HOFFRICHTER

Datasheet

Micro-pressure sensors
Economic series
Small

PasCal

PC 100 / 500 1000 / 2000

Features

- extreme maximum overload
- high signal to noise ratio
- offset stability <400 ppm/K
- linearity fault <0,3%
- chamber volume <25µl

Applications

- industrial process control
- medical instrumentation
- clean room technology
- flow measuring
- analytical instrumentation
- leakage measurement

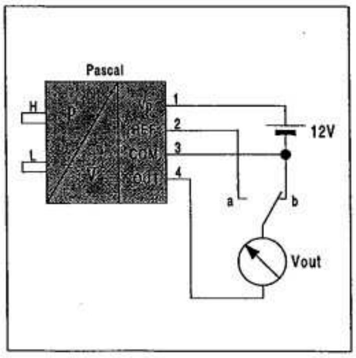
General Description

HOFFRICHTER's differential pressure sensors combine the high quality of the capacitive principle with the economic advantages of other technologies.

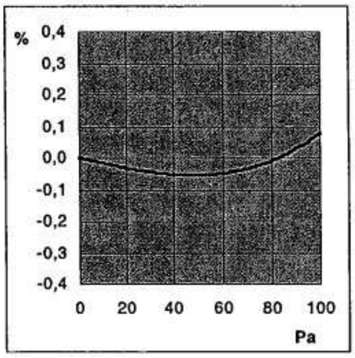
The sensors are made of a ceramic component and an integrated electronic part both built in a box consisting of hardly flammable material.

Only a single voltage supply between 10 V and 18 V is necessary. The range of the output voltage is between 0 V and 10 V. The pressure sensors can also be operated with a dual voltage supply, e.g. ± 5 V, and a bipolar output signal is also possible.

For standard operation, no additional components are required. The small size allows a very simple mounting directly on the circuit board. Sensors with 2 mm tube connector or with M3 female thread for 2 mm tube-coupling are available.



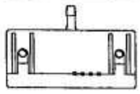
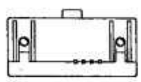
Electrical Characteristics Test Circuit



Typical Linearity Fault (PC 100)

MAXIMUM PERMISSIBLE VALUES

Power supply . . . . 20 V
Operating temperature range . . 0 ... 80 °C
Storage temperature range . . . . -40 ... 125 °C
Differential pressure . . . . 2 bar
System pressure . . . . .2 bar

	PC 100 SDET, PC 500 SDET PC 1000 SDET, PC 2000 SDET
	PC 100 SDEF, PC 500 SDEF PC 1000 SDEF, PC 2000 SDEF

Stresses beyond those listed under "ABSOLUTE MAXIMUM RATINGS" may cause permanent damage to the device.

CHARACTERISTICS

$V_p = 12$ V, 4 °C < ϑ_u < 70 °C

ELECTRICAL CHARACTERISTICS

SYM.	PARAMETER	CONDITIONS	PC100			PC500			UNITS
			MIN	TYPE	MAX	MIN	TYPE	MAX	
V_p	Supply voltage		10	12	18	10	12	18	V
I_s	Supply current	Io = 0	9	10	12	9	10	12	mA
U_{out}	Output voltage	Io = 0 Io = 100 µA Io = 1 mA	0,01	5	Vp -1	0,01	5	Vp - 1	V
U_z	Power supply rejection	Δp = 0, 10 V < Vp < 18 V		2	3		2	3	mV
R_a	Output resistance			51			51		Ω
SNR	Signal to noise ratio [1]			74			74		dB
C_{aut}	Capacitive load	Iout = 0	0		1000	0		1000	pF
U_{ref}	Reference voltage	Iref = 0	4,95	5	5,05	4,95	5	5,05	V
I_{ref}	Reference load	Vp > 12 V			1			1	mA

PNEUMATIC CHARACTERISTICS

SYM.	PARAMETER	CONDITIONS	PC100			PC500			UNITS
			MIN	TYPE	MAX	MIN	TYPE	MAX	
p_d	Linear differential pressure range	Vp > 12 V	-100		100	-500		500	Pa
p_g	Critical pressure	system pressure = 1 bar		1			1		bar
F_{lin}	Linearity fault			0,07	0,1		0,15	0,25	%
TK_N	Offset drift		200	400	600	-200	400	600	ppm/K
TK_0	Amplification drift		200	400	600	200	400	600	ppm/K
	Position dependence [2]	Δp = 0			0,3			0,1	%/g
F_{ges}	Total fault [3]	20 °C < ϑ_u < 50 °C		1	2		1	2	%
f_g	High frequency cut off	-3 dB		75			150		Hz

CHARACTERISTICS

$V_p = 12$ V, 4 °C < ϑ_u < 70 °C

ELECTRICAL CHARACTERISTICS

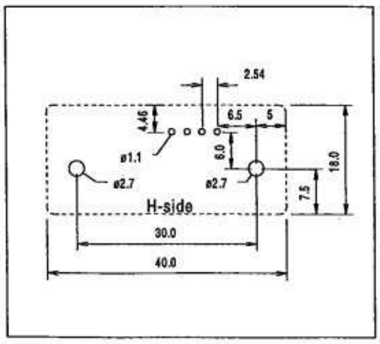
SYM.	PARAMETER	CONDITIONS	PC1000			PC2000			UNITS
			MIN	TYPE	MAX	MIN	TYPE	MAX	
V_p	Supply voltage		10	12	18	10	12	18	V
I_s	Supply current	Io = 0	9	10	12	9	10	12	mA
U_{out}	Output voltage	Io = 0 Io = 100 µA Io = 1 mA	0,01	5	Vp -1	0,01	5	Vp - 1	V
U_z	Power supply rejection	Δp = 0, 10V < Vp < 18V		2	3		2	3	mV
R_a	Output resistance			51			51		Ω
SNR	Signal to noise ratio ¹)			74			74		dB
C_{out}	Capacitive load	Iout = 0	0		1000	0		1000	pF
U_{ref}	Reference voltage	Iref = 0	4,95	5	5,05	4,95	5	5,05	V
I_{ref}	Reference load	Vp > 12V			1			1	mA

PNEUMATIC CHARACTERISTICS

SYM.	PARAMETER	CONDITIONS	PC1000			PC2000			UNITS
			MIN	TYPE	MAX	MIN	TYPE	MAX	
p_d	Linear differential pressure range	Vp > 12V	-1000		1000	-2000		2000	Pa
p_g	Critical pressure	System's pressure = 1 bar		1			1		bar
F_{lin}	Linearity fault			0,15	0,25		0,25	0,35	%
TK_N	Offset drift		200	400	600	200	400	600	ppm/K
TK_0	Amplification drift		200	400	600	200	400	600	ppm/K
	Position dependence ²)	Δp = 0			0,1			0,05	%/g
F_{ges}	Total fault ³)	20 °C < ϑ_u < 50 °C		1	2		1	2	%
f_g	High frequency cut off	3dB			250			400	Hz

¹) The signal to noise ratio is defined as the 20th logarithm of the quotient of the range#s end to the effective value of the noise voltage.
²) There is no position dependence if changing the position around the axis between the pressure inlets.
³) The total fault is the geometric addition of the single faults.

Layout from the component side



Ranges

Type	PC 100	PC500	PC1000	PC2000
±Pa	100	500	1 000	2 000
±mbar	1	5	10	20
±cm WS	1.01973	5.0965	10.1973	20.3946
±PSI	0.014505	0.072525	0.14505	0.2901
±inch WS	0.40147	2.00735	4.0147	8.0294
±inch Hg	0.02953	0.14765	0.2953	0.5906
±mm Hg	0.75006	3.7503	7.5006	15.0012

The technical data are subject to alteration, especially for the purpose of technological progress.

GENERAL INFORMATION

During the operation with capacitive pressure sensors, the pressure to be measured effects a variation of the distance between a flexible membrane and a fixed electrode. By this, the capacity between these two components is changed.

In comparison with other physical principles, capacitive pressure sensors are characterized by a very high precision and an extremely good resolution especially for the measurement of very small absolute and differential pressures.

In principle, the characteristic of capacitive pressure sensors is not linear. Some manufacturers solve this problem by using special electronics. HOFFRICHTER developed a certain sensor design which guarantees a relatively wide linear range.

For this reason it was possible to adapt the electronic optimally for a linear operation. So, electronic compensation components which are likely to negatively influence the stability are unnecessary.

The PasCal and CPS pressure sensors are made of a ceramic substrate with silver-palladium or silver-platinum thick layer electrodes. The membrane is made of a special steel or ceramic and is fixed by glass rings.

THEORY OF OPERATION

According to the differential principle, the differential pressure moves the membrane from one electrode in the direction of the other electrode. This is illustrated in figure 1. With the equations

$$C_1 = \frac{\varepsilon A}{(d - s)} \quad \text{and} \quad C_2 = \frac{\varepsilon A}{(d + s)}$$

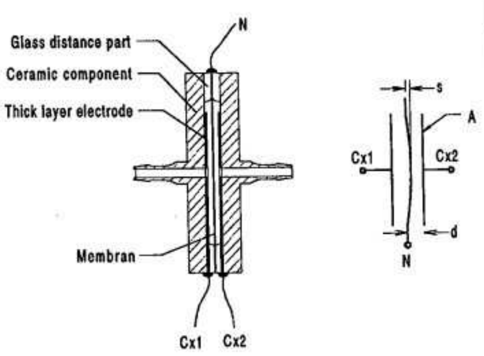


Fig. 1: Electrode arrangement for a differential plate condenser

e = 8,86 10-6 As/Vm
d = Distance between the electrodes without pressures
s = Defection of the membrane by pressure
A = Area of the electrode

we get the converter's equation

$$\Delta C = \frac{2 s \varepsilon A}{(d^2 - s^2)}. \qquad (1)$$

This equation shows the smaller s becomes compared to d the better the linearity will be. From this follows

$$\Delta C = \frac{2 s \varepsilon A}{d^2} \qquad [d >> s]. \qquad (2)$$

The deflection s is extensively proportional to the differential pressure. But additionally it depends on the membrane's characteristics e.g. the thickness. If all parameters are combined to a constant called K, finally follows

$$\Delta C = K \Delta p. \qquad (3)$$

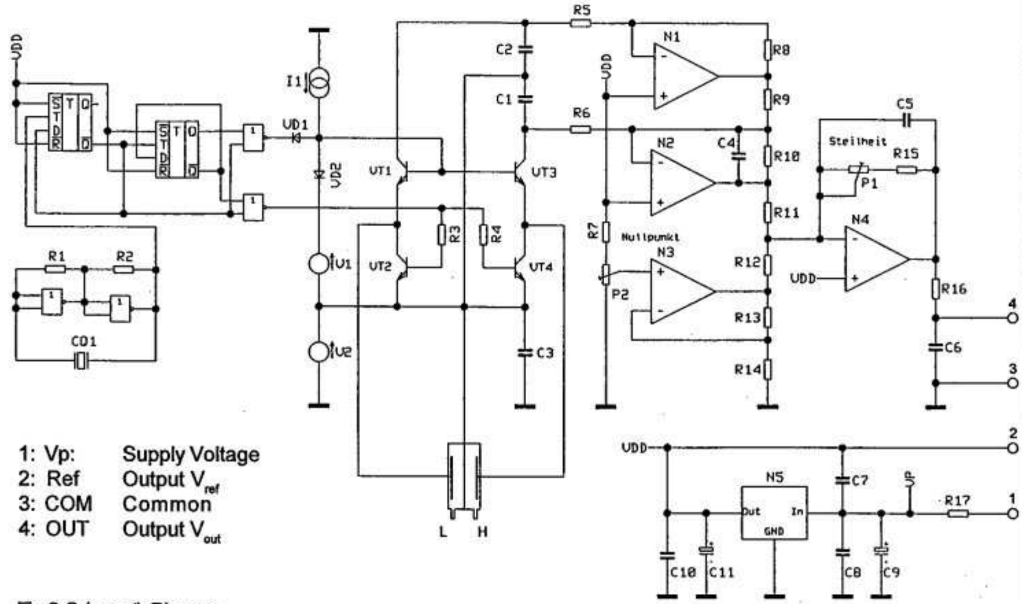


Fig. 2: Schematic Diagram

THE ELECTRONICS

For measuring the differential capacity, HOFFRICHTER uses a procedure which is described in literature as condenser recharge procedure. This means that the capacity is being charged and discharged permanently with a certain constant frequency. During this the average current is measured, because this current is independent of the characteristics of the charging and discharging function. Figure 2 shows the simplified schematic diagram.

Origin: HOFRICHTER-Patent; the patent rights have ended because of time reasons.

A quartz-generator controls two transistors in series connection, VT_1 and VT_2 or VT_3 and VT_4. A logic connection between the quartz-generator and the transistors generates a break between every switching.

If the transistors are conductive, the sensor capacities are charged by the much higher capacities of the condensers C_1 and C_2.

The voltage increase of the charging is V_{ref}. When the charging voltage has reached $V_{ref,}$ the controlling current Is is led through the diode VD_2 to the source V_{ref}.

After switching over by the controlling generator, VD_1 becomes conductive and the basis potential of the transistors is led nearly to earth potential. Thus, the transistors become non-conductive. After a period of time of about 100 ns the generator addresses the transistors VT_2 and VT_4. They totally unload the sensor capacities by a short-circuit.

The frequency of the periodic recharging is high. The OPA's N_1 and N_2 prevent the condensers C_1 and C_2 from unloading by generating corresponding currents with the negative feedback resistors R_8 and R_{10}. The capacities C_1 and C_2 are much larger than the sensor-capacities. Additionally, the resistors R_5 and R_6 cause a RC-low-pass-effect. Therefore the OPA-output-voltage is a DC-voltage.

PC 100/500/1000/2000 E-Series

During every period T of the recharging frequency f, every sensor-capacity takes a charge of

$$Q = C_x U_{ref}$$

C_x = sensor-capacity
U_{ref} = voltage increasing above C_x

and afterwards it will be unloaded by a short-circuit. During this periodical charging the condensers C_1 and C_2 are holding their voltage by a certain current provided by the resistors of the OPA's that are working in a negative feedback mode.

This is explained by the following equations:

$$I_{R8} = I_{R5} = f U_{ref} C_{x1} R_{11} \quad \text{and}$$

$$I_{R10} = I_{R6} = f U_{ref} C_{x2} R_{13}.$$

By that, following voltage is generated at the output of OPA N_2:

$$U_{N2} = f U_{ref} R_{10} (C_{x1} - C_{x2}),$$

After inserting equation (3) follows:

$$U_{N2} = K f U_{ref} R_{10} Dp. \qquad (4)$$

Additional amplification and offset-correction is done by OPA N_4.

DEFINITIONS

Absolute pressure

A definition of pressure concerning a vacuum without any additional pressure. E.g. the barometric pressure is defined as an absolute pressure. Sensors for measuring the absolute pressure normally have only one pressure connection to the outside of the housing. A second connection is mostly connected to a vacuum-chamber inside the sensor.

Relative pressure

The difference between a pressure-source and the atmospheric pressure. Typically the tyre pressure is a relative pressure. Differential pressure sensors are measuring the relative pressure if one connection is open.

Differential pressure

Difference between two pressure values. The pressure drop over a flow resistance is a typical differential pressure. With the help of differential pressure sensors, both relative and absolute pressure can be measured. The absolute pressure is measured if one of the two connections is connected to a vacuum.

Many technical and physical quantities can be traced back to the quantity PRESSURE. Mostly small differential pressures are generated. During flow measurement, for instance, the pressure loss on a flow resistance is measured. During height difference measurement, the principle of hose scales is applied, and during sensitive measurements of gap widths or distances, the method of flow or back-flow is employed.

Conversion table for pressure units

	PSI	in. WS	in. Hg	Pa	mbar	cm WS	mm Hg
PSI	1,000	27,680	2,036	6894,7	68,947	70,308	51,715
in. WS	3.6127 10^{-2}	1,000	7,3554 10^{-2}	249,1	2,491	2,5400	1,8683
in. Hg	0,4912	13,596	1,000	33864	33,864	34,532	25,400
Pa	0,014504 10^{-2}	0,40147 10^{-2}	0,02953 10^{-2}	1,000	0,01	1,01973 10^{-2}	0,75006 10^{-2}
mbar	1,450 10^{-2}	0,40147	2,953 10^{-2}	100	1,000	1,01973	0,75006
cm WS	1,4223 10^{-2}	0,3937	2,8958 10^{-2}	98,06	0,9806	1,000	0,7355
mm Hg	1,9337 10^{-2}	0,53525	3,9370 10^{-2}	133,32	1,3332	1,3595	1,000

SPECIAL PARAMETERS

Sensitivity

The sensitivity or the gradient of the characteristics is defined as the ratio of the output variation to the pressure value that has effected this variation.

Resolution

The resolution is defined as the minimal output variation that can be traced back to a pressure variation. The resolution limit is reached if the output signal cannot be distinguished from the noise level.

In contrast to resistors, condensers have no noise jamming. In this respect capacitive sensors are superior to all resistive sensors.

But for changing the variation of the capacity into an electric signal, an electronic circuit is necessary. The amplifiers used in such an electronic circuit have a certain noise signal and so the resolution of capacitive sensors is also limited. With capacitive sensors, it is possible to get a dynamic range of 4 to 5 decades. Only the imperfect electronic limits the resolution of capacitive pressure sensors.

Linearity

The sensor's sensitivity is not constant but it depends on the value of the input signal. The linearity fault is defined as the maximum deviation of the measured value from an ideal straight line which represents the connection between the input and the output signal.

In principle, capacitive pressure sensors do not work linear. But in case the membrane deflection is very small, the capacity variation is linear. That means it is proportional to the variation of the pressure.

The PasCal-electronic is able to distinguish capacity values in the range of femtofarads with a high stability. Very small membrane deflections in the range of nanometers can be detected so that the PasCal-sensors show an excellent linearity. For this reason, complicated electronic compensation circuits are not necessary.

Hysteresis, Reproduction

After deflecting the membrane by a pressure, the membrane does not return totally to the original state. This permanent deviation is called hysteresis.

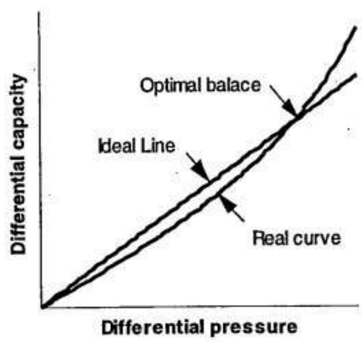


Fig. 3: Concerning the definition of the linearity fault

Offset

The output of a converter without pressure is called offset-voltage or only offset. The offset is an additive fault.

Offset-drift

Especially under the influence of an altering of the environment temperature or the sensor age, the offset can vary. A low offset-drift is one of the most important quality features of pressure sensors.

The unit of the temperature coefficient is normally PPM/K at the end of the measurement range. The following equation describes this physical connection:

$$W = W_0 \,(1 + TK\,\Delta\vartheta) \qquad (5)$$

W = Measured value after temperature variation
W_0 = Measured value before temperature variation
TK = Temperature coefficient
$\Delta\vartheta$ = Temperature variation in Kelvin

E.g. 100 PPM/K (= $100\ 10^{-6}\ K^{-1}$) means that the zero point of the sensor varies by 0,1 % of the total measurement range from a temperature variation of 10 K.

Sensitivity-drift

Not only the offset but also the sensitivity of a sensor varies. Temperature and the sensor's age have a main influence to the sensitivity. In this case, the unit is again PPM/K and concerns the measured value.

Before delivery, the PasCal-sensors are artificially aged in a climate chamber with different temperatures according to a certain program. This procedure guarantees a minimum drift of offset and sensitivity.

Dynamic range

The dynamic range of a pressure sensor characterizes the ability of its output-signal to follow the pressure-variation without time-lag. The dynamic characteristics are described by the limiting frequency and the transient time.

On principle, pressure sensors are low passes, because of their flexible membrane and their flow resistances. If measuring tubes are used, even an oscillating device is formed which is comparable with an electrically oscillating series circuit with a certain resonance frequency.

System pressure

In contrast to the differential pressure $\Delta p = p_2 - p_1$ which has an effect on the membrane, the system pressure influences the sensor's housing. For this reason, the system pressure is an absolute pressure or a relative pressure between the chamber and the environment.

Overload pressure

It must be distinguished between a **differential** and a **system overload pressure**. The membrane has to stand the differential pressure, the housing has to stand the system pressure. In case of exceeding the limiting maximum pressure, the sensor will be changed irreversibly. In case of exceeding the destroying pressure, the sensor will become leaking. Concerning the maximum and the destroying pressure, it must also be distinguished between differential, absolute and relative pressure.

The PasCal-sensors are extraordinarily resistant to overload pressures concerning both differential and system pressure. In spite of their excellent sensitivity, the PasCal-sensors are nearly indestructible.

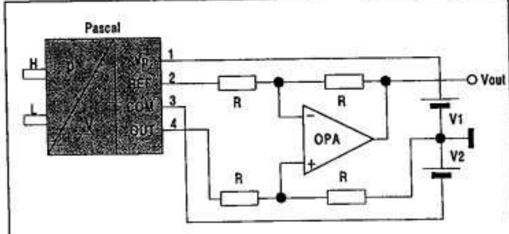
APPLICATIONS INFORMATION

Mounting

PasCal sensors can be mounted on an electronic board like any other electronic component. Additionally two cheese-head screws ensure a safe fixing.The housing is not totally water-proof. So liquids may damage the device. Beyond this, the pressure connectors must be protected against dust or dirt coming in. The screwing in of a tube-coupling must be done very carefully. For this reason, the used tool should have a stop dog so that the membrane cannot be damaged.

Power supply

The sensors can be used with single or with dual voltage supply. For bipolar operation, the output zero point has 5 V comparing to COM. Negative pressure differences reduce the output voltage down to some milivolts, positive pressure differences raise the output up to Vp - 1,5 V. In case of dual power supply and connecting the negative supply pole with the COM-pin, the differential voltage between COM and REF should be used as reference. Otherwise the changes of the negative supply voltage would distort the measurement (fig. 4).

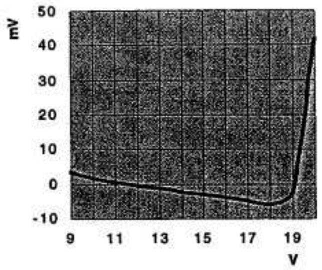


V1 = 5 V ... 9 V; V2 = -5 V ... - 9 V
(V1) + (V2) ≥ 12 V; Vout = ±5 V

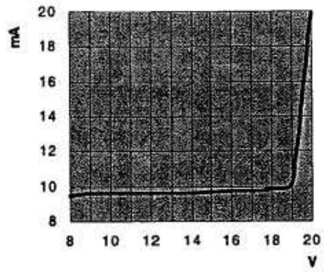
Fig. 4: Operating with dual voltage supply

The components are tested for operating with ± 5V. But in this case the maximum potential difference doesn't reach 5 V. This can be avoided by reducing the amplification or by using a less sensitive sensor e.g. by exchanging a PC 200 for a PC 100.

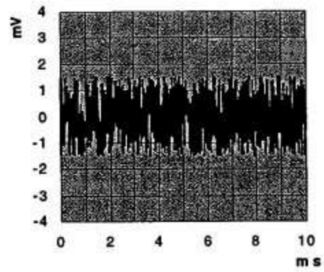
Aotput Voltage vs.
Supply Voltage (Δp = 0)



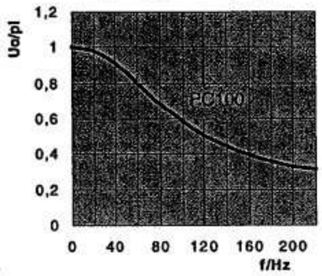
Supply Current vs.
Output Voltage (Δp = 0)



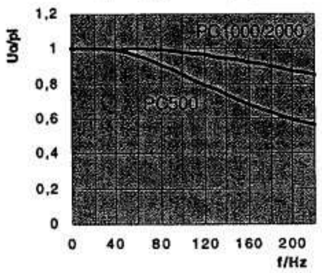
Wideband Noise
Δp = 0



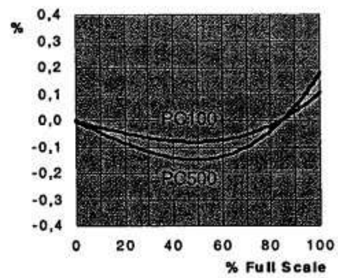
Gain vs.
Frequency (Sinus-Input)



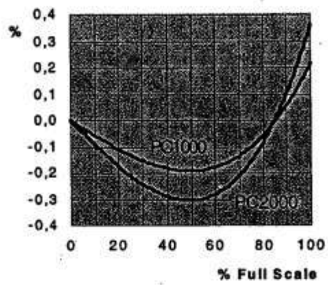
Gain vs.
Frequency (Sinus-Input)



Linearity fault
PC100, PC500



Linearity fault
PC 1000, PC2000



Maximum overload capacity

PasCal - sensors are extremely resistant against overload pressure. Only if the differential pressure is higher than 2 bar some PasCal-types show first changes. The overload behaviour can be divided into three phases:

Phase I: In the range between single and fivefold nominal maximum pressure only the linearity fault increases exponentially. But this has no effect, because output voltage is limited.

Phase II: If pressure becomes higher than in phase I the membrane is pressed to the electrode. So the output voltage either is 0 V or maximum. Up to the pressure limit which is much more higher than 1 bar concerning the PasCal-S-types there are no deformations of the membrane.

Phase III: Differential pressure values above the pressure limit may deform the membrane. This means an irreversible offset of the zero point. In this case the sensor must be newly adjusted. It is remarkable that such a overloaded sensor is resistant against further overloads in the same direction.

TYPICAL APPLICATIONS

Fine pressure sensors are often used for indirect measurements if the parameter to be measured can be traced to a pressure measurement. Because of their high maximum overload capacity, the PasCal-sensors are suitable for applications which may have extremely high pressures from time to time e.g. leakage measurement.

Flow measurement

The volume stream or the speed of a gas can be traced to a pressure measurement if the stream is led through a resistance by measuring the pressure drop. Concerning this there is a difference between effective and back pressure resistance. An effective resistance has a proportionality between flow and pressure drop and measurement ranges from 100/1 can be realized. A back pressure resistance has a proportionality between flow and the radical of the back pressure value. This extremely reduces the range of measurement. In the range of small back pressure values, the change of the radical value is high. For this reason, the zero point fault amplification is very high and so the measurement range becomes small. On principle, for the same range a squared value of precision is necessary. Therefore a range of 100/1 needs $100^2 = 10\,000$ amplitude steps from the sensor.
A classical example for back pressure measurement is the measuring of the flow rate with a PRANDTL tube.

Effective resistances for flow measurement are known as laminar flow elements (LFE). The flow channel is either divided into many thin tubes or equipped with a close-meshed sieve in the stream. The pressure drop from this resistance is measured.

Figure 5 shows the application of a PasCal-Sensor in a spirometer. In this case a special nozzle with two sieves is used. The interference from the streaming conditions in front of the first sieve is suppressed by the pressure compensation between the two sieves. The blind volume and the total resistance of the system are small. Additionally only one measuring tube is needed, because it is satisfactory to measure the relative pressure.

The differential amplifier N_1 compensates changes of the supply voltage of -5V. The N_1 output is, in every case, the difference between V_{ref} and V_{out}. The exhaled air is warmed up and saturated with water steam. For this reason the volume has increased by about 10%. The component N_2 compensates this volume difference (BTPS-correction). N_3 and N_4 serve for the output of flow and volume data issued in the form of a voltage signal which is intended for further processing.

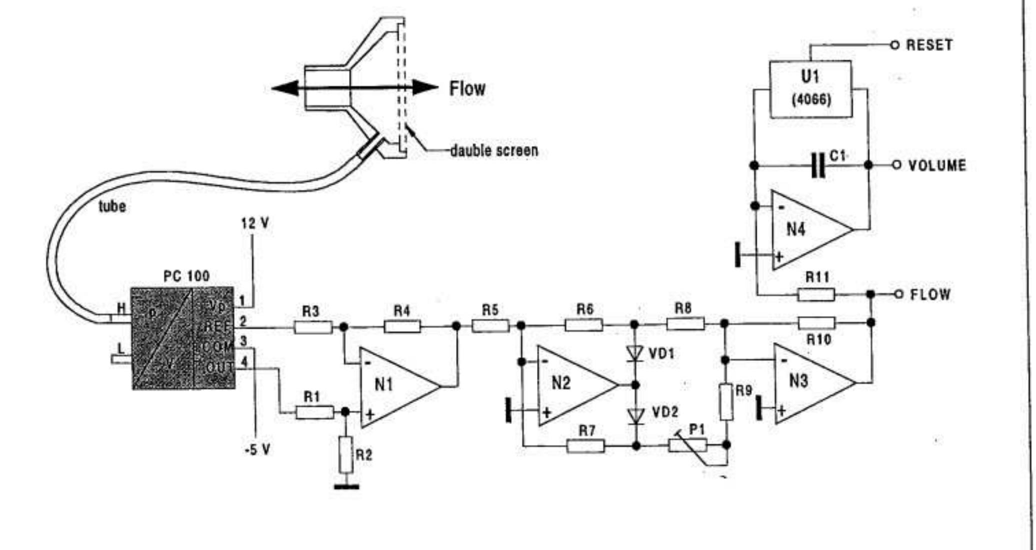


Fig. 5: Using a PasCal 100 for creating a spirometer

Density measurement

A simple way for measuring density of liquids is demonstrated in figure 6. The probe consists of two tubes with a certain length difference e.g. $h_2 - h_1 = \Delta h = 50$ mm which is positioned in the liquid. The same constant gas flow is given into the two tubes. The gas bubbles come out of the tubes in the liquid in a different height of Δh.

The difference of hydrostatic pressures in liquids is a parameter of the density ρ and can be measured very easily by using a PasCal-sensor. This is described by:

$$\rho = \frac{\Delta p}{\Delta h \ g} .$$

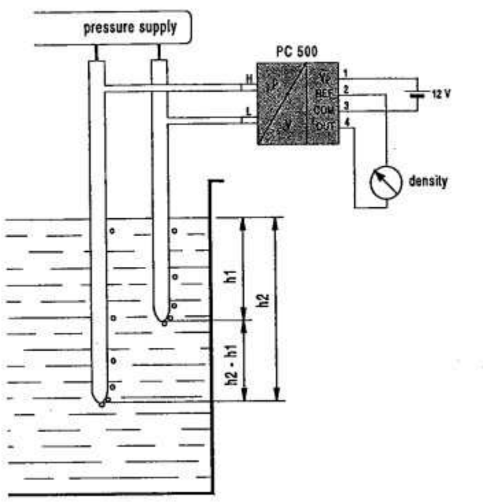


Fig. 6: Density measurement of liquids with a PasCal-sensor

Leakage measurement

Because of their extremely high overload capacity PasCal-sensors are extraordinarily suitable for use in leakage measurement devices. Figure 7 illustrates a leakage measurement device that is based on the back stream principle. A relative testing pressure of 2 bar is led through a capillary with a diameter of 1 mm to the device that shall be tested. In case of leakage, air streams through the capillary and a certain differential pressure can be measured. This is a parameter for the size of the leakage. The principle is described according to HAGEN-POISEUILLE:

$$\Delta p = \frac{128 \rho \nu l \dot{V}}{\pi d^4} .$$

Δp = differential pressure above the capillary in Pascal
l = distance between the pressure pick off in Meter
d = diameter of the capillary in Meter
ρ = density of the testing gas kg/m³
ν = cinematic viscosity in m²/s
$\dot{V}$ = Flow in m³/s

There is a proportionality between flow and pressure difference in case Reynolds number Re is less than 2000.

$$Re = \frac{4 \rho \dot{V}}{\pi \eta d} .$$

η = dynamic viscosity in Pa s

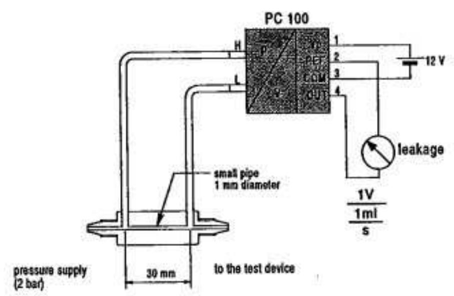


Fig. 7: Leakage detection according to the back stream prinziple

This procedure detects smallest leaks with a high sensitivity. The sensitivity of the device illustrated in figure 7 is about 1V for a flow of 1ml/s under normal pressure. For wider leakage measurement ranges more parallel capillaries are recommended. An extremely high sensitivity is given by a coil of copper capillary. Leakage measurements according to the pressure increase procedure detect the pressure change behind the tested device in a certain period of time during a high testing pressure. On the one hand, PasCal-sensors detect a leakage very fast, because of their high density. On the other hand, they won't be destroyed even if there is a large-sized leakage.

PC 100/500/1000/2000 E-Series

High precision pressure switch

Pressure switches are often used for filter monitoring in clean rooms. If extraordinarily high setting accuracy and switching precision are required, figure 8 illustrates a suitable wiring plan. The relay switches on if the differential pressure in front of and behind a filter or between two clean rooms exceeds a certain pressure value P_1.

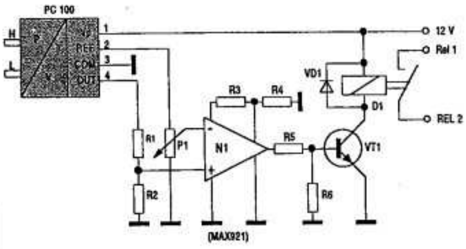
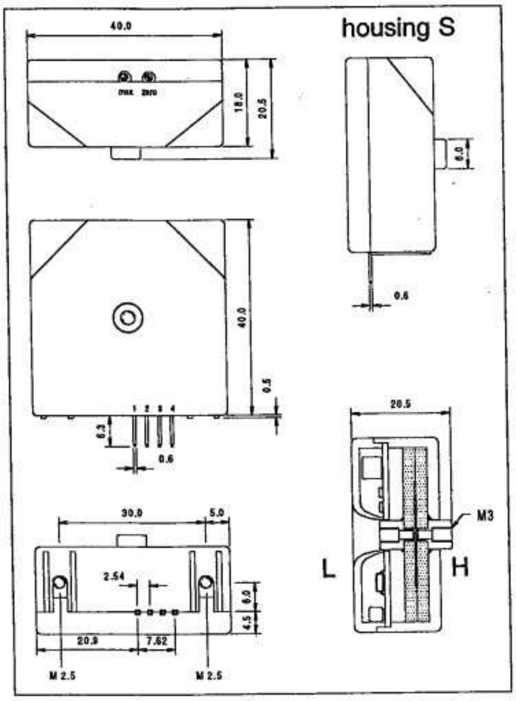
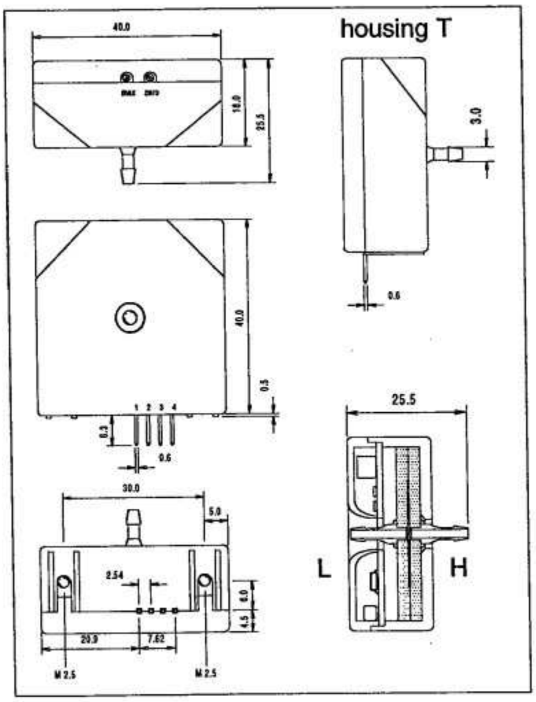


Fig. 8: High precision pressure switch





Specification code: PC | 1 | | 2 | 3 | 4 | 5 |

PC:	*PasCal* Series			
1:	Value of the range (Pa)			
2:	housing	S = Small	L = Large	C = Ceramic
3:	Kind of measurement	D = Differential pressure	A = Absolute pressure	
4:	Class	E = Economic	S = Standard	H = High Performance
5:	Pressure connection	T = Tube connector	F = Female thread	

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