Detecting and counting unwanted particles

Condition monitoring of working fluids usually comes with a lot of drawbacks. The FCS100 series overcomes these problems with a redesigned flow-cell and traceable field calibration by the user.

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Figure 1: The FCS100 connector complies with CiA 303-1

In the field of condition monitoring of working fluids (especially hydraulic oils and lubricants) many solutions have already been developed that reliably measure and also show important fluid parameters in certain areas. Although the available devices basically do their job, they could not yet really establish themselves in a wider application front.

The reason for this is complex, but some major drawbacks are the poor integration capacity of these devices (fluidic, mechanical, and electronic), their low range, and their poor resistance to harsh environmental conditions (temperature, vibration, humidity, pressure, etc.). In addition, they are large and expensive, and the calibration of the sensors as part of an effective quality management is unsatisfactory. Consequently, the requirements for a sensor device that can be used in all areas of mobile hydraulics include a miniaturized thread-design, integration without additional fluid conditioning (fluid flow regulator), compatibility compared to all fluids without additional variants, no additional electronics, a low power consumption, no need for a mechanical adapter, and an extended measuring range. Online calculations of a system-specific risk measure should also be possible. In addition to the mastery of all standards, the additional distinction of material composition (solid, gas, ferrous metal, nonferrous metal) should be given. Other desirable characteristics are a wide operating temperature range and insensitivity to moisture and water splash. The sensors should also cover all practical pressure ranges and be vibration-resistant. These are obviously ▷

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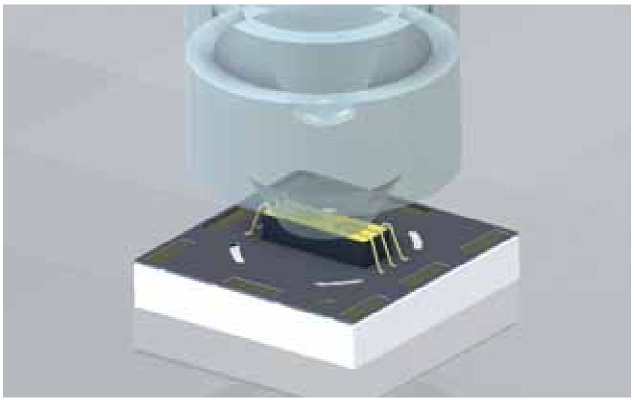

Figure 2: The core of the measuring cell – a Flip-chip semiconductor stack with triplet lens

competing parameters and there seemed to be no solution – at least not with previous designs.

Prior designs

The sensors usually consist of a flow-cell comprised of two plane-parallel glass plates, which are held apart by a metal structure. A light source – typically a laser diode – forms a "light curtain", which is perpendicular to the direction of the flow in the measuring flow-cell. Passing through the measuring cell, the light is collected from a point on the optical axis of the photodetector and converted into an analog electrical signal, which is processed and subsequently evaluated.

This design entails disadvantages that hinder miniaturization. First of all, this composition requires a great distance between light source and photodetector. Accordingly elastic internal seals are required, which limit the fluid compatibility. Thick-walled glass plates, which would make it possible to achieve high compressive strengths, cannot be used. The metallic structure, which forms the measuring channel, is fluidically less than optimal and can easily clog.

Due to the design of the measuring cell neither coincident magnetic coils nor scattered light detectors can be attached, with which the distinction between solids, ferrous or non-ferrous metals, and gas particles would be possible.

Design of the measuring cell

Key points for the design of the new measuring flow-cell were the simultaneous matching of demands for a pressure stable flow-cell, the small distance between the light source and the photodetector, and the coincident arrangement of a differential magnetic coil configuration and a detector for scattered light. The fluidic cell is represented in this design with a streamlined and extremely pressure-resistant cylindrical glass capillary. The coil system is disposed coaxially around the capillary, with a gap so that the light can pass through.

Contrary to commonly used laser diodes, a compact stack structure was used in this design. It consists of both custom AlN thinfilm substrate and a customized line-shaped LED as flip-chip construction. This stack can be fitted directly onto the circuit board in the automatic pick and place process and soldered using standard reflow, which reduces manufacturing costs.

To bridge the relatively large light path through the capillary, a new triplet lens was constructed. Through direct optical bonding between the lens and the light source or the detector and the capillary, reflection losses and at the same optical distortion through the cylindrical capillary were largely avoided. In this case, the light emitted from the LED is initially formed with a diverging lens to a reduced intermediate image of the upright. The middle lens was designed as a meniscus and provides for the shift of the main level of the overall configuration toward capillary. This made it possible to reduce the magnification to improve the optical resolution and still fulfill the law of imagery. The light transition to the capillary is formed by an optically bonded condenser. This minimizes reflection losses and ensures a high light intensity. Because in an optical imaging system, the image and the object can replace each other, it was possible to use the same structure for the receiving lenses. Thus investment in optical molding tools could be reduced. Through the use of the same parts, material and installation costs were also reduced. The ▷

lenses all have an aspherical shape and are manufactured with injection-molded plastic.

This optical construction created an intensive line-shaped light field inside the capillary through which the fluid flows. This light field interacts with passing particles as follows: 100 % of large particles are detected – these large particles are also always in low concentration in the fluid. Particles are detected less the smaller they are. The smaller they are, the higher is their natural concentration in the fluid. The relation of measurement signal to particle size is linear, resulting in a very large size range from 1 µm to 500 µm. Due to the size-dependent control of the detectability for the coincidence-free metering, the maximal measurable particle concentration could be greatly expanded. The measuring range extension amounts to more than 5+ ISO classes. This makes the sensors applicable for highly contaminated fluids.

Perpendicular and coincident to the optical axis, a light scattering detector is arranged, which also synchronously detects the signal of the scattered light to the signal of the extinction sensor. The synchronous acquisition and analysis allows reliable differentiation of solid particles and gas bubbles.

Two essential features allow reliable differentiation: Firstly, solid particles have an irregular and rough surface structure and scatter light, while gas bubbles are perfect spheres and have optically smooth surfaces, which have geometrically reproducible light scattering properties. Secondly, solid particles have either a high refractive index and/or absorb light, while gas bubbles have a refractive index of uniformly 1, which is always lower than that of the fluid. This always leads to scattered light signals, which is on the one hand proportionally to the particle size and thus also proportional to the extinction signal. On the other hand, the scattered light signal in the case of the gas bubbles is always significantly larger than the scattered light signal of solid particles. Due to the perfect geometric form of gas bubbles, their volume can be calculated. The volume fraction of free gas in the fluid is calculated and output from the sensor in ppm (parts per million). The measuring range is up to 10000 ppm with a resolution of 1 ppm.

Ease of use

Not only the cost of the sensor itself determines usability, but also the total effort required to integrate it into a system. The following points are essential for this: installation space, hydraulic connection, and fluid conditioning. To enable the integration of the sensor into smaller hydraulic components such as pumps, cylinders, filter housing, etc., the sensor must not only be very small, but must be able to be connected directly to the pressure line. For this purpose, certain variants are offered, providing an integrated flow regulator, which is fixed to the flow required by the sensor. The miniaturized internal structure enables a housing shape that is common for cartridge valves in accordance with the ISO 7789 standard. The new design of the sensor allows abandoning the elastomeric material of the inner seals. Thus no special sensor variants are required for mineral oil based fluids and phosphate esters. The costs associated with logistics and warehousing are thereby reduced.

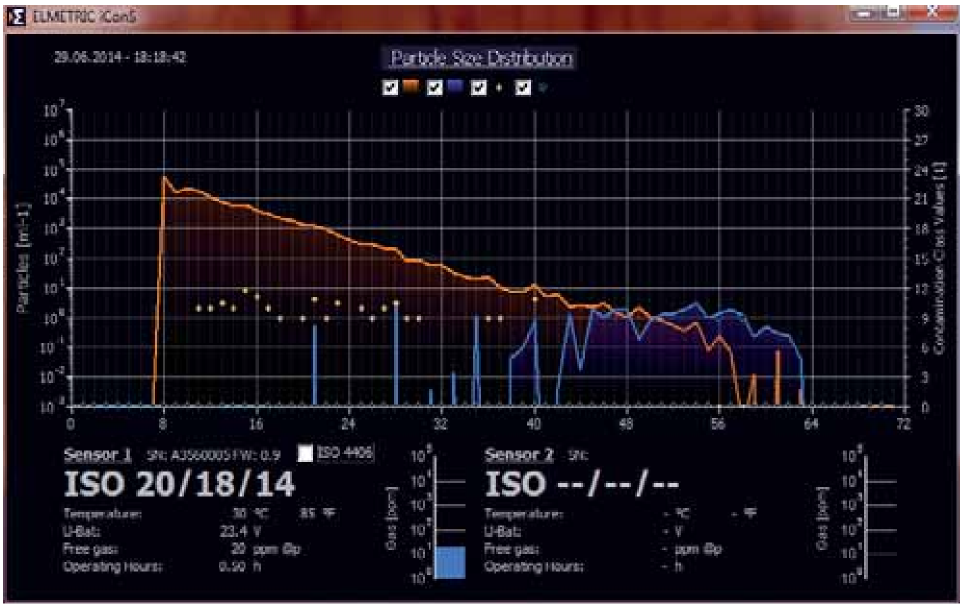

Figure 3: Typical distribution of solid particles and gas bubbles taken with the PC application iConS (integrated contamination system)

Figure 4: The world's tiniest particle counter

Electrical interfaces

The sensors of the FCS100 series come with many integrated standard interfaces: LIN, NMOS switching output, analog current and voltage output, and the fieldbus interfaces EIA-485 and CAN with connector pin-out according to CiA 303-1. The respective interface is set via a firmware update and can thus be adapted to the respective requirements. An extensive inventory of appropriate sensor models becomes therefore unnecessary. The electrical connection is made with a standard 5-pin M12 Sensor connector. The supply voltage range of 9 V to 60 V covers all battery voltages used in mobile hydraulics (12 V, 24 V, and 42 V). The total power consumption is only 500 mW. ▷

Figure 5: The sensor vanishes almost completely after installation into an appropriate cavity

Protocols for data transmission

To display all sensor data in real time, PC evaluation software is available for free. In this case the data transmission via EIA-485 uses a proprietary protocol. Data is transmitted from the sensor and immediately displayed graphically. All data is calculated in real time on the DSP of the sensor and is available without additional programming when integrated in a user's system. Also available is a galvanically isolated USB data cable that also powers the sensor. A separate power supply is not required.

For field applications there is a focus on the implementation of the CANopen protocol according to the CiA recommendations. All data will be accessible by the user. The host system will be supported by an EDS (electronic data sheet).

The low response time of the sensor to sudden changes of the state of the working fluid is possible thanks to the low dead volume of the sensor from the entrance to the measuring point of only 35 µl and the fast data collection and analysis by the DSP. This makes the sensor the first choice for bottle sampling where only a restricted volume of the fluid is on-hand.

The end of non-traceable calibration

To ensure the effectiveness of quality management, it is necessary to check the used measuring instruments in fixed intervals. For example, the calibration of length measuring instruments or voltmeters is standard and is offered by all calibration services. However, this is currently not feasible for particle sensors. That is because suspensions are by their nature not traceable. The sensors have to be calibrated with an expensive reference fluid having a particular contamination. This process is also expensive and time consuming and prevents a broad application of contamination sensors.

For the FCS100 series, for the first time there will be a new system, which overcomes these drawbacks. On a glass substrate with lithographically deposited structures that are introduced into the measuring cell, the sensors can be quickly and cost-effectively calibrated by the user in the field. These microstructures are always traceable and verifiable. This allows the users to equip their systems with inexpensive contamination sensors and to ensure the proper functioning throughout the whole lifecycle. ◀