DYNAMIC CHARACTERISTICS OF FLOW METERS FOR FUEL CONSUMPTION MEASUREMENT IN SHIPS

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ABSTRACT

The dynamic characteristics of various flow meters for fuel consumption measurement aboard shipswere evaluated. The flow rate was measured using the Korea Research Institute of Standards and Science (KRISS) oil flow standard system using K-oil(density : 0.804 g/cm^3, viscosity : 3.679 cSt), which has similar fluid properties as diesel oil. The flow meters were tested in a test bed that simulated the vibration conditions in ships. The vibration conditions were established in accordance to vibration standard IEC 60068-2-6 as follows: a ±0.7g acceleration and 30 Hz frequency. The K-factors (mL/pulse) of various flow meters (PD meter, turbine flow meter, Coriolis flow meter, and ultrasonic flow meter) were obtained for various flow rates (60 L/h ~ 300 L/h). The PD meter, Coriolis flow meter, and ultrasonic flow meter were found to have almost constant K-factors according to the flow rates. However, the K-factor of the turbine flow meter was reduced at a low flow rate owing to bearing friction in the turbine blade. The flow rate errors of the PD meter, Coriolis flow meter, and ultrasonic flow meter were found to be under ±0.5 % with and without vibration. However, the flow rate error of the turbine flow meter was approximately -4.3 % at a low flow rate (60 L/h) owing to the friction effect. The Coriolis flow meter had the lowest flow rate error (< 0.1%) according to the flow rate. The vibration influenced the flow rate error of the Coriolis flow meter at high flow rates owing to its measuring principle. However, the difference in flow rate errors was a negligible value (0.05 %) with and without vibration. Therefore, we confirmed that the PD meter, turbine meter, Coriolis flow meter and ultrasonic flow meter could be used for measuring flow rates in ships with a ±0.5 % flow rate error.

INTRODUCTION

Fuel consumption is an important parameter for measuring the engine efficiency and exhaust gases of a ship [1]. The rate of fuel consumption can be obtained by measuring the fuel quantity in the storage tank or the flow rate from the flow meter. The dynamic characteristics of the ocean waves have to be considered when we measure the flow rate of fuel in a ship. However, the flow meters in the ship have not been tested under dynamic excitations caused by the ocean waves and engine vibration. Therefore, in this study, the flow meters were evaluated according to the dynamic conditions imitating those of a real ship in the ocean. The flow rate errors for flow meters such as the PD meter, turbine flow meter, Coriolis flow meter, and ultrasonic flow meter were obtained with and without vibrations. We evaluated the dynamic characteristics of the flow meters for an accurate measurement of fuel consumption in a ship.

EXPERIMENT

We used the oil flow standard system with the reference flow meter as shown in Fig. 1. K-Oil was used as working fluid because it has similar flow properties (density: 0.804 g/cm^3; viscosity: 3.679 cSt) with diesel oil and it is inflammable oil. K-Oil is pumped through the magnetic gear pump (IWAKI MDG-R15T200) to the flow meter with low pulsation. The flow rate was adjusted by the controlling valve in the bypass pipeline, which is connected to the oil reservoir. Pressure and temperature were measured in the header, which is located between the pump and the flow meter. Further, the air bubbles and flow pulsation were removed in the header. The flow rate was measured using the reference flow meter (Endress + Hauser, Promass 83A04, DN4 1/8"), which was calibrated using the KRISS water flow standard system [2]. The dynamic characteristics of the test flow meters were evaluated using a vibrator. We tested various types of flow meters, including a PD flow meter (Aichi tokei denki microstream flow sensor : 21 ~ 300 L/h, Bronkhorst fuel-view : 5 ~ 250 L/h), turbine flow meter (Flow technology FT4 : 6.6 ~ 660 L/h), Coriolis flow meter (Micro motion ELITE sensor 1/4-inch : 24 ~ 300 L/h), and ultrasonic flow meter (Deaduck : 30 ~ 300 L/h). The test flow meters were placed on the vibrator (Tira, TV50303), which was operated with at a 2–4000 Hz frequency and at 80g. We simulated the vibration of the ship in sea conditions using this vibrator. We followed the IEC 60068-2-6 test Fc [3] for simulating the vibration condition. We found the resonance frequency of the test flow meters through frequency sweeping from 1 Hz to 13.2 Hz with an amplitude of ±1 mm and from 13.2 Hz to 100 Hz with an acceleration of ±0.7g. If there was no resonance condition, we tested the flow meters at 30 Hz with an acceleration of ±0.7g, following IEC 60068-2-6. The test flow meters for our study had no resonance condition, so we tested the flow meters at 30 Hz with an acceleration of ±0.7g. The test flow rate was from 60 L/h to 180 L/h.

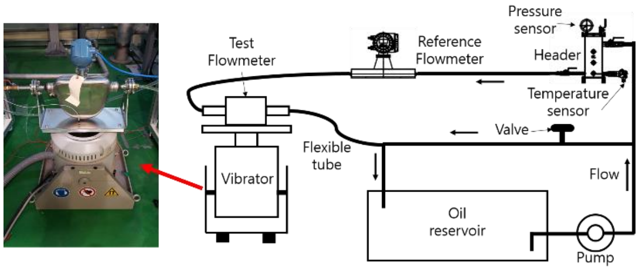
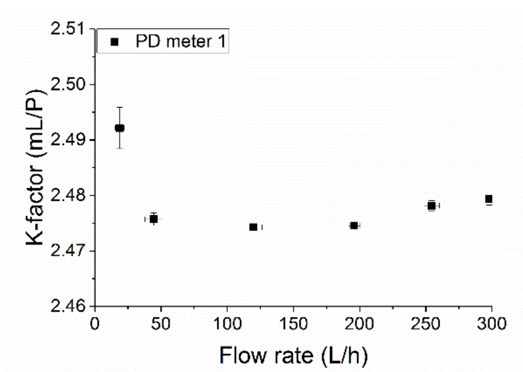
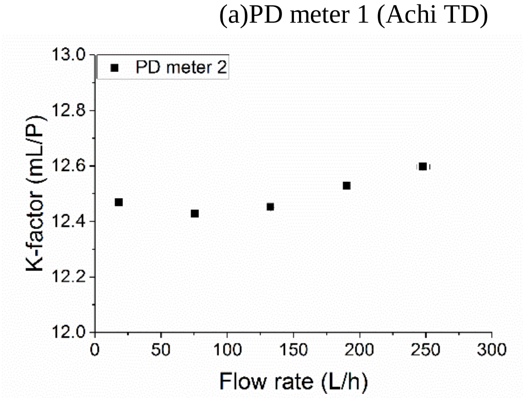


Figure 1 Experimental setup

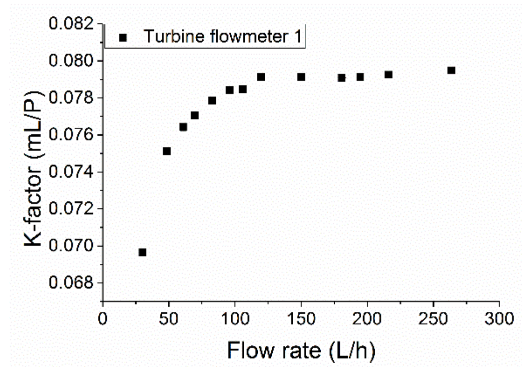
RESULTS



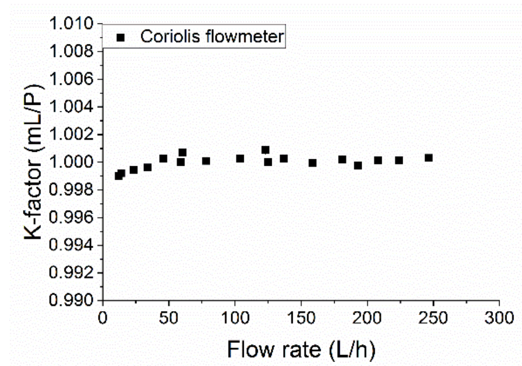
(a)PD meter 1 (Achi TD)



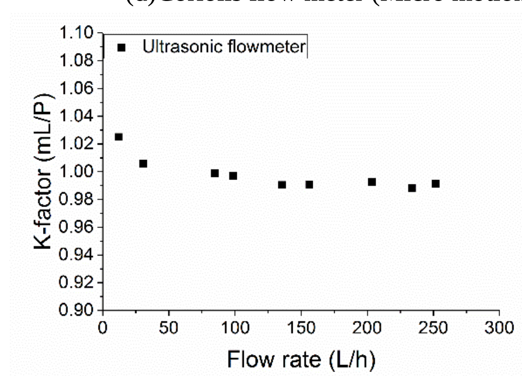
(b)PD meter 2 (Bronkhorst)



(c)Turbine flow meter (Flow technology)



(d)Coriolis flow meter (Micro motion)



(e)Ultrasonic flow meter (Deaduck)

Figure 2 K-factor according to the flow rate for different flow meters (a) PD meter 1 (Achi TD), (b) PD meter 2 (Bronkhorst), (c) Turbine flow meter1 (Flow technology), (d) Coriolis flow meter (Micro motion) and (e) Ultrasonic flow meter (Deaduck)

We tested various types of flow meters including a PD meter, turbine flow meter, Coriolis flow meter, and ultrasonic flow meter. They have different characteristics depending on the flow conditions such as the flow rate and flow parameters as they utilize different measuring principles. One of the important parameters in flow meters is the K-factor (mL/P), which is the ratio between the measured volume and number of output pulses. Consequently, we obtained the K-factors as a function of the flow rate for different flow meters as shown in Fig. 2. When the K-factor has a constant value for different flow rates, the flow meter has high accuracy. The K-factor of the PD meter is almost constant with respect to the flow rate, as shown in Figs. 2 (a) and (b). However, the K-factor of PD meter 1 increases at a low flow rate (<50 L/h) as shown in Fig. 2 (a). The turbine flow meter has a constant K-factor at a high flow rate (>150 L/h). When the flow rate decreases, the K-factor is reduced as shown in Fig. 2 (c). This is because the friction of the bearing in the turbine blade influences the flow measurement in the low flow rate regime. The Coriolis flow meter has constant K-factor from 30 L/h to 250 L/h as seen in Fig. 2 (d). The flow velocity is the dominant parameter in measuring the flow rate in the ultrasonic flow meter. When the flow velocity is high, we can obtain enough signal to noise ratio. Hence, the K-factor is changed at a low flow rate (<30 L/h) in the ultrasonic flow meter as shown in Fig. 2 (e).

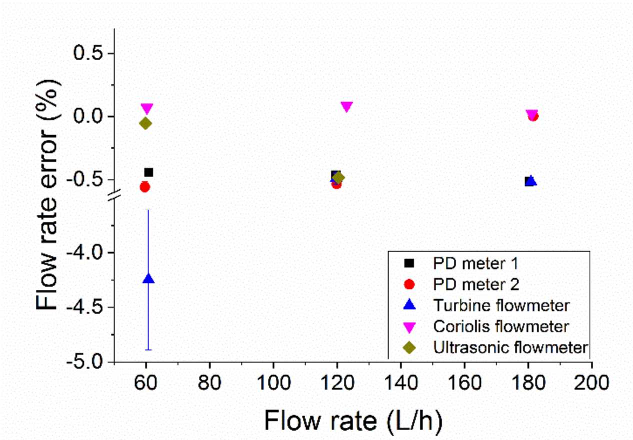
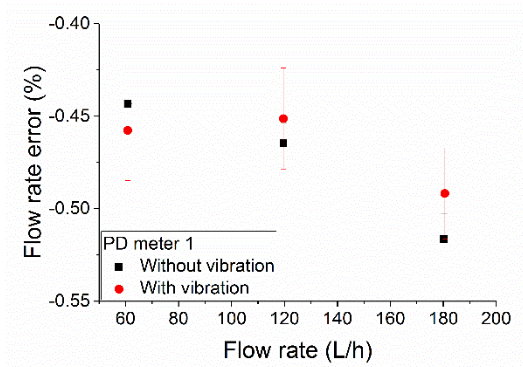


Figure 3 Flow rate errors according to the flow rate for different flow meters - PD meter 1(Achi TD), PD meter 2 (Bronkhorst), Turbine flow meter (Flow technology), Coriolis flow meter (Micro motion), and Ultrasonic flow meter (Deaduck)

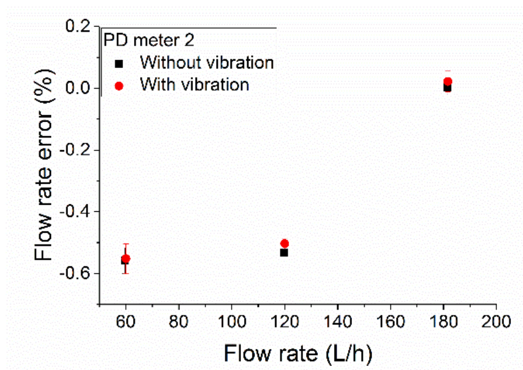
$$\epsilon = \frac{q_{ref} - q_{test}}{q_{ref}} x100 \qquad (1)$$

The flow rate error (ε) is calculated using equation (1). q_{ref} and q_{test} are the flow rates from the reference and test flow meters, respectively. Figure 3 shows the flow rate errors according to the flow rate for different flow meters (PD meter, turbine flow meter, Coriolis flow meter, and ultrasonic flow meter). The flow rate errors of the flow meters are within ±0.5 %, but the flow rate error of the turbine flow meter is approximately -4.3 % at a low flow rate (60 L/h) owing to the friction effect. The Coriolis flow meter has the lowest flow rate error (< 0.1%) with respect to the flow rate.

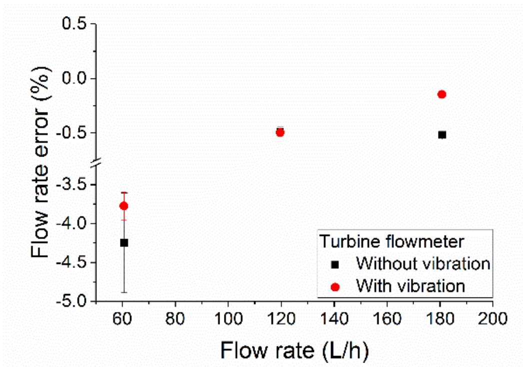
The flow rate error was evaluated with respect to the flow rate for the different flow meters under vibration as shown in Fig. 4. The flow rate errors of the PD meter have similar uncertainty with and without vibration as shown in Figs. 4 (a) and (b). In addition, the turbine flow meter error has a larger uncertainty at a low flow rate (60 L/h) than that at a high flow rate (120 L/h and 180 L/h). The flow rate error of the turbine meter with and without vibration is almost similar in Fig. 4 (c). The flow rate error for the Coriolis flow meter is very small (<0.1 %) with respect to the flow rate. When the flow rate increases up to 180 L/h, the flow rate error for the Coriolis flow meter decreases up to 0.02 % without vibration. However, the flow rate error with vibration did not decrease at a high flow rate (180 L/h). This is because the Coriolis flow meter measures the flow rate based on the vibration of the tube in the flow meter. Hence, the flow rate error of the Coriolis flow meter may be influenced by external vibration. The ultrasonic flow meter with and without vibration shows similar flow rate errors in Fig. 4(d). Consequently, the flow rate errors of various flow meters, including the PD meter, turbine flow meter, Coriolis flow meter and ultrasonic flow meter, are rarely influenced by the vibration, which simulate the dynamics of the ship at sea. The turbine flow meter has a high flow rate error at a low flow rate (60 L/h) owing to the friction effect of the bearing in the blade. The Coriolis flow meter has the lowest flow rate error with respect to the flow rate. However, the vibration does influence the flow rate error of the Coriolis flow meter as it measures the flow rate using vibration. We confirm that PD meter, turbine flow meter, Coriolis flow meter, and ultrasonic flow meter can be used for measuring flow rates under vibration in ships with a ±0.5% flow rate error.



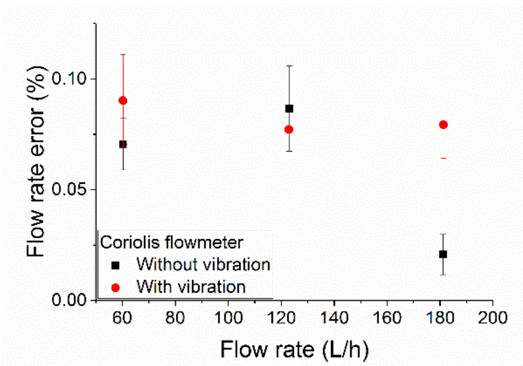
(a)PD meter 1 (Achi TD)



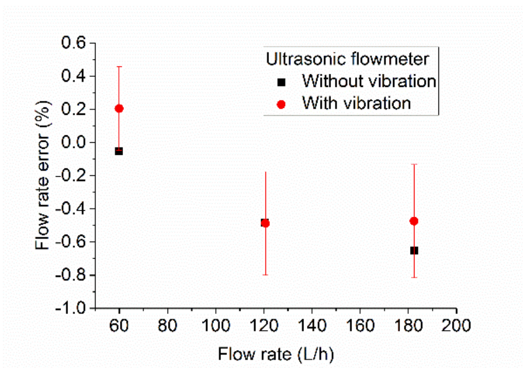
(b)PD meter 2 (Bronkhorst)



(c)Turbine flow meter (Flow technology)



(d)Coriolis flow meter (Micro motion)



(e)Ultrasonic flow meter (Deaduck)

Figure 4 Flow rate errors with and without vibration according to the flow rate for different flow meters (a) PD meter 1 (Achi TD), (b) PD meter (Bronkhorst), (c) Turbine flow meter1 (Flow technology), (d) Coriolis flow meter (Micro motion) and (e) Ultrasonic flow meter (Deaduck)

CONCLUSION

We tested various flow meters (PD meter, turbine flow meter, Coriolis flow meter, and ultrasonic flow meter) using a reference flow meter under vibration conditions that simulate the dynamic conditions in a ship. The reference flow meter was calibrated using the KRISS water standard flow system. The K-factors of the flow meters were obtained for various flow rates (60 L/h ~ 180 L/h). The flow rate errors were evaluated using the reference flow meter with and without vibration. The PD meter, Coriolis flow meter, and ultrasonic flow meter had a ±0.5% flow rate error according to the flow rate. The flow rate error of the turbine flow meter was high at a low flow rate as the friction in the bearing influenced the turbine blade. Furthermore, the flow rate errors of the various flow meters were rarely influenced by the vibration, which simulated the dynamics of a ship in the sea. However, the Coriolis flow meter had a higher flow rate error with vibration than without vibration at a high flow rate. This was because the Coriolis flow meter measured the flow rate using the vibration in the tube. Therefore, we confirmed that all the tested flow meters could be used for measuring flow rate under vibration in a ship with a ±0.5 % flow rate error.

ACKNOWLEDGMENTS

This research was a part of the project titled ' Development of tax free oil metering system for fishery industry', funded by the Ministry of Oceans and Fisheries, Korea.

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