MULTIPLE ELEMENT PARTICLE SENSOR AND SIGNAL PROCESSING ELECTRONICS

BACKGROUND OF THE INVENTION AND RELATED ART STATEMENT

The present invention relates to a sensor element and a particle sensor having a sensor element with multiple sensing surfaces. The sensor element includes a piezoelectric film for detecting particles in a fluid. The multiple sensing surfaces allow the average size of particles in a fluid flow to be measured.

When fluid, which is liquid or gas, contains solid particles, it is sometimes necessary to detect the presence of the particles as well as the particle size. Particularly, when the particles are undesirably present in fluid impeding the function of the fluid, it becomes important to detect the particles and also to determine relative size of the particles and to discriminate from bubbles or other non-particle signals.

For instance, an internal combustion engine, such as an engine for a car or an engine for a heavy machine, uses gasoline or diesel fuel as its power source. These internal combustion engines employ a lubricant to reduce friction drag and abrasion on rotating and sliding surfaces of the engine. In an internal combustion engine, particles such as metal powder generated by abrasion may mix with the lubricant so as to accelerate abrasion of the rotating or sliding surfaces. Particles in the lubricant are generally removed by a filter such as an oil filter. The conditions of a lubricant can be monitored in more detail by detection and size measurement of particles in the lubricant. Size measurement of the particles in the fluid is important because wear rates can be related to the size of the particles causing the wear. Therefore more particles of a size that do not cause wear can be tolerated than particles of a size that do cause wear.

One conventional method used to detect particles in fluid employs a pair of electrodes which are arranged with a gap of predetermined size therebetween, and electric resistance between the electrodes is monitored. In this method, when metal particles come in contact with both of the electrodes, the electrical resistance between the electrodes decreases, thus detecting the particle. However, this method cannot detect particles smaller than the gap between the electrodes, and also cannot detect electrically insulating particles.

In another method, a magnetic field is generated in a detecting unit by an electric magnet or the like so as to detect the amount of particles such as metal particles accumulated on the detector. However, this method cannot detect non-ferromagnetic particles, and thus its accuracy is limited.

In still another method, the amount of particles in the fluid is correlated with the transmittance of light through the fluid so as to detect the amount of particles in the fluid. However, the transmittance of the fluid is not always constant, and dirt on a window for incident light or a window for transmitted light adversely affects measurement accuracy, which limits durability of the sensor.

U.S. patent application Ser. No. 08/443,464 discloses a particle sensor including a piezoelectric film mounted onto a vibrating portion, and the piezoelectric film converts vibration caused by particles into an electric signal. The subject matter of U.S. patent application Ser. No. 08/443,464 is hereby incorporated by reference thereto.

However, the sensor element may generate an electric signal upon impact of a bubble in the fluid, causing an error.

Therefore, it is desired to discriminate electric signals induced by solid particles from electric signals induced by bubbles.

Moreover, in some applications, it is desired to detect bubbles in the fluid. For example, the working fluid in a transmission is preferably bubble-free because bubbles reduce the effectiveness of the fluid for power transmission. Monitoring the presence of bubbles assures smooth and efficient operation of the transmittion.

SUMMARY OF THE INVENTION

The present invention alms at solving the problems described above and providing a low cost sensor element and particle sensor having excellent detection accuracy, particle sizing capability, and durability.

One object of the present invention is to provide a sensor element for detecting a foreign solid particle in a fluid and measuring the average size of particles in the fluid. The sensor element includes a number of diaphragm sensor elements each having a sufficiently small mass for responding to a collision with a solid particle, and an apparatus for converting a vibration of the diaphragm portion into an electrical signal so as to detect the vibration. The multiple elements are arranged in the fluid flow stream such that different size particles will preferentially strike different elements. In particular, a first element is aligned with a center of the fluid flow stream, while a second and any additional elements are offset from the center of the fluid flow stream.

Another object of the present invention is to provide a multiple element sensor with improved reliability. Reliability is improved by using multiple elements. If any of the individual elements becomes damaged or worn, the remainder of the elements continue to function and the sensor as a whole continues to function although with reduced accuracy.

Another object of the present invention is to provide a sensor element including: a detecting unit including multiple elements each consisting of a piezoelectric film consisting essentially of a first ceramic material, a first electrode coated onto at least a portion of the outer surface of the piezoelectric film, and a second electrode coated onto at least a portion of the inner surface of the piezoelectric film; a vibrating portion consisting essentially of a second ceramic material, the detecting unit being placed on the vibrating portion so that the second electrode contacts at least a portion of the vibrating portion; and a fixed portion for holding the vibrating portion such that the vibrating portion may vibrate; wherein the detecting unit and/or the vibrating portion make contact with and are vibrated by solid particles in a fluid and the piezoelectric film converts the vibration into an electrical signal. The vibrating portion of each sensor element vibrates only when it is struck by a particle, thus providing means for detecting which element was struck.

The vibrating portion and the fixed portion may be portions of a ceramic substrate having a unitary structure, and the ceramic substrate is preferably formed with a cavity so that the vibrating portion has a plate or diaphragm shape of small thickness.

The first ceramic material preferably comprises at least one material selected from the group consisting of lead zirconate, lead magnesium niobate, lead nickel niobate, lead zinc niobate, lead manganese niobate, lead antimony stanate, lead titanate, and barium titanate. The fluid is preferably a lubricant. The piezoelectric film preferably has a thickness ranging from 1 to 100 micrometers, and the vibrating portion preferably has a thickness ranging from 1