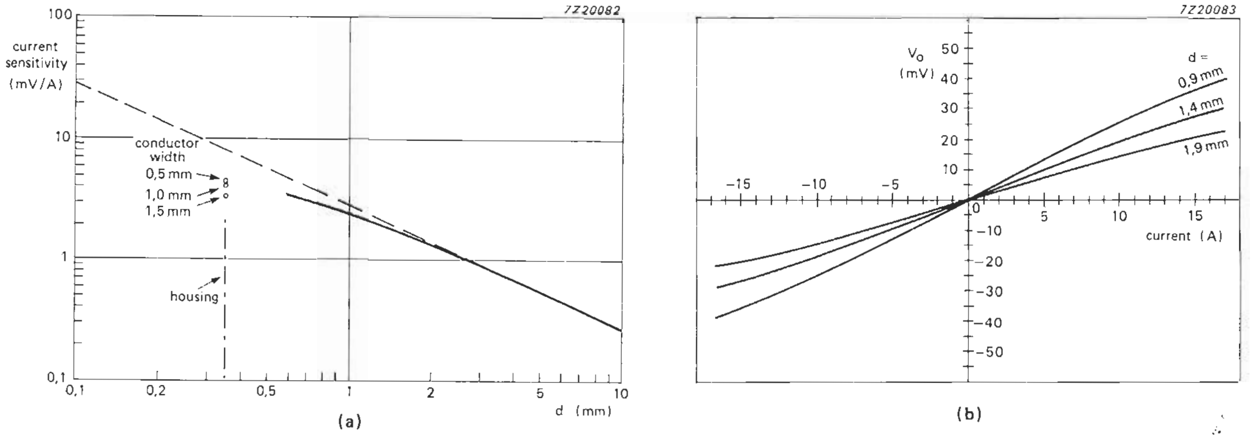


Fig.17 (a) Sensor sensitivity (in mV/A) versus distance d between the axis of the wire and the plane of the sensor chip. The figure also shows, for three conductor widths, the sensitivity of the sensor when laid directly onto a conductor of a printed-circuit board
(b) Sensor output versus current for various distances d

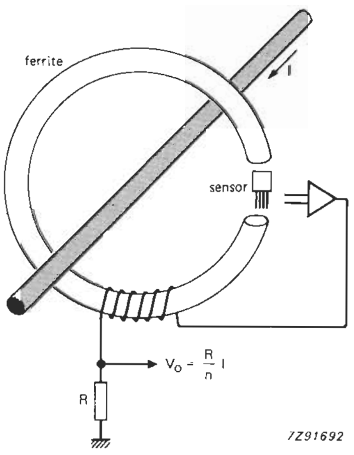


Fig.18 Current measurement. In this setup a current-carrying wire is wrapped around a ferrite core, with the sensor located in the air gap between its ends.

Angular-velocity measurement – ferrous gear wheel

Figure 19 shows how a KMZ10B can be used to measure the angular velocity of a ferrous gear wheel, and Fig.20 shows the sensor output as an oscilloscope trace.

As the wheel's rpm increases, so will the frequency of the oscilloscope trace. This setup therefore provides a very sensitive means of measuring rpm and could be used, for example, in anti-lock breaking systems (ABS) for motor vehicles.

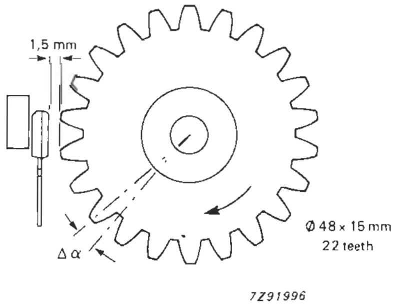


Fig.19 Measuring the rpm of a ferrous gear wheel using the KMZ10B sensor with the FXD100 8 x 8 x 4,35 magnet

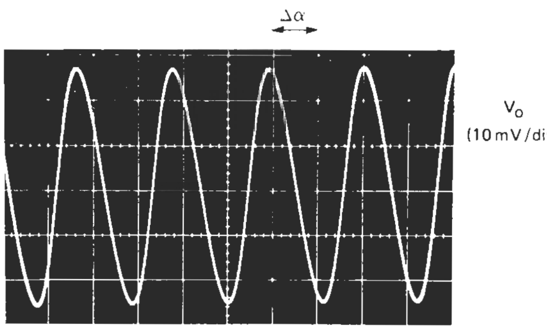


Fig.20 Oscilloscope trace for the setup of Fig.19. As you increase the wheel's rpm the frequency of the trace on the oscilloscope will also increase

Angular-velocity measurement – eddy-current effect

A KMZ10B sensor can also measure the speed of a rotating non-ferrous metal object (for example, a copper wheel) using eddy-current detection. Figure 21 shows a simple arrangement for doing it, and Fig.22 shows how the sensor output varies with rpm.

The sensor measures the magnetic field produced by eddy currents induced in the copper wheel by the auxiliary magnet. The faster the wheel rotates, the greater the eddy currents and the higher the sensor's output signal.

This arrangement would enable the sensor to operate as an extremely simple tachometer unit which could be permanently mounted in a wide range of mechanisms.

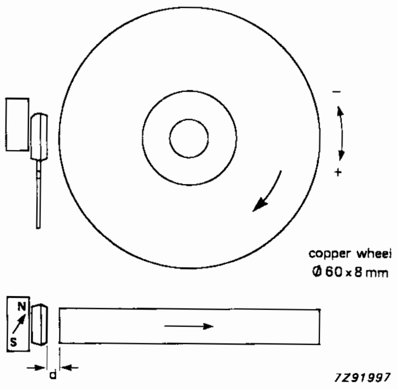


Fig.21 Measuring the rpm of a copper wheel using eddy currents.

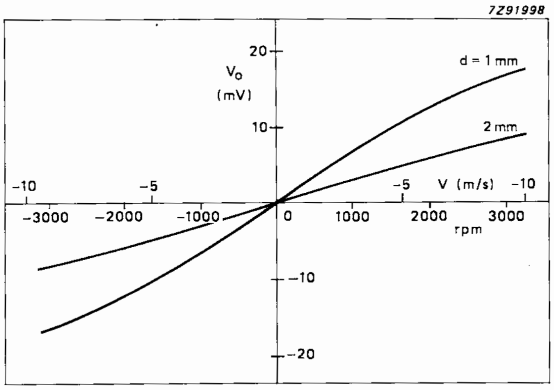


Fig.22 Sensor output versus rpm. The sensor measures the magnetic field produced by eddy currents induced in the copper wheel by the auxiliary magnet

Proximity switch

Figure 23 shows a simple arrangement, that, together with a comparator, can be used as a proximity switch.

By orienting the sensor axis at 45° to the axis of the permanent magnet, the sensor gives a negative signal (Fig.24) for both axial arrangements of the magnet, which could, in a practical circuit, be applied to the inverting input of a comparator. Experience indicates that with a supply of 5 V, a KMZ10C sensor with a switching level above 10 mV is probably the best choice for this application. Below this switching level, strong external fields may disturb the sensor and give ambiguous results. Switching level may be set by means of offset adjustment in the comparator circuit.

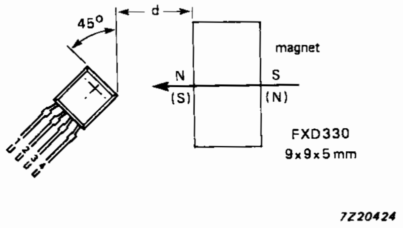


Fig.23 By orienting the sensor axis at 45° to the axis of the permanent magnet, a negative signal can be obtained from the sensor which can be applied to the inverting input of an opamp

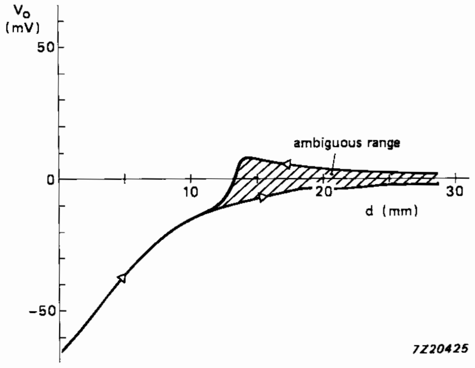


Fig.24 Sensor output as a function of distance d between the sensor and the permanent magnet

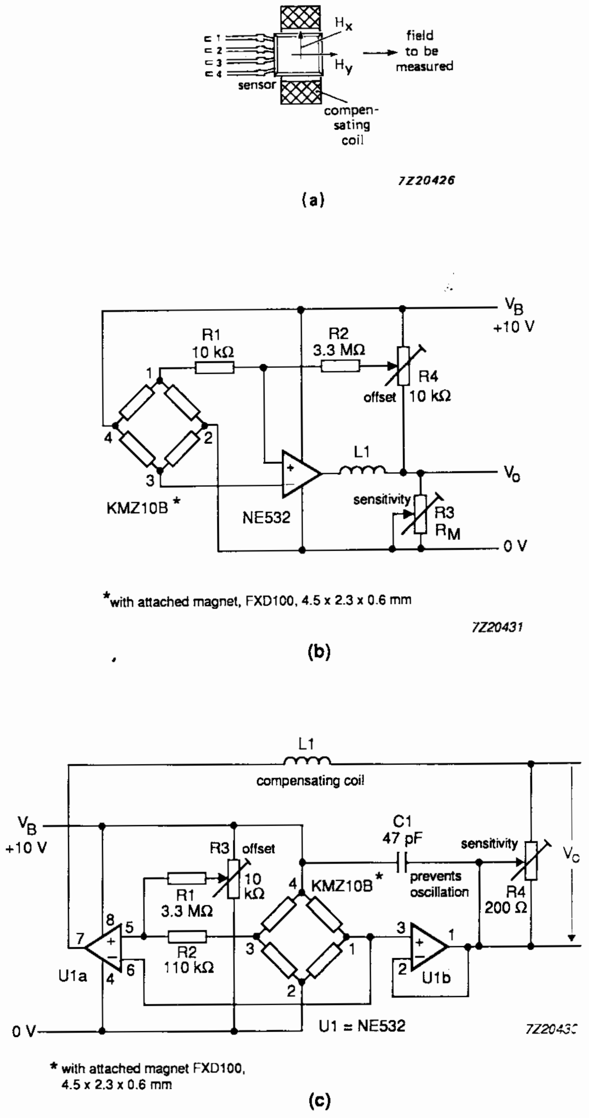
General magnetic-field measurements

Thanks to its high sensitivity, the KMZ10 sensor is ideal for measuring magnetic fields by so-called ‘null-field’ methods, in which the field to be measured is compensated by a coil, the current through which serves as a measure of the field. The advantage of such methods is that since they operate around a null-field position, tolerances and drift of sensitivity can be ignored, as can slight non-linearities in sensor characteristics. The high sensitivity of the sensor also means that the compensating coils can do without ferromagnetic cores (and the inevitable hysteresis effects that these would introduce). It does, however, limit the number of turns and the current that can be used, and restricts the measuring range to a few kA/m.

Figure 25(a) shows the sensor/coil arrangement and Fig.25(b) the drive circuitry. With zero external field applied to the sensor (by, for example, arranging the sensor’s y-axis perpendicular to the earth’s magnetic field), bridge offset is initially set by potentiometer R4 to just below the switching voltage of the comparator (which has a gain of around 10^5). An external field applied to the sensor will then cause the comparator to switch and current to pass through the coil L1. This then sets up a magnetic feedback system in which the magnetic field generated by the coil almost compensates the external field but leaves a small residual field that’s sufficient to maintain the current through the coil and hence the compensating field generated by it. The output voltage V_o is thus a direct measure of the magnetic field generated by the coil and hence of the external field to be measured.

Figure 25(b) is suitable for measuring magnetic fields in only one direction. For bi-directional field measurement, the circuit of Fig.25(c) should be used.

Finally, Table 4 suggests some coils suitable for this application.



(a)

*with attached magnet, FXD100, 4.5 x 2.3 x 0.6 mm

(b)

* with attached magnet FXD100, 4.5 x 2.3 x 0.6 mm

(c)

Fig.25 (a) Measuring magnetic fields by means of a compensating coil
(b) Drive circuitry for the setup given in (a) for measuring field in one direction only
(c) Drive circuitry for the setup given in (a) for measuring field in either direction

Table 4
Compensating coils

coil	turns	wire dia (mm)	resistance (Ω)	H/i* ([A/m]/mA)
1	365	0.10	18	48
2	720	0.07	75	100

* H - magnetic field   i - current   coil former Philips 4322 021 30240

Measuring weak magnetic fields – magnetic compass

In the measurement of weak magnetic fields (for example the earth's field), it's often advantageous to omit the auxiliary magnet in order to get maximum sensitivity from the sensor. The sensor, however, is then in danger of being flipped by any stray magnetic field. The circuit of Fig.26 shows an excellent way of removing this danger by the use of a coil to periodically reset the sensor's polarity.

Another problem of measuring weak magnetic fields is that precision is limited by drift in both the sensor and amplifier offset. In these instances it's possible to take advantage of the 'flipping' characteristic of the KMZ10 series to generate an output that's independent of offset.

The sensor, located in a coil (Fig.27(a)) whose axial field is periodically reversed by alternate positive and negative going pulses (Fig.27(b)), is continually flipped from its normal to its reversed polarity and back again. The polarity of the offset, however, remains unchanged, so the offset itself can be eliminated by passing the two output signals (Fig.27(c)) through a comparator circuit.

For the most sensitive sensor, the KMZ10A, the switching field should not be less than 3 kA/m. Since there's no auxiliary field in this arrangement, the sensitivity of the KMZ10A is about 22 mV/V/(kA/m), and fields up to around 250 A/m can be measured without stability problems.

The normal KMZ10A sensor chip is encapsulated with its x axis (the axis of its permalloy strips) perpendicular to its leads, and this is rather inconvenient for locating it in a coil with its x axis aligned with the coil axis. A special 'turned' sensor, with its x axis parallel with its leads, type KMZ10A1, is therefore available for this application.

Figure 28 shows how a magnetic compass can be made using two mutually perpendicular 'turned' sensors inside a coil. As in the previous example, the magnetic field is periodically reversed to produce an output that's independent of offset. What's more, the compass needs no temperature correction since the determination of field direction relies on the ratio of the two signals and not on their absolute values.

A suitable coil for this compass would be 100 turns of 0.35 mm copper wire wound on a Philips 4322 021 30270 coil former – giving a resistance of 0.6 Ω, an inductance of 87 μH and a axial magnetic field of 8.3 (kA/m)/A.

Figure 29 gives a circuit for delivering the current pulses (50 μs) and for processing the outputs of the two sensors. The current pulses for the coil L1 (70 Hz, 50% duty factor) are generated by transistors TR1, TR2 driven by a 140 Hz pulse generator via a 2:1 frequency divider.

Capacitors C5 and C6 suppress the offset of the two sensor signals. These are then amplified and fed to two synchronous demodulators which generate output voltages V_x and V_Y proportional to the x and y components of the earth's magnetic field.

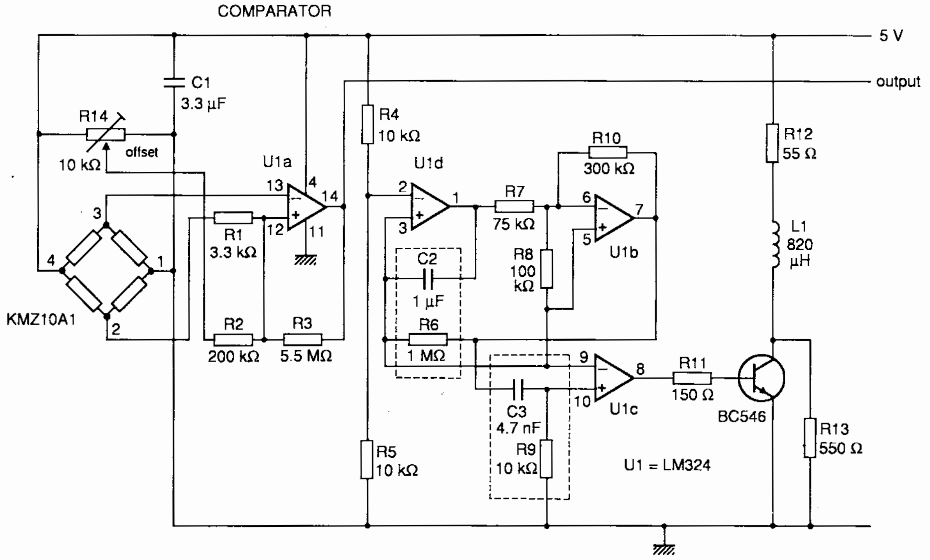


Fig.26 To remove the danger of flipping when the sensor is used without an auxiliary magnet (for maximum sensitivity), the sensor's polarity can be periodically reset by a coil L1

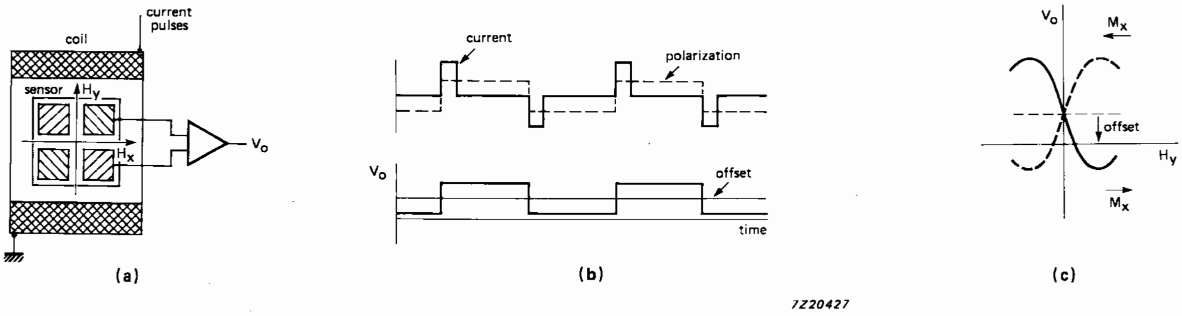


Fig.27 (a) Setup for measuring weak magnetic fields using a coil whose magnetic field is periodically reversed to continually flip the sensor's polarity and eliminate the effects of offset
(b) Pulse diagram
(c) Sensor output

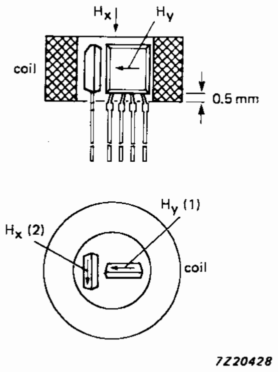


Fig.28 Magnetic compass using two mutually perpendicular 'turned' sensors inside a coil. As in the previous example, the magnetic field is periodically reversed to produce an output that's independent of offset

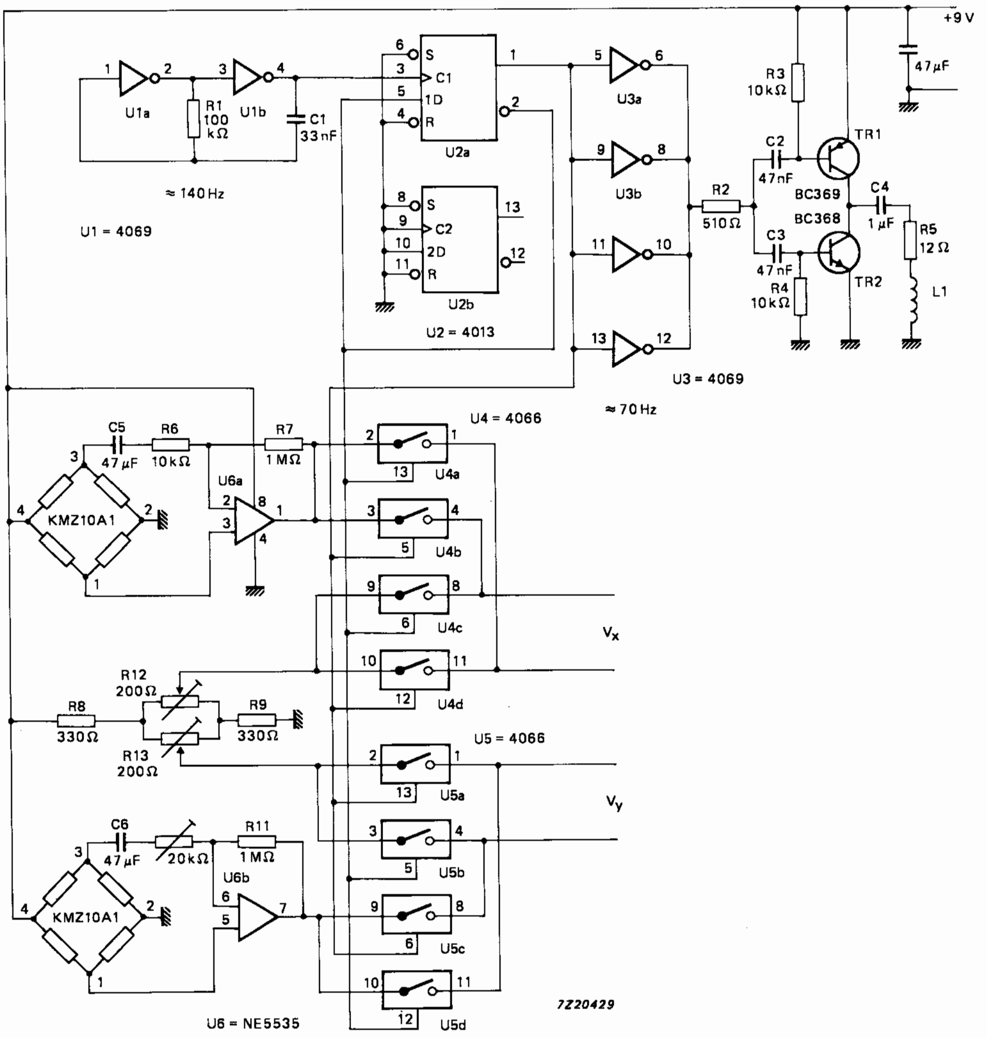


Fig.29 Circuit for delivering the current pulses and for processing the outputs of the two sensors