Magnetoresistor Differential Sensor FP 210

Operating Principle and Applications

The magnetoresistor differential sensor is used in many branches of electronics as an aid in evualting mechanical processes in digital and analog form in independence of speed. As a noncontacting signaling device it also serves as a further link between mechanics and electronics.

Constructional design and operating principle of magnetoresistor differential sensor

The magnetoresistor differential sensor FP 210 consists of two indium-antimonide resistors attached to a soft iron pole piece on the face of a permanent magnet (Fig. 1a). The magnetic flux Φ threads through both magnetoresistors simultaneously with the same flux density. The magnetic bias increases each magnetotransistor's intrinsic resistance R_0 (resistance at 25 °C in absence of magnetic field) of, say, 250 Ω to about 500 Ω.

The operating point (Fig. 1b) then lies higher up the curve. When a soft magnetic part is rotated past the sensor, one of its two magnetoresistors is influenced relative to the position of the iron part, i. e. the magnetic flux increases along with the resistance of the magnetoresistor. If the two magnetoresistors are used in a bridge (Fig. 1c), the signal will have the waveform shown in Fig. 1d: in position I, FP 1 exhibits high resistance and the bridge output voltage rises to a maximum. In position II both magnetoresistors are influenced equally and the bridge is in balance. In position III the soft iron part faces magnetoresistor FP 2 and the output signal again reaches a maximum but has the opposite polarity.

Data and characteristics

Since magnetoresistors respond to the absolute change ΔB of the magnetic induction B and not, as with inductive systems, to the rate of change, the output signal for a moving and for a fixed iron part is of the same amplitude. The maximum permissible speed depends on how fast the magnetization is reversed in the solid iron parts of the pole piece of the magnetoresistor differential sensor, whose sensitivity depends on the slope of the characteristic at the biasing point and on the absolute value of the bias resistance. A magnetoresistor differential sensor composed of the magnetoresistors FP 1 and FP 2 with the resistances R_{FP1} and R_{FP2} (Fig. 1c) in a bridge configuration yields at constant bridge voltage U the signal voltage

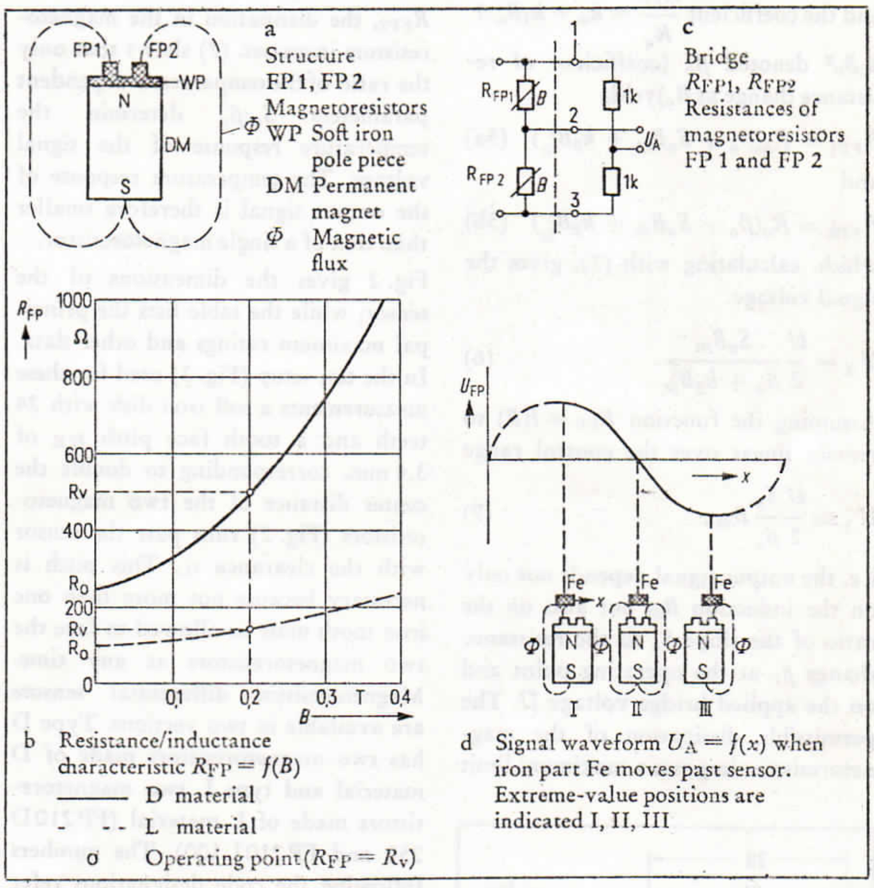


Fig. 1 Magnetoresistor differential sensor

$$U_A = \frac{U}{2}\,\frac{R_{FP1} - R_{FP2}}{R_{FP1} + R_{FP2}} \tag{1}$$

The magnetoresistor equation

$$R_{FP} = R_0(k_0 + k_1 B + k_2 B^2) \tag{2}$$

yields, when differentiated with respect to the induction B, the slope at the operating point

$$S_R = R_0(k_1 + 2\,k_2 B) \tag{3a}$$

or the relative slope

$$S_0 = \frac{S_R}{R_0} = k_1 + 2k_2 B. \tag{3b}$$

When the magnetoresistors are operated balanced, the inductances are

$$B_1 = B_0 + B_{St} \tag{4a}$$

$$B_2 = B_0 - B_{St}. \tag{4b}$$

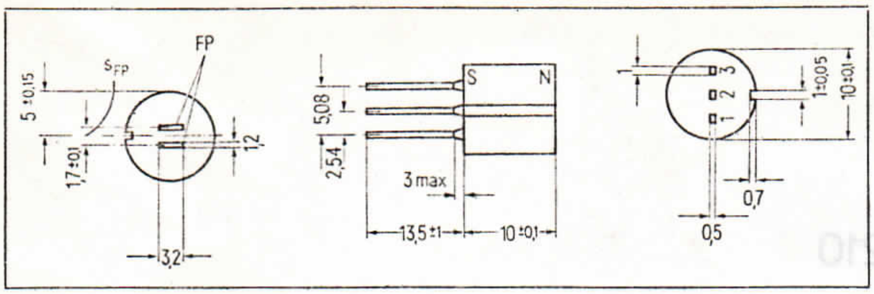


Fig. 2 Magnetoresistor differential sensors FP 210 D 250 and FP 210 L 100: dimensional drawing
FP Magnetoresistors; s_{FP} Center-to-center distance between magnetoresistors (1.7 mm)

(4a) and (4b) substituted in (2)

and the coefficient $\frac{R_{FP}}{R_0} = k_0 + k_1 B_0 + k_2 B_0^2$ denoted β_0 (coefficient of resistance change at B_0) yelds

$$R_{FP1} = R_0(\beta_0 + S_0 B_{St} + k_2 B_{St}^2) \quad (5a)$$

and

$$R_{FP2} = R_0(\beta_0 - S_0 B_{St} + k_2 B_{St}^2) \quad (5b)$$

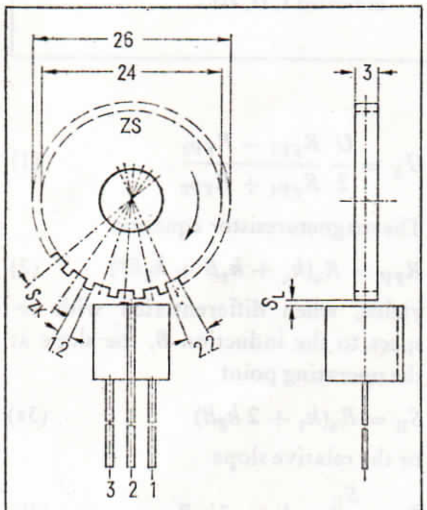
which, calculating with (1), gives the signal voltage

$$U_A = \frac{U}{2} \frac{S_0 B_{St}}{\beta_0 + k_2 B_{St}^2} \quad (6)$$

Assuming the function $R_{FP} = f(B)$ to remain linear over the control range

$$U_A \approx \frac{U}{2} \frac{S_0}{\beta_0} B_{St}, \quad (7)$$

i.e. the output signal depends not only on the induction B_{St} but also on the ratio of the slope S_0 to the resistance change β_0 at the operating point and on the applied bridge voltage U. The permissible dissipation of the magnetoresistors imposes a maximum limit



ZS Toothed disk
s_{ZK} Tooth face pitch $s_{ZK} = 2 s_{FP}$ (see Fig. 2)
s_L Clearance

Fig. 3 Setup for measuring the electric characteristics of a magnetoresistor differential sensor

on the bridge voltage U. Since any rise in temperature reduces $R_{FP1} + R_{FP2}$, the dissipation in the magnetoresistors increases. (7) shows that only the ratio of the temperature-dependent parameters $S_0 : \beta_0$ determin the temperature response of the signal voltage. The temperature response of the output signal is therefore smaller than that of a single magnetoresistor.

Fig. 2 gives the dimensions of the sensor, while the table lists the principal maximum ratings and other data. In the test setup (Fig. 3) used for these measurements a soft iron disk with 24 teeth and a tooth face pitch s_{ZK} of 3.4 mm, corresponding to double the center distance of the two magnetoresistors (Fig. 2) runs past the sensor with the clearance s_L. This pitch is necessary because not more than one iron tooth must be allowed to face the two magnetoresistors at any time. Magnetoresistor differential sensors are available in two versions. Type D has two magnetoresistors made of D material and type L two magnetoresistors made of L material (FP 210 D 250 and FP 210 L 100). The numbers following the code designations refer to the intrinsic resistance of one magnetoresistor at an ambient temperature ϑ of 25 °C. Fig. 4a shows the dependence of the output voltage U_A on the width of the clearance s_L between sensor and toothed disk, while Fig. 4b, c shows the temperature response and the frequency response respectively.

Typical applications

Pulse sender

A voltage pulse is produced when an amagnetic disk D with an iron pin Fe (Fig. 5a) runs past the magnetoresistor differential sensor FP. Fig. 5b shows the output voltage at the sensor when the disk rotates at about 3000 min⁻¹. The pulse waveform and height are independent of the rotational speed. The same output voltage remains available when the disk is at a standstill. Fig. 5c shows the sensor used in a simple trigger circuit.

Tachometer, remote-position indicator, rotary digitizer

A toothed wheel ZR (Fig. 6a) can be used in place of a disk with a pin. The tooth face pitch is again 3.4 mm. Teeth of any shape can be chosen; ratio of tooth width to tooth gap should be 1:2.

Fig. 6b,1 shows the output voltage at the sensor when a wheel with 24 teeth runs past. The pulses can be doubled by adding a second sensor (FP 2 in Fig. 6a; waveform as in Fig. 6b,2) or trebled by adding a third and arranging all three one pitch apart around the periphery. This may be necessary for rotary digitization. A variant version has a ratchet instead of a wheel.

Fig. 6c shows the circuit configuration of a tachometer built around a differential sensor.

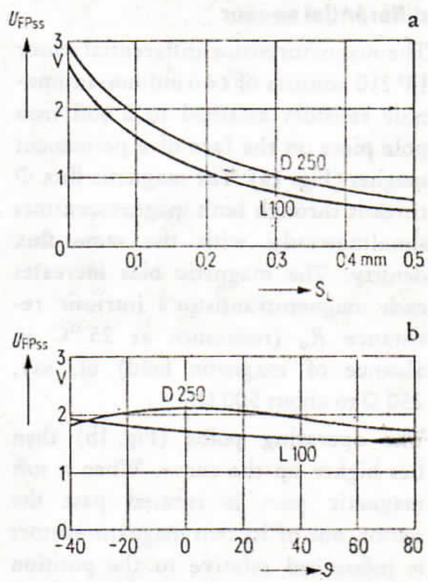
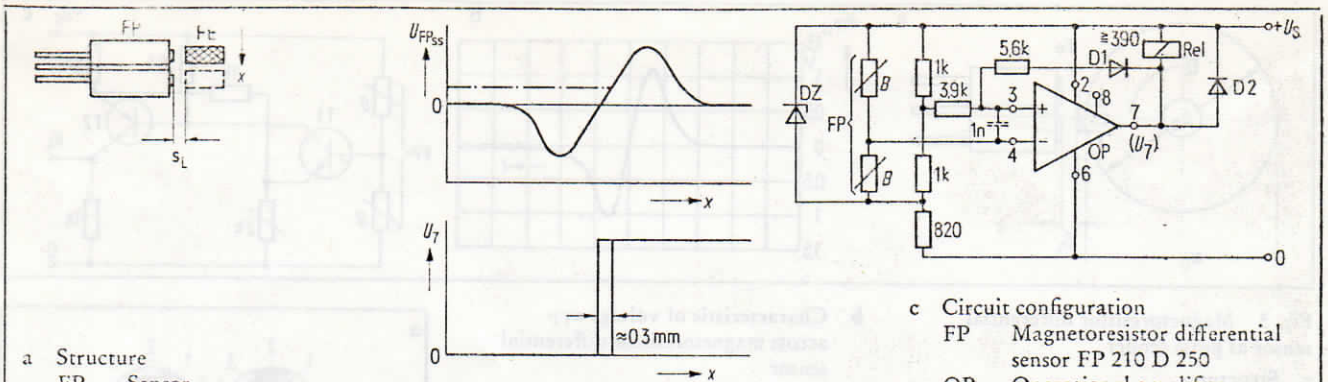


Fig. 4 Characteristics of a magnetoresistor differential sensor

a Signal voltage as a function of the clearance: $U_{FP} = f(s_L)$

b Signal voltage as a function of the ambient temperature $U_{FP} = f(\vartheta)$

c Signal voltage as a function of the frequency: $U_{FP} = f(f)$



a Structure
FP Sensor
FE Iron part (1.5 mm by 4 mm by 4 mm)
s_L Clearance (0.1 mm)
→ Direction of motion of Fe

b1 Waveform of voltage u_{FP} across sensor
—·—·— Trigger threshold
b2 Output voltage U_7 (hysteresis)

c Circuit configuration
FP Magnetoresistor differential sensor FP 210 D 250
OP Operational amplifier TAA 861
D1, D2 Diodes BAY 61
Rel Relay ($R \geq 390\ \Omega$)
U_s Supply voltage (20 V)

Fig. 8 Magnetoresistor differential sensor as noncontacting limit switch

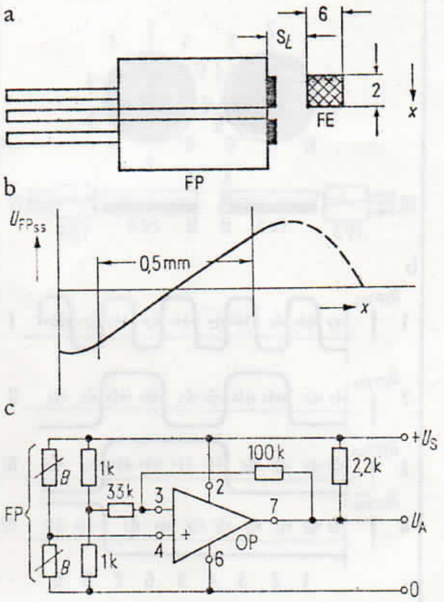
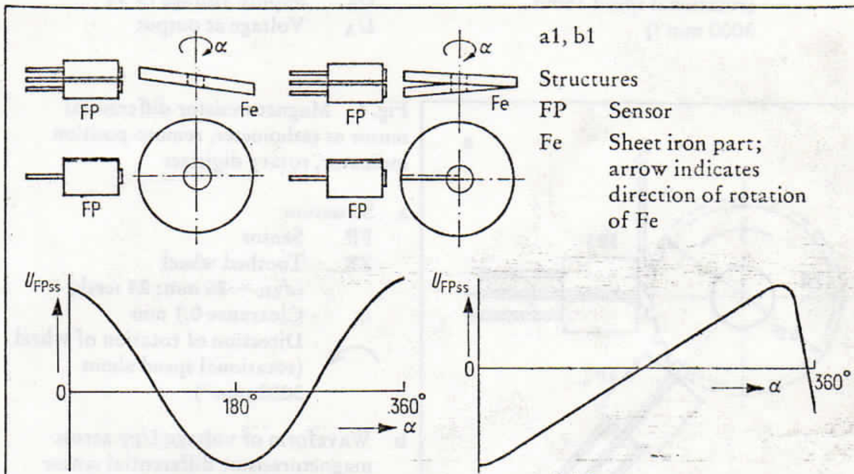


Fig. 9 Magnetoresistor differential sensor as displacement indicator

a Structure
FP Sensor
FE Iron part
s_L Clearance (0.1 mm)

b Waveform of voltage u_{FP} across sensor

c Circuit configuration
FP Magnetoresistor differential sensor FP 210 D 250
OP Operational amplifier TAA 861
U_s Supply voltage (6 V)



a1, b1
Structures
FP Sensor
Fe Sheet iron part; arrow indicates direction of rotation of Fe

a2, b2
Response of voltage u_{FP} across magnetoresistor differential sensor with the angle α

Fig. 10 Magnetoresistor differential sensor as noncontacting sine potentiometer (a) and noncontacting linear potentiometer (b)

Coding switch

The magnetoresistor differential sensor can also be used to form selectors such as the coding switch shown in Fig. 7a. Four sensors (FP I, II, III, IV) and four double iron disks (Fe 1, 2, 3, 4; disks A and B) can be used to represent the digits 0 through 9 in binary-coded decimal digits. A pair of disks with differently positioned segments is rotated past each sensor to produce the required signal (Fig. 7b), which is analyzed by a logic circuit. Any code can be represented by means of punched sheet metal disks.

Noncontacting limit switch

When an iron part passes a sensor (Fig. 8a) a signal with the waveform shown in Fig. 8b,1 appears. Assuming a clearance of 0.1 mm between sensor and iron pin and a supply voltage U_B of 10 V, the slope at the zero crossover is about 2 V/mm. With the circuit configuration shown in Fig. 8c it is possible to realize, assuming constant temperature, a switching repetition accuracy of ±1 µm. To assure stable switching states even in the presence of vibrations or other unstable external conditions, a hysteresis of about 0.3 mm has been introduced (Fig. 8b, 2).

Displacement indicator

The signal waveform shown in Fig. 7b indicates the practicality of converting a displacement into a proportional voltage (utilizing the linear portion of the characteristic at the zero crossover). The width of the iron part (Fig. 9a) affects the shape of the curve. Optimum linearity was realized with an iron part with a width of 2 mm. With the circuit configuration shown in Fig. 9c a signal voltage U_A proportional to a displacement of 0.5 mm is obtained when an iron pin is moved past the sensor with the stated clearance ($U_A \approx 0.3$ to 6 V).

Noncontacting potentiometer

Potentiometers can be designed for different functions by appropriately shaping the sheet iron part which is moved past the sensor. It is possible in this way to realize a sine potentiometer or a linear potentiometer which can be set to anywhere over about 300° (Fig. 10a, b).

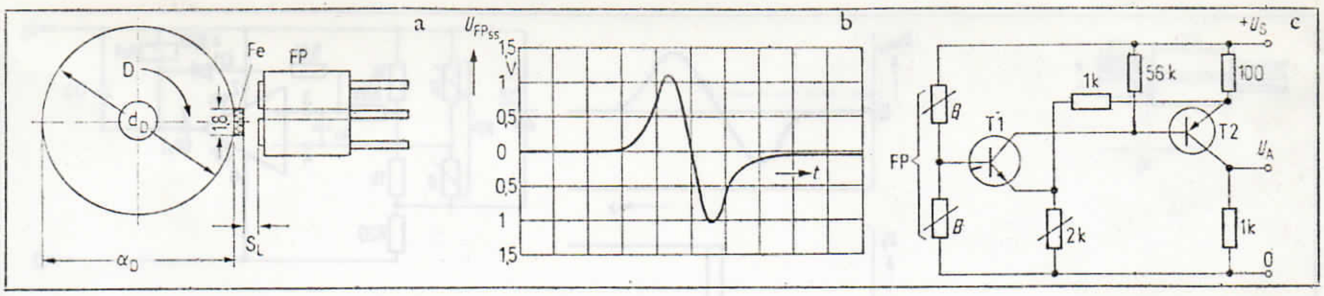


Fig. 5 Magnetoresistor differential sensor as pulse sender

a Structure
- FP Sensor
- Fe Iron pin (1.8 mm by 4 mm by 4 mm)
- D Amagnetic disk (d_D = 26 mm)
- s_L Clearance (0.1 mm)
- Direction of rotation of D (rotational speed about 3000 min⁻¹)

b Characteristic of voltage u_{FP} across magnetoresistor differential sensor
Abscissa: 0.5 ms/scale div

c Circuit configuration
- FP Magnetoresistor differential sensor FP 210 D 250
- T1 Transistor BCY 58
- T2 Transistor BCY 78
- U_S Supply voltage (5 V)
- U_A Voltage at output

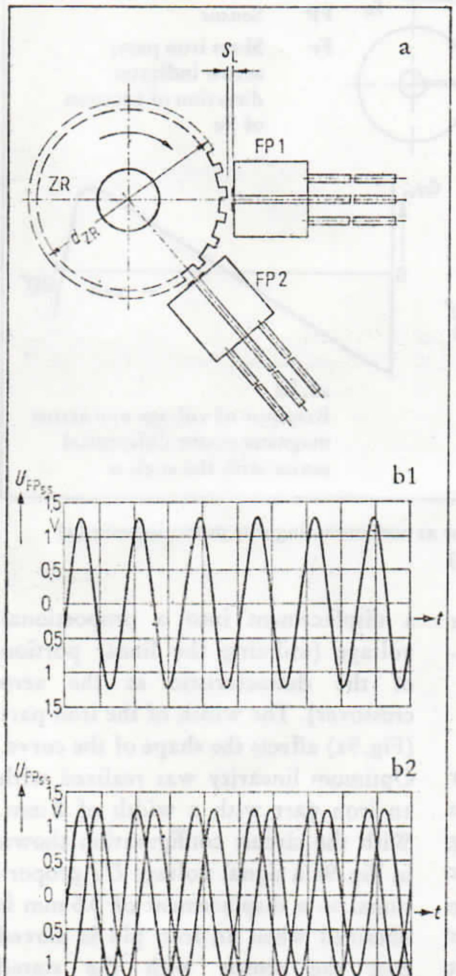


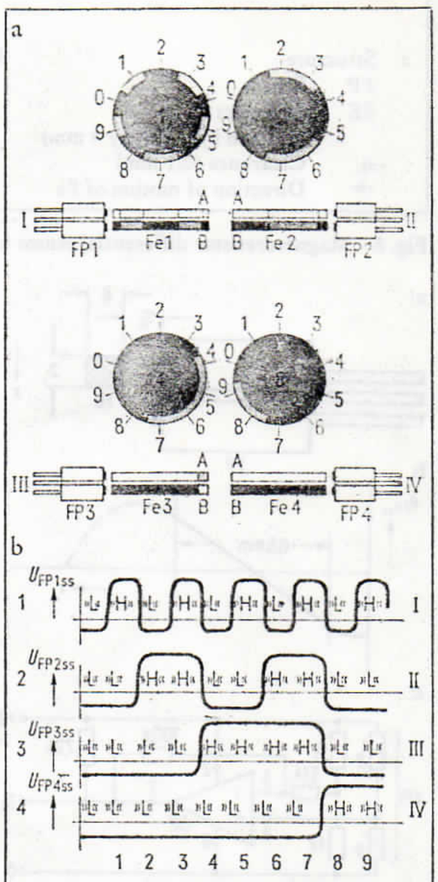
Fig. 6 Magnetoresistor differential sensor as tachometer, remote-position indicator, rotary digitizer

a Structure
- FP Sensor
- ZR Toothed wheel (d_{ZR} = 26 mm; 24 teeth)
- s_L Clearance 0.1 mm
- Direction of rotation of wheel (rotational speed about 3000 min⁻¹)

b Waveform of voltage U_{FP} across magnetoresistor differential sensor
- b1 with one sensor
- b2 with two sensors

Abscissa: 0.5 ms/scale div

c Circuit configuration of a rotary digitizer
- FP Magnetoresistor differential sensor FP 210 D 250
- T1, T2 Transistor BCY 58
- U_s Supply voltage (6 V)
- $C \approx \frac{0.75 \cdot 60}{nzR}$ [F]; n Max. rotational speed (min⁻¹)
- z Number of teeth; R = 100 kΩ



a Structure
FP I, FP II, FP III, FP IV sensors
Fe 1, Fe 2, Fe 3, Fe 4 Double iron disks (A, B)

b Signals

Fig. 7 Magnetoresistor differential sensor as coding switch

Electrical data of magnetoresistor differential sensor FP 210

<table>
<tr><th></th><th>FP 210 D 250</th><th>FP 210 L100</th></tr>
<tr><td>Maximum ratings</td><td></td><td></td></tr>
<tr><td>Operating temperature ϑ_B (°C)</td><td colspan="2">80</td></tr>
<tr><td>Electrical power-handling capability P (mW) of each magnetoresistor (at ϑ_{case} = 25 °C)</td><td colspan="2">250</td></tr>
<tr><td>Insulation voltage U_i (V) (between structure and case)</td><td colspan="2">100</td></tr>
<tr><td>Thermal conductivity G_{th} (mW/K)</td><td colspan="2">>5</td></tr>
<tr><td>Supply voltage U_{13} (V) (at ϑ_{case} = 25 °C)</td><td colspan="2">10</td></tr>
<tr><td>Parameters (ϑ = 25 °C)</td><td></td><td></td></tr>
<tr><td>Total resistance R_{13} (Ω) (clearance $s_L = \infty$)</td><td>1000</td><td>300</td></tr>
<tr><td>Tolerance Tol R_{13} (Ω)</td><td>± 300</td><td>± 80</td></tr>
<tr><td>Total resistance R_{12} (Ω) (clearance s_L = 0.1 mm)</td><td>≈ 2000</td><td>≈ 550</td></tr>
<tr><td>Output voltage U_{Ass} (V) (R_a = 1 MΩ, U_{13} = 6 V, s_L = 0.1 mm)</td><td colspan="2">2 (>1.5)</td></tr>
<tr><td>Center symmetry $M = \frac{R_1 - R_2}{R_1}$ for R_1/R_2 (%) (Clearance $s_L = \infty$)</td><td colspan="2">< 10</td></tr>
<tr><td>Cutoff frequency f (kHz)</td><td colspan="2">20</td></tr>
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