Thin-film or Piezoresistive ?

Hardly another question has divided the camps of manufacturers and users of pressure transmitters as much as this basic technological decision regarding the design or selection of the sensor element. It was the data sheets and above all the prices from Keller AG that already 10 years ago repeatedly put manufacturers such as Bell & Howell (today Imo Industries), Statham, CEC or Hottinger under the compulsion of explanation.

In the following letter to the editor, H. W. Keller has combined his answers to two contributions from WIKA, D-Klingenberg, (appearing in the mpa magazine 10/95) and Baumer Electric,CH-Frauenfeld (appearing in SENSOR report, issue 6/95). The editors wish to particularly motivate the users amongst the readers to outline their experiences with the various types of sensor element. Here the letter from H. W. Keller, founder and Managing Director of Keller AG für Druckmesstechnik:

Two recently appearing articles in technical journals, namely ”Druckerfassung in der Serienapplikation” (Uwe Scherf/ Wikatronic) mpa journal 10/95 and ”Genauigkeitsmerkmale in der Druckmesstechnik” (Daniel Züllig/Baumer) SENSOR report 6/95, addressed the advantages of the thin-film technology and the doubts regarding the quality of mass-produced piezoresistive transmitters. Here, the content of the articles will be analysed and the advantages of the piezoresistive technology emphasized.

In the article from Wikatronic, it is firstly argued that the low-cost products must consent to a compromise in quality. It is said that:

“Increasing market competition and product comparability can cause the price pressure to continually increase especially for suppliers of series products. The call from the market for industrial pressure measurement technology at a ‘low price’ seemed to be heightened (not heard) by pressure measurement technology suppliers and should bring the long hoped-for price relief. The grasp towards pressure measurement technology from the newly created low-cost segment was therefore more or less preprogrammed. Yet one had soon to recognise that the continually growing demands on quality and product availability in series use was completely contrary to the low (cheap) idea. High product quality at an economic price is the formula.”

Disregarding that mental environmental contamination of the language is expressed here, the statement will no doubt insinuate that quality suffers with high volume suppliers at favourable prices. As the article generally refers to pressure measurement technology and WIKA belongs to the low-cost suppliers in the mechanical pressure measuring technology. They have not really been successful with their ”Tronic Line”, it is firstly said that at Wika, the low-cost approach is fully contrary to quality and product availability.
A classic home-goal.

Technology and mass-production have brought us electronic equipment such as pocket calculators, PCs, Fax machines or radio telephones in much higher quality and availability at much more affordable prices. This development has come relatively late into being in the electronic pressure measurement technology, is now however in full swing.

Also in the article from Baumer AG, it says at the end:

“It is not a margin of around 450 DM which lies between a 50DM transmitter and a 500DM, but generally transmitters which do justice to considerably higher demands.”

At Keller, special transmitters which are fabricated and sold in small quantities at high prices have a higher failure rate of than the high volume low cost transmitters manufactured in tens of thousands. In our opinion this is so for all products.

In both articles, the overload of the thin-film transmitters is addressed as advantageous in comparison with the piezoresistive ones. D. Züllig from Baumer Electric AG writes:

“For these (high) pressure ranges, sensors with sensor elements on steel membranes should be considered as preferable because, on overload resulting from pressure peaks, the ductile steel pressure sensor, in contrast to the brittle silicon, only shows an increased offset and not a total failure.”

This statement is similar to the argument that the seat belt should be preferred to the airbag because it has been statistically demonstrated that with the airbag the occupants after a crash either survive uninjured or are dead, with seat belts however all possible injuries occur, even paraplegia.

The overload statistics of todays silicon sensors are, depending on the full-scale output, 5 to 20 times the full-scale pressure. Anyone who knows Hook’s curve for steel knows that the signal of a thin-film sensor is no longer usable after five times overload. Add to this that (in contrast to people), the damage is not immediately discernable. If measurement continues over 3 months with a 10 percent error, the damage can really be very much higher than the replacement of a transmitter. If we were thin-film manufacturers, we would integrate a mechanism which made the sensor unusable at a certain overload so that measurement is not continued with intolerable errors. Silicon can be described as the absolutely ideal sensor material. Transmitters have been constructed so that after an overload crash, measurement can continue without hesitation if the sensor has survived.

We also defend ourselves against the term brittle. Materials with differing component stability are brittle, agglomerations of crystal formations where the adhesion between the formation is much less than inside a crystal structure. Silicon is a pure single crystal where molecular displacement is only possible by fissure. A hysteresis-free sensor can be built on the basis of silicon which is not possible with ductile materials as sensor carriers. We confront all statements that thin-film sensors excel on overload with the statement:

For applications where high overload peaks occur, sensors based on semiconductors are preferential to sensors with ductile sensor carriers. Semiconductor sensors excel through their high overload and the fact that there is no impairment of accuracy after an overload. With ductile sensor carriers, the sensor signal can distort as far as being absolutely unusable without it being immediately recognised.

We consider the statement in the article from D. Züllig: *”Sensor elements based on pure metals are superior to diffused semiconductor elements in their long-term performance.”* as being unfounded.

Yokogawa writes in the Product Information for Differential Pressure Transmitters with Semi conductor Resonator (**Verfahrenstechnik** Nr 12 / 95):

“The biggest drawback with metal sensors is the pronounced hysteresis characteristics, the effects of which measuring unit manufacturers in the past have made great efforts to try to minimize. The demand for higher accuracy however led inevitably to semiconductor sensors.”

This is written by a manufacturer who masters both technologies. In addition, the statement from D. Züllig is again a classic own-goal. The thin-film transmitters have therefore acquired a new attractiveness because the amplifier technology has improved enormously in recent years. And these amplifiers can can only be as good and as stable as the disapproved diffused resistors which are used in the semiconductor sensors.

We have already indicated this in our last Keller exhibition journal. In a two-year field trial in boreholes, stabilities of 0.02% were achieved for all ten enclosed Keller sensors. The applied temperature was between 60 and 120 °C. A similar long-term stability has still to be proved by the thin-film manufacturers and, until they have done this, lets formulate it the other way round:

Sensor elements based on diffused semiconductor elements are superior in their long-term performance to sensors with ductile sensor carriers.

D. Züllig from Baumer writes further:

“The amplifier electronics deteriorate somewhat similarly for every product.”

We can agree with this. But, when the amplifier demonstrates a deterioration of 20µV then this is 0.1% of the full-scale with a 20mV signal from a thin-film sensor, with a signal of 1000mV from the piezoresistive sensor, it is 50 times less in relation to the measuring range.

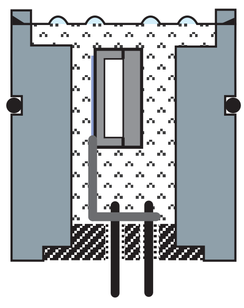
Furthermore, the article is worded:

“The more direct and durable the coupling of the active sensor element to the measuring membrane, the more stable the behaviour of the sensor over time.”

In the illustration it is indicated how, with thin-film sensors, the pressure effect is direct, with isolated incorporated silicon sensors many individual components come together.
Conclusion: The thin-film sensor is more stable.

The following argument to this: The separating diaphragm technology will soon be 100 years old and is used in differential pressure sensors down to a measuring range of 1 mbar. The pressure transmission can be practically resistance-free over the membrane diameter and constructed without temperature effect via compensating exposed conductive parts. The membrane is therefore also in a neutral condition over the entire temperature range.

In contrast to the thin-film sensors where the humid reference atmosphere directly effects the sensor elements, the oil chamber forms a perfect protection for the sensor. Furthermore, the piezoresistive OEM sensor enables stress-free integration into a pressure housing via an O-ring seal while the thin-film sensor is welded to the housing and therefore exposed to the body tensions of the housing which change uncontrollably with the temperature.



The ideal sensor design.
Piezoresistive pressure measuring cell, free of body tensions, hanging in oil. Body with separating diaphragm and O-ring for floating integration into the housing.

Conclusion:
The piezoresistive sensor can be mounted without any stress effect from the housing and is much better protected than the thin-film.

The article from D. Züllig begins with a discussion about the usefulness of the ISO standards. Unfortunately he makes the confusion even greater with his article by mixing up temperature stability and temperature effect. He writes:

"For the most part, the temperature stabilities are described with the temperature coefficients of the zero point and the output voltage.

Hard to believe that something like this can appear in a renowned technical journal. It literally provokes contradiction.

A PRESSURE SENSOR IS AS ACCURATE AS IT IS PRECISE

Mr. Art Zias already worded it this way 30 years ago. Everything which is repeatable under the same conditions can be compensated. Today, a temperature error of 3% can easily be compensated. That which can not be compensated, are the instabilities, ie, the temperature or pressure hysteresis and symptoms of deterioration. These are the uncertainties which are summarized under the term "precision".

Conclusion:
A sensor or transmitter is as accurate as it is precise. The accuracy of every sensor can be trimmed as far as the limits of precision. A piezoresistive sensor is a potentially 0.02% accurate sensor and this without recalibration for years over the entire temperature range of -40 to 120 °C, even after overloads of up to 10 times the measuring range.

Of course the costs of compensation are determined by the demands on accuracy and only as much expense is applied as is necessary. With digital compensation based on customer-specific circuits however, fantastic possibilities are given today and high value transmitters trimmed to 0.1% at costs of 50DM are today absolutely within the realms of the possible.

One can also deny that measurement through the entire temperature range is very expensive. In systems, up to 300 units are run simultaneously over the temperature and pressure, trimmed and, in the same installation, checked for stability in two further temeperature cycles. Such a test station demands a high initial investment, the test itself, with installation and dismantling, costs less than a one-days-labor. The surplus hardware costs for the digital compensation are around $ 2 which by far does not cover the cost of the individual adjustment. This new µP-based technology therefore presents us with much more accurate highly qualified transmitters at low production costs.

Another word on stability, which in the article from D. Züllig is addressed as a large uncertainty factor. Of course the stability is an uncertainty factor. One can only express it as a statistical value. And this statistic is the more accurate and reliable the more examples are recorded. At Keller, over 20'000 transmitters per month are recorded statistically for stability behaviour over three temperature cycles and thousands of pressure cycles.

Lots of 100 transducers or transmitters are continually tested in ovens and conclusions drawn on the first test. This subsequently enables us to make a statement about each transmitter such as: The probability that, under certain circumstances, this transmitter maintains a stability of 0.1% over one year is 99.5%. One observes that with stability, the application conditions must always be included. The DIN wording which relates the stability only to laboratory conditions does not help the user at all.

We can only agree with the basic concern in the article from D. Züllig that the DIN standards 10086 for measuring transducers are absolutely useless. In the exhibition journal for Sensor 91 we have already drawn attention to this. Here some extracts from this article

A year ago, the new DIN standards were presented to the public for checking and comment. Nobody seems to be interested, the trade press has not taken up this topic. Besides, amendments and guidelines in this matter are long overdue. With these lines, the author hopes to open the discussion about it.

At the end of the article (from Baumer in issue 6/95), the trade journal SENSOR report calls for comments. We are availing ourselves of this here. The article in the exhibition journal says the following about specifications:

SPECIFICATIONS:

In our almost 20 years of business activity only once have we called on the DIN standards for the design of the specifications. Sensors drifted away in the field. We asked if the reference conditions according to DIN (temperature 23±1°C, position of the transmitter 90±2 degrees, etc.) had also been nicely adhered to. They just shook their heads.

That such DIN documents are hardly taken notice of has surely to do with the fact that they are written in such a way as if the measuring technology had stood still. Page for page they harp on about 10% Hysteresis and repeatability curves as if one was still in the aera of the badly glued strain gauge.
The term stability does not exist or only appears in bad German translations. The extent to which the measured value of a sensor can drift after one year of use can not be determined from any of the 55 specifications requested.

Maybe it has also not escaped the notice of the DIN committee that transmitters are no longer only used under laboratory conditions.

Generally, the transition should be made to information from error bands which then really contain all possible influences. These error bands can have temperature, time and load factors. This method enables immediate error assessment without a lot of unclear data having to be added or calculated according to whatever method.

This would also put a stop to abuses in the nature of specifications. It is a beloved bad habit to promote values of several zeros after the comma for particular accuracy for hysteresis or repeatability. First of all, the customer can never verify this and, in the majority of cases, a temperature drift of one degree already brings the larger error.

Linearity is still an important advertisement for pressure transmitters. In the majority of data sheets it is impossible to find out how it is determined. Here the Americans are distinguished above all in that they always determine the linearity according to the method with the best straight line, even with sensors and recorders where the zero point is undefined.

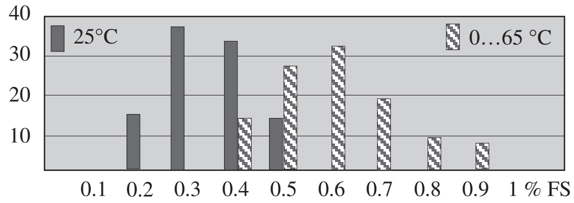
Also from the same corner comes the method of the typical error band information. According to the DIN standards this is permissible when the assessment method is given.
However, as far as is known, nobody does that. It is difficult to withdraw from this development while a maximum error calculation demonstrates an economic and often negative picture. As the adjustment can be designed so that errors can be rectified, the error tape method gives the manufacturers significantly more room for play.

In its new catalogue, Keller AG für Druckmesstechnik provides the error bands of the different classes of transmitters. Here, a maximum error and a typical error is given for various temperature ranges. The maximum value, as the greatest deviation of the actual value to the set value over the entire pressure and temperature range, is determined to 100%. As a typical value, the maximum of the error distribution curve is given. See diagram.
The linearity, the stability and the temperature coefficients of zero and gain are also given in the data sheets. For an OEM customer, the statistical distribution can be of great use as from this he can see that with an order for 100 items, he can seek out 10 with a linearity better than 0.1%, 50 items with a linearity better than 0.25%, etc.

Further values such as the EMC values or acceleration sensitivity, resonance frequency, rate of response or dead volume variation are only then offered when they could be relevant for the normal application of the product. Hysteresis is no longer given as it is practically no longer measurable for piezoresistive sensors.

Closing Remark:

Arguments such as in the two articles addressed have only been met in the past at customer level (and this time and again). We are grateful to the authors and journals that they addressed the public with them. This has at last given us the opportunity for a counterrepresentation.



Error Band Statistics from 100 Transmitters
PA-21-50 bar; 4…20 mA; Class 0,5 %

53 items (38+15) with max. error at 25°C of < 0,3%
42 items (28+14) with max. error < 0.5% in the range 0…65°C
Typ. max. error at 25°C: 0,3%; in the range 0…65°C: 0,55%

KELLER Data for Class 0,5 %

Temperature	20…25°C	0…50°C	-20…80°C
Max. error	0,5%	1%	2,5%
Typ. max. error	0,3%	0,6%	1,5%

Remarks:
Typical error information is statistical information concerning the size of the maximum error in a production series. It is not a statement concerning the error of an individual transmitter in specific pressure or temperature ranges.

With the typical error information, KELLER AG defines the