5th International Conference on Experimental Fluid Mechanics – ICEFM 2018 Munich
Munich, Germany, July 2-4, 2018

Development Elastic Sensor for Wall Shear Stress by MCF Rubber

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Abstract

The purpose of this study is to develop the sensor to measure the wall shear stress due to the flow by using MCF rubber. MCF is the name of Magnetic Compound Fluid. MCF rubber is combining the metal particles in a natural rubber (NR) latex. The MCF rubber can measure the force normal to the rubber and shearing force. The response from the rubber can be measured using as the resistance in the electric circuit. The MCF rubber deforms when the force acting on the rubber. This causes the change of electric conductivity of rubber. For the first step to develop the sensor to measure the wall shear stress due to the flow, we investigate the measurement of wall shear stress by using MCF rubber.

1 Introduction

The measurement for shear stress due to the liquid flow acting on solid wall can be realized with pressure transducer, Clauser chart method, and etc. These techniques have both advantage and disadvantage. For example, these have the limitation of space for measurement device to be installed like a bending pipe. MCF rubber is the flexible rubber sensor. MCF rubber is constructed with the natural rubber, nickel powder, and magnetic fluid by Shimada et al.,(2016) and by Shimada et al.,(2012). These materials are mixed, then polymerized with electrolytic. The electric conductivity of MCF rubber sensor changes with the transformation of sensor. The flexibility of MCF sensor gives us the advantage for the installation and measurement.

The objective of this research is the development of sensor for measuring wall shear stress due to the liquid flow. To achieve the development, we need to understand the characteristics of MCF rubber. We investigate two types of experiments. First experiment is the MCF sensor rubs on the solid wall to know the influence of transformation of sensor due the force by mechanical contacting. The other experiment is the measurement of wall shear stress under the water. The wall shear measurement under the water is carried out under the constant wall shear stress. The MCF rubber sensor has the good responsibility to the wall shear stress during both measurement of mechanical rubbing and wall shear stress.

2 Method

We carried out two types experiments to investigate the MCF rubber sensor. First experiment is that the MCF rubber rubs on the solid surface. The MCF rubber moves along the solid smooth surface. The MCF rubber has a pair of electrode to measure the electric conductivity as shown in Figure 1. To ignore the normal force by the motion of rubber, we used the linear actuator to control the motion of rubber and the jig to fix the rubber to actuator. The sampling rate of measurement is 1k Hz for the understanding of the time response of MCF rubber sensor. The data is considered the time averaged with every 100 data. The LabView by National Instruments is used for the data acquisition to computer.

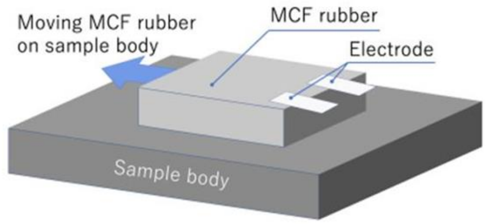

Figure 1: Experimental setup for shear stress measurement using MCF rubber

The other experiment is the measurement of wall shear stress caused by a flow of water. To control the wall shear stress, we use the mechanism of rotational viscometer as shown in Figure 2. The rotational viscometer has the several techniques to measure the viscosity of fluid. In our measurement, we consider the measure the torque acting on motor shaft. The motor rotates constant angular velocity during the measurement. So, we construct the apparatus with motor, torque converter, and cone type rotor. The motor which we used is BLEM23 by Oriental motor, and the torque converter is TP-2KCD by Kyowa Dengyo. The LabView is also used for the data acquisition. The cone type rotor rotates in the water container. The sampling rate is 1k Hz, and the data is averaged with every 100 data. The water container fixed on the table to ignore the influence of container motion. The MCF rubber fixed in a bottom of the water container. The electric conductivity of MCF rubber measures to investigate as the characteristics of sensor.
The way to calculate the shearing force σ [MPa] acting on MCF rubber shows as Equation (1). This relation and the geometry of rotor fixed with the torque converter come from the mechanism of rotational viscometer based on Japan Industrial Standard (JIS).

$$\sigma = 3M / 2\pi R^3 \qquad (1)$$

M [10^{-7} N·m] in equation denotes the torque which acts on a body of motor shaft. R [10^{-2}m] is the radius of the rotational body. The rotor rotates 30 sec. to develop the flow from the rest. The rotor stopped immediately at 30 sec. from the starting of motor rotation. So, we can measure the three phases of flow. One is accelerating from the rest, second is the fully developed region of flow, finally is the deceleration phase of flow. In other words, first is the increasing phase of wall shear stress, second is the constant phase, third is decreasing phase. The six types of angular velocity used as 100, 200, 300, 400, 500, 600 [rpm, revolution per minute]. The angular velocity relates the strength of wall shear stress.

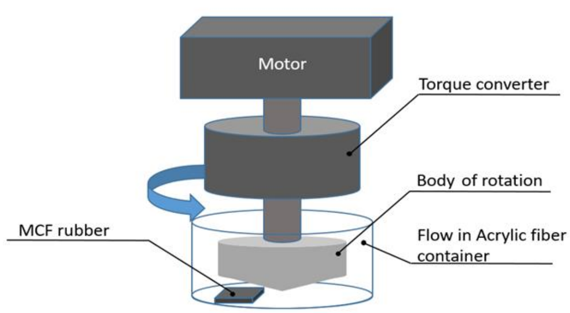

Figure 2: Experimental setup for the measurement of shear stress due to shear flow.

3 Result and Discussion

The results with the experiment of MCF rubber sensor rubbing on a smooth plate is shown in Figure 3. This shows the time series of the change of electric conductivity of MCF sensor and motion of MCF sensor. We considered three phases of motion. First is the rest which means that the sensor is not moving. Second phase is the phase of moving of sensor. The sensor is initially accelerated from the rest. The motion of sensor keeps the constant velocity. Then, the motion of sensor decelerated to the rest of third phase. The diamond symbol in figure shows the speed of sensor. The increasing of speed means the increasing shear stress acting on the MCF sensor. The circular symbol shows the voltage acting on the MCF. In a first phase, the voltage acting on sensor is about 5 V. Then, the voltage is decreasing with the increasing of speed of motion. In the constant speed phase in moving, the voltage keeps constant. This clearly shows the electric resistance is increasing with the increasing of rubbing speed of sensor. The electric resistance of MCF increases with the increasing of shear stress acting on sensor.

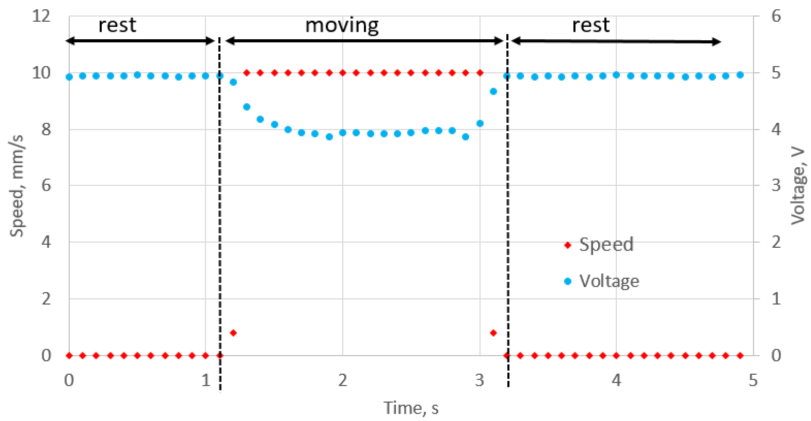

Figure 3: Time series of shear stress measurement using MCF rubber

The results of the measurement on wall shear stress under the water tank are shown in Figure 4. The results show the time series of changing on electric conductivity of MCF sensor. The color of results shows the difference of angular velocity of rotor. Increasing of angular velocity corresponds to the increasing of wall shear stress. This measurement also has three phases of motion. First is rest phase as the rotor stopped. Second phase is moving phase of rotor. In a second phase, rotor is initially accelerated. After the acceleration, the rotor rotates with the constant velocity. Then, the rotor is decelerated to the end phase of rest. The voltage

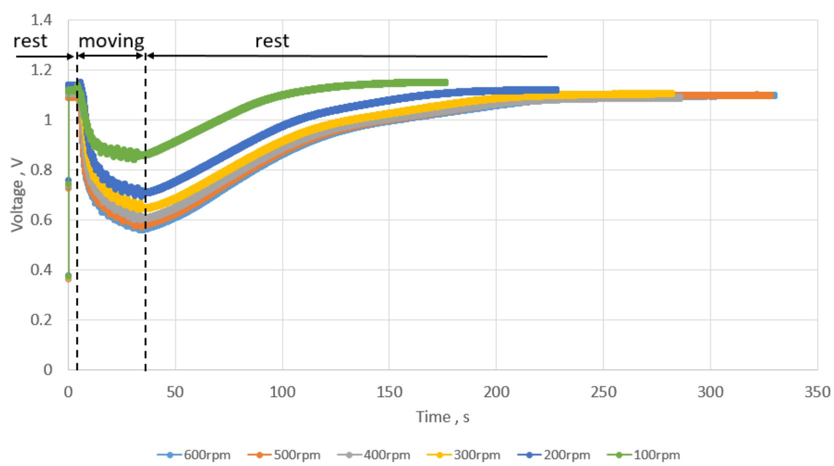

Figure 4: Time series of shear stress measurement under the shear flow using MCF rubber.

acting of MCF sensor is changed since the results of voltage changing show the changing of force acting on a MCF rubber sensor. When starting the rotation, the voltage acting on MCF sensor is decreasing. After the acceleration phase in motion, the decreasing of voltage becomes slowly. The decreasing rate of voltage changes with the angular velocity. This is agreed with the relation of angular velocity and the wall shear stress. Finally, the voltage gradually increases after we stopped the rotation. In a moving phase, we can observe the oscillation of data. This comes from vibration of rotor. This clearly shows that the MCF sensor has the good time response against the changing of wall shear stress. Moreover, the results in rest of third phase shows the decreasing of shear stress since the velocity of flow in container decreases with the rotor stopped.

Figure 5 shows the result from torque converter. This shows the time series of wall shear stress when the angular velocity of rotor is 200 rpm. This also has three phases of motion. In moving phase, we can observe the increasing of wall shear stress. This is agreed with the results of MCF sensor. However, torque converter cannot measure after the rotor stopped. The measurement with torque converter is basically carried out under the steady flow. So, the torque converter technique is not suitable for the measurement under the unsteady condition. Therefore, the measurement with MCF sensor has the good opportunity to measure the wall shear stress under the unsteady flow condition.

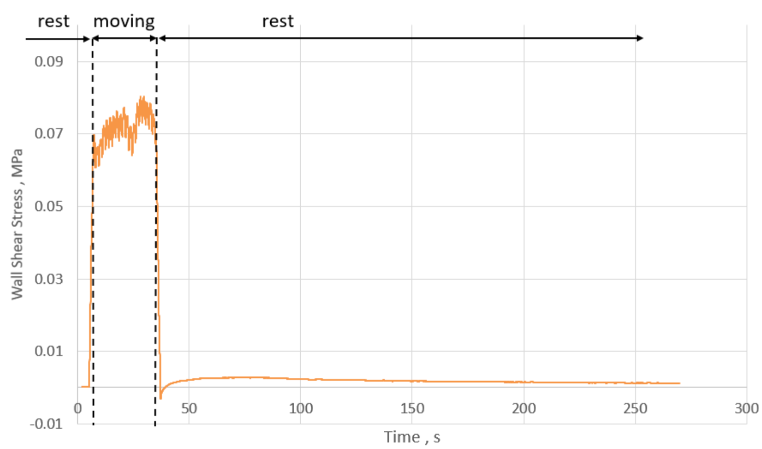

Figure 5: Time series of shearing force under the shear flow acting on MCF rubber.

4 Conclusion

The measurement of wall shear stress with MCF rubber sensor was investigated. The MCF rubber has the higher flexibility as the sensor. The electric conductivity was changed with rubbing on smooth body. The change of conductivity of sensor corresponds to the speed of rubbing. The wall shear stress measurement under the water was carried out. The MCF sensor is measured the change of the wall shear stress. Furthermore, the MCF sensor has the good time response for the measurement.

References

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