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A high sensitive multi-parameter micro sensor for the detection of multi-contamination in hydraulic oil

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ABSTRACT

A high sensitive multi-parameter micro sensor consisted of a microfluidic chip and a sensing unit is presented. The sensing unit, which composed of a dual-coil and two silicon steel sheets, is embedded in the simple microfluidic chip with a straight microchannel structure. The micro sensor can be used not only as an inductive sensor to distinguish between ferromagnetic and non-ferromagnetic metal particles, but also as a capacitive sensor to distinguish between water droplets and bubbles in hydraulic oil. The simulation results show that both the magnetic field and the electric field of the sensing unit are enhanced under the effect of the silicon steel sheets. In the experiments, the number of turns of the coil was optimized first, and then the comparative experimental results show that the detection amplitudes of both iron and copper particles were increased about four times compare with the sensing unit without silicon steel sheets, which verified the simulation results. Using the simple micro sensor, without any complicated external circuits, in the inductance detection experiments, we demonstrate the successful detection of 33 μm iron particles and 90 μm copper particles in hydraulic oil; and in the capacitance detection experiments, we can detect 100 μm water droplets and 180 μm bubbles in hydraulic oil. For both the inductance and capacitance detection, the results of particles with different sizes were in good agreement with the simulation results.

1. Introduction

The Hydraulic oil plays an important role in maintaining the stability of the hydraulic system. The metal particles and some non-metallic particles (such as water droplets and air bubbles) are the main contamination in hydraulic oil [1]. During normal conditions, metal particles in hydraulic oil have a constant concentration and smaller size, usually in the range of 10–20 μm. However, when abnormal wear occurs on mechanical equipment, the size of particles will increase to 50–100 μm and the concentration will increase sharply as well, and then the increase in the concentration and size of the metal particles in turn accelerates the wear of the equipment, which will eventually lead to failure of the hydraulic equipment [2,3]. The water droplets in hydraulic oil will accelerate the oxidation of oil and equipment corrosion [4]; and the bubbles in the hydraulic oil will generate cavitation, which will cause equipment damage [5]. Therefore, keeping the cleanness of hydraulic oil can greatly improve the working stability and extend the service life of the hydraulic system.

Laboratory analysis is a comprehensive and systematic analytical method for the detection of hydraulic oil, but it requires a large number of instruments and long analysis times, so the method is not suitable for all hydraulic machines. Therefore, a series of rapid detection methods for the detection of particle contamination in mechanical oil have been developed in recent years. The common methods are optical method [6], ultrasonic method [7], capacitive method [8–10] and inductive method [11–13]. However, most of these detection methods can only detect a part of the particles in the oil, and they are difficult to distinguish the particle properties. The optical method and ultrasonic method can only detect solid particles, and cannot distinguish their properties; based on the difference of dielectric constant of non-metallic particles in oil, capacitive method can achieve the detection of non-metallic particles, but it cannot distinguish the metal particles; the inductance method can distinguish between ferromagnetic and non-ferromagnetic metal particles, which is widely used in oil particle detection. The oil debris monitor (ODM) developed by GasTOPS is an earlier application of aircraft oil monitoring, it consists of three solenoid coils [14], which can identify metal par-

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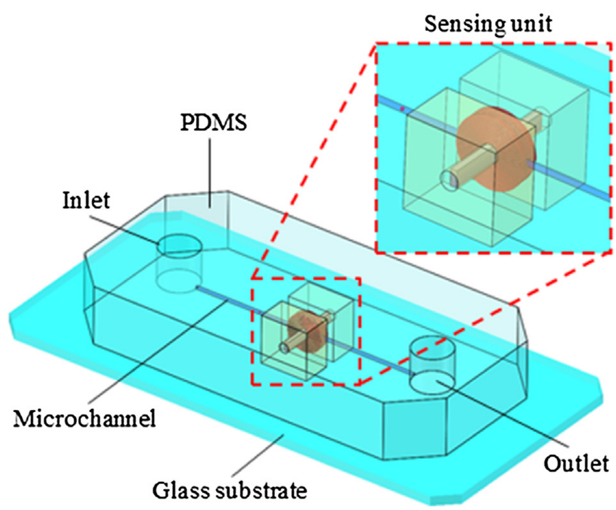
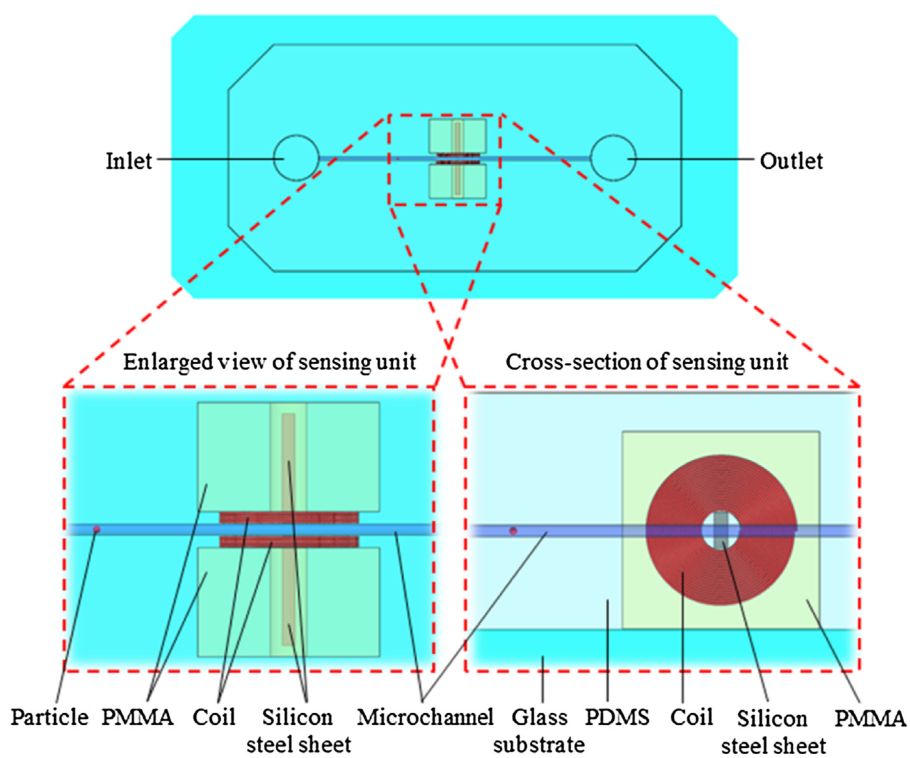
ticles with an equivalent sphere diameter of 125 μm on-line. For this kind of oil debris monitor with typical inductive structure, Bozchalooi et al. [15] and Luo et al. [16] adopted wavelet-based adaptive subband filtering technique and resonance-based signal decomposition method, respectively, which effectively reduced the background noise, so that the signal to noise ratio (SNR) could be improved. Wang et al. [17] proposed an improved inductive sensor with saddle-coil probe that can detect 100 μm ferromagnetic and non-ferromagnetic oil debris. Hong et al. [18] proposed an in-line debris sensor based on dual excitation sources, which can detect 81 μm iron particles in 12 mm outside diameter organic glass pipe. Zhu et al. [19] A resonant inductor with a ferrite core senses 11 microns of iron particles in a 1 mm diameter pipe. And Zhu et al. [18] proposed a resonant inductive sensor with a ferrite core that can detect 11 μm iron particles in 1 mm diameter fluidic pipes. The above two methods both can achieve large flux detection due to the large channel, but according to the previous research [20,21], the radial position of the metal particles in the channel will greatly affect the amplitude of the detection signal. Therefore, the larger the channel, the larger deviations in particle size estimation, so it is unable to accurately determine the size of a single particle. Furthermore, both the two sensors have a large size due to the use of large magnetic core and complex resonant circuit, which also makes the measurement more inconvenient. Our group had also developed a series of micro inductive sensors based on microfluidic chip [22,23], which not only improve the detection sensitivity



(a)



(b)

Fig. 1. (a) The overall design of micro sensor; (b) the details of sensing unit.