# Oxide Ceramic Precision Sensors for the Magnetic-Inductive Flow Meter

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## Summary

This document offers an overview of the development of the ceramic sensor for magnetic-inductive flow meters over the past 20 years. The result today is a product which combines high precision measurement with robust thermo-mechanical properties.

## 1. Introduction

According to a study published in June 2001 (1), the market volume for flow meters in Europe grew from 867.6 to 890.3 million US $ in the period from 1997 to 2000. Magnetic inductive flow meters (MID) have now exceeded a 27% share of the market. Annual growth of over 2% is expected. MID with ceramic precision sensor will also benefit from this positive development due to a considerable increase in their reliability in the past few years. The following overview will summarise the level of technology which has been achieved.

## 2. Measuring Principle

The MID – measuring principle (figure 1 from (2)) is based on Faraday's law of induction:

$$U = c * D * v * B$$

(c = unit constant, U = voltage, D = gap between electrodes, v = flow speed of medium,
B = magnetic induction)

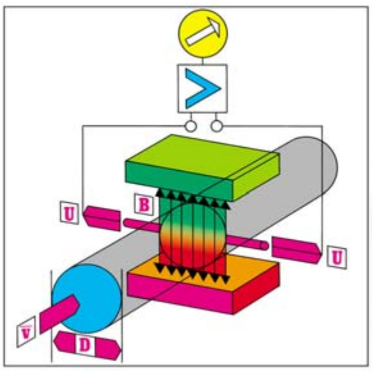


**Figure 1:** Measuring Principle

The essential advantage of this measuring principle is fundamentally the linear connection between the flow speed of the medium transmitting electricity and the tapped voltage. This allows a wide range of measurements to be recorded without any difficulty and to be analyzed straight away without the need for any complex correction measurements (2).
Further advantages are the negligible effects of viscosity, density, pressure and temperature of the flowing medium during application in practice and the fact that there is absolutely no need to install any components in the flow diameter of the analyzer.
Of course, it is not possible to measure gases and liquid dielectrics using this principle. Processes which work on, for example, the Coriolis principle (3) are suited to this task.

## 3. Material Outline

The geometrical stability of the tubular sensor under load by temperature and pressure is among the properties of the electrical and mechanical components a deciding factor in the adequate reproduction of the electrical signal of a MID, as this significantly affects the distance between the electrodes and the resulting precision of the measurement. The choice of the materials for the measuring pipe and the electrodes as well as the suitable technology for connecting the electrodes with the measuring pipe is of central importance for the long term reliability of the MID.
Core properties of suitable materials for precision – MID can be summarised as follows:

- Non magnetic
- deformation < 0.1 % under maximum load by temperature and pressure
- leak rate for He < $10^{-7}$ mbar * l/s with pressure load of 60 bar on the inside of the sensor
- may be steam sterilized
- corrosion resistant in acid and alkaline solutions
- certified for use in the food industry
- marketable prices

According to the state of the art, ceramic materials have the most comprehensive potential to fulfil this complex profile, bearing in mind that the specific demand for special chemical and electrical qualities limits the range of useful materials to oxide ceramics based on alumina and zirconia.

The aim of making MID applicable for media transmitting electricity as universally as possible requires the use of precious metals as material for the electrodes. For this reason, based on the results of various pre-studies, platinum is used as this metal is resistant to a wide range of chemicals and is suited for the manufacture of highly vacuum tight joints with oxide ceramics due to its thermal and mechanical properties.

# 4. History and Current State of Affair

Since the beginning of the joint development with Fa. Krohne Messtechnik GmbH & Co. KG (Duisburg) approximately 20 years ago, the basic requirements of a precision sensor have remained the same. However, both the materials and the construction of the sensor have been continually improved during that time.

## 4.1 Materials and construction

Originally highly pure ceramic made from $Al_2O_3$ (Friatec, Type F 99.7) was used for all manufactured MID-diameters (DN 2.5 – DN 100), which was very well suited to the requirements listed as it is corrosion resistant in all known areas where MID is applied. Figure 2 shows the typical microstructure of this material.

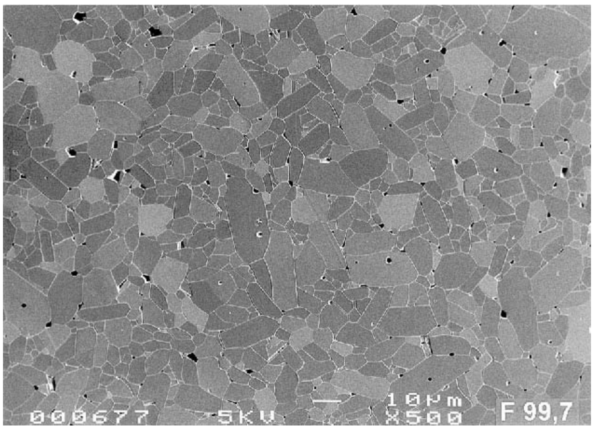


**Figure 2:** Microstructure of F99.7

However, in the past it was noted in individual cases that the sensor was potentially damaged by extreme changes in temperature. In order to increase the resistance to thermal shock (TWB) significantly, its design was optimized using Finite Element Analysis (FEA) and at the same time a new ceramic material of increased strength was developed. Figure 3 illustrates the contrast between the original construction and the product once FEA had been applied.

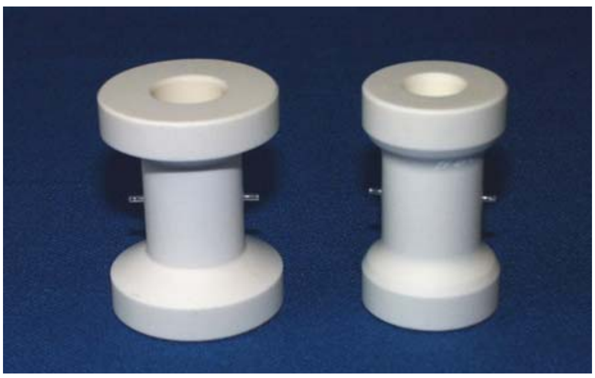

**Figure 3:** Sensors before (left) and after (right) FE-analysis

A further improvement of TWB in the ceramic was expected due to the connection as shown and the increase in strength of the material:

$$R' = \sigma B \, (1 - \nu) \, / \, E \, / \, \alpha$$

(R‘ = first heat stress factor, $\sigma B$ = bending strength, $\nu$ = cross contraction value, E = elasticity module, $\alpha$ = thermal expansion coefficient)

One way to achieve this is in principle the reduction of the size of crystallites in the microstructure of the ceramic. With this in mind, a new material (Friatec, Type FZT) was developed which had smaller grain sizes in its microstructure compared to F 99.7 (5). Figure 4 shows the typical microstructure of this material.

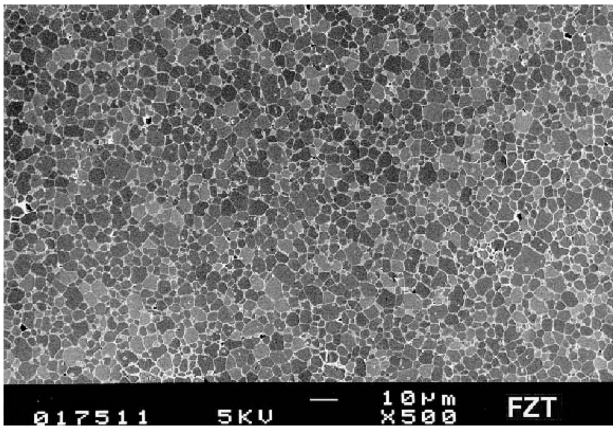


**Figure 4:** Microstructure of FZT

Some of its essential properties are summarized in Table 1, where its significantly improved strength compared to F 99.7 needs to be emphasized.

**Table 1:** Ceramic material parameters

| **Size** | **Condition** | **Dimension** | **F 99,7** | **FZT** |
|---|---|---|---|---|
| Density | 20 °C | g / cm³ | 3,90 -3,95 | 4,10 -4,15 |
| Average bending strength | 20 °C | MPa | 350 | 450 |
| Young’s modulus | 20 °C | GPa | 380 | 360 |
| Poisson’s ratio | 20 °C | - | 0,22 | 0,23 |
| Thermal expansion coefficient | 20 -100 °C | ppm / K | 5,8 | 5,6 |
| Specific electrical resistance | 20 °C | $\Omega$ * cm | $> 10^{15}$ | $> 10^{13}$ |
| Dielectrical constant | 20 °C, 1 GHz | - | 9,5 | 10 |

Result: FZT – material is a robust material even for MID – applications requiring a high TWB.

## 4.2 Joining Technology Ceramic - Electrode

When considering the sensor, special attention must be directed to the joint between ceramic and electrode, as different materials with different properties must be joined to ensure that leaks in operating conditions are permanently prevented.

The original joining technique involved the platinum being shrunk into the ceramic in the shape of a solid pin during the sintering process creating a leak free joint in this clamping process. This process demands a highly sophisticated knowledge about the hole's construction, where the pin has to be mounted, as the contraction of the ceramic during the sintering process is what allows the platinum pin to be shrunk in. So the manufacture of sensors using such technology is expensive.

This state of affairs led to an electrode being developed with closer thermal properties to the ceramic. The solution was a cermet electrode which is manufactured from a mixture of ceramic and platinum powder and was sintered into the ceramic after a pre-sintering process to adjust the required level of contraction (6). The cermet electrode was made using a platinum powder characterised during processing by a carefully targeted morphology. This type of powder which has been developed by FA. Heraeus GmbH (Hanau) allows for a platinum content of less than 35 Vol.-% in cermets and resulting comparatively low precious metal expenditure (7).

A significant aspect of the MID and its ability to be applied in practice is its thermo-mechanical
stressability as is required for example during cleaning and sterilizing processes before a change of product. According to results of simulation tests a TWB of 100 K was achieved following the introduction of cermet electrodes in the case of DN 15 during several hundreds of thermal shocks. As the specific application requirements for MID may also demand a higher TWB, a new procedure was developed to ensure improved operational safety, which consisted of the cermets being integrated in the ceramic already during the design stage, resulting in a homogenous joining zone between ceramic and electrode (8).

Figure 5 illustrates that the joining zone between ceramic and cermets is visible only because of the presence of platinum. There are no other signs of a ceramic contact zone.

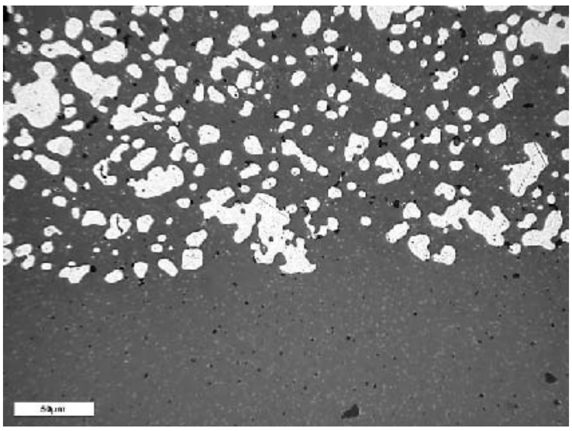

**Figure 5:** Joining zone ceramic - cermet

The joining quality, macroscopically, is characterized by a considerable increase in TWB and by unusually high forces required to burst the sensors, but also by extremely low leakage rates when subjecting the sensors to 60 bar internal pressure using helium.
Another positive effect is the fact that the underground of the electric signal is considerably lower than that of the metal pin due to its widespread metal framework in cermets. The integration of the cermets already during the design process of the precision analyzers results in a significant reduction in its inductive resistance which seems to be a result of the higher density compared to the pure sintering technique.

Table 2 gives an overview of these technically relevant parameters of the current MID.

**Table 2:** Technical properties of ceramic sensors

| Normal width DN | TWB (K) | Internal pressure load capacity (bar) | Impedancy of sensors 15,6 Hz (kΩ) | Leak rate of sensors for He with 60 bar internal pressure (mbar * l/s) |
|---|---|---|---|---|
| 2,5 | 100 | > 900 | < 40 | $10^{-10}$ |
| 4 | 80 | > 900 | < 40 | $10^{-10}$ |
| 6 | 110 | > 900 | < 40 | $10^{-10}$ |
| 10 | 130 | > 900 | < 40 | $10^{-10}$ |
| 15 | 140 | > 650 | < 40 | $10^{-10}$ |
| 25 | 90 | > 450 | < 40 | $10^{-10}$ |
| 80 | 80 | > 250 | < 40 | $10^{-10}$ |

## 5. Perspectives

As a result of these developments, we have today a product of high reliability offering top precision and stability of measurement. This means that the areas of application for ceramic MID are wide ranging. Some examples are:

- volumetric bottling of liquids in the food, pharmaceutical and beauty industry
- flowing acid and alkaline liquids in the chemical industry
- dosage plants for animal feed

**Figure 6:** Sensors made from FZT

Figure 6 illustrates one sensor in each DN 2.5 and DN 15 which were manufactured according to latest technology.

The current manufacturing technique for the sensor enables significantly lower manufacturing costs at a simultaneous improvement in quality. This means that MID with ceramic sensors achieve a stronger position compared with other systems. Figure 7 shows a typical sensor in today’s construction style.


**Figure 7:** Magnetic inductive flow meter DN80

Development continues as the MID with ceramic sensors face continuous economic pressure, at least where technical demands are less high. Current research focuses on a further reduction of manufacturing cost by reducing the proportion of precious metal and increasing manufacturing safety.

## 6. Literature


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(7) German Patent DE 4029066 „Keramischer Formkörper“

(8) German Patent DE 4335697 „Keramikbauteil mit einer Cermet-Elektrode“

(9) German Patent DE 19502129 „Verfahren zur Herstellung eines elektrisch leitenden Cermets“

(10) German Patent DE 19837953 „Verfahren zur Herstellung eines Keramikbauteils mit einem Cermetkörper“