

Development of a Diverting System Employing a Rotating Double Wing Method

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Abstract A new design for a diverter and weighing tank system has been developed. Experiments have been carried out on a prototype. Diverter wings are set as partitions on a diameter line of a half-cylinder tube. The axis of rotation is at the center of the half cylinder and runs parallel to liquid jets that flow vertically downward from several independent nozzles. This design contributes to small diverter timing error, compact design, small wet area, a simple and robust mechanism, easy implementation of an ISO4185 test, and easy adjustment of diverter trigger timing. After adjustment of start and stop signal timings, the estimated diverter timing error of this system falls within ± 1 msec over a wide range of flow rate at any nozzle position.

Keywords: Diverter, Liquid flowmeter, Double wing, Calibration, Weighing tank

1. Introduction

The diverter system is a key component in achieving a highly accurate liquid flow rate standard by use of a static gravimetric system employing a flying start and stop method. This system has an excellent feature, in that the diverter does not disturb the flow in the test line when it switches the flow line (to a bypass course or to a collection tank) at the beginning and end of measurement. However, the diversion causes a timing error in measurement of a collection time. ISO4185^[1] recommends adjustment of the diverter on the basis of an estimated diverter timing error. In the case of a conventional diverter with a single wing, ideal trigger timing may move when the velocity profile of a liquid jet changes. Confirmation and adjustment of the error should be done under all calibration conditions, because the profile is dependent on the flow rate and the shape of the nozzle. However, estimation the error under all calibration conditions is difficult; therefore, the uncertainty of calibration includes some value of uncertainty derived from the diverter timing error.

In view of this problem, the double wing method was developed by Shimada *et. al.*^[2]. The new system has two diverter wings which, at the beginning and end of measurement, are made to move in the same direction at a constant speed against the liquid jet. In this method, the diverter timing error is not dependent on the flow velocity profile of the liquid jet from the

nozzle. Therefore, once the diverter has been appropriately adjusted, adjustment of the trigger timing becomes unnecessary for any given flow rate and any given nozzle width. This system is already used in the primary standard facility for hydrocarbon flow at NMIJ. The uncertainty analysis has confirmed that the contribution of the adjusted diverter timing error is negligible as compared with other sources of error.

NMIJ plans to extend the facility's range to smaller flow rate by providing another calibration line. A new diverter and weighing tank system have been specially developed for the small line to be constructed. Improvements to the diverter employing the double wing method and to the weighing tank system have been contrived. The new design of this system aims to satisfy several demands: accurate measurement, low cost, small weighing tank, wide range of flow rate, efficient calibration time, easy maintenance, and applicability to hazardous areas. Experiments have been carried out on a prototype in a water flow circuit in order to confirm that the new system has the demanded features.

2. Diverter timing error

On the basis of the static gravimetric method, mass flow rate q is given by Eq. (1).

$$q = \frac{m_1 - m_0}{t_D (1 - \rho_A / \rho_w)} \quad \dots \dots \dots (1)$$

Here, m_0 is initial weight, m_1 is weight after collection, ρ_A, ρ_W denote the density of air and water, respectively, and t_D is the time interval between starting and stopping signals. This duration t_D may include the diverter timing error Δt . This timing error influences the calibration results systematically, and cannot be reduced by repeating calibration. The diverter timing error should be estimated by an experimental method. The following bursts test is one of the estimating methods recommended in ISO4185. First, the initial weight m_0 is measured. Then the weighing tank is filled up by a single diversion to measure the weight after collection m_1 and the duration of diversion t_{D1} . Second, the total weighing scale $\sum_{i=1}^n m_i$ and total time $\sum_{i=1}^n t_i$ are measured in a series of n (as many as 25) diversions without resetting the timer and the scales. Finally, the error results are obtained from these values by the following formula.

$$\Delta t = \frac{t_{D1}}{n-1} \left(\frac{q_1}{q_n} \cdot \frac{\sum_{i=1}^n m_i / \sum_{i=1}^n t_i}{(m_1 - m_0) / t_{D1}} - 1 \right) \dots \dots \dots (2)$$

Here, q_1 represents the flow rate during a single diversion measured by a flowmeter, and q_n is the average of the flow rates measured by the flowmeter during n diversions.

If the duration of diversion is sufficiently long in comparison with the timing error, the error will be negligible. However, in many calibration facilities for large flow rate, duration is insufficient, because of economical or physical limitations. In many calibration facilities, the error caused by the diverter has often been the main source of uncertainty. This error also constitutes one reason to limit maximum flow rate with reference to the volume of the weighing tank.

3. Design of the prototype system

3.1. Diverter with rotating double wing

The new design achieves small diverter timing error, compact design, small wet area, simple and robust mechanism, easy implementation of an ISO4185 test, easy adjustment of diverter trigger timing. This diverter system is based on the concept of

symmetric diversion by two wings. Both wings should be moved in the same direction against the liquid jet, at both the beginning and end of measurement, and actuated at constant speed. See the reference article^[2] for the theory of the double wing method. In the present design the wings are rotated, whereas in the previous double wing method they are moved linearly.

Figure 1 illustrates the design of the diverter with two rotating wings. The diverter wings are set as partitions on a diameter line of a half-cylinder tube. The diameter is about 20 cm. The axis of rotation is at the center of the cylinder and runs parallel to liquid jets that flow vertically downward. One side of the diverter has a rectification surface which resembles a half cone as a closed bottom (Bypass side). When this side comes under the nozzle, the liquid flow is led into a bypass line. The other side (Collection side) has the shape of a semicircle having an open bottom, so that liquid jets can drop directly into the weighing tank. The diverter is rotated by a servo motor via a center shaft linked to a timing belt. Two photosensors and a disk having a slit are used as a trigger signal generator for starting and stopping a timer, and are set at the top of a shaft.

Before collection, the half cylinder is set on the bypass position so that the bypass side is located just under the nozzle. In this paper, this angular position is defined as 0°. To start collection, the cylinder is rotated 180° (to the collection position). On the way to the collection position, one of diverter wings cuts the liquid jet, at around 90°. At that moment, one of the photosensors detects the slit of the disk and sends the start trigger signal to the timer. While the cylinder is at the collection position, the liquid jet falls into the weighing tank. When the tank is filled up, the cylinder again rotates 180° in the same direction (to 360°), in order to stop the collection. The other diverter wing cuts the liquid jet at around 270°, and the other photosensor sends the stop trigger signal to the timer. The sensors are fixed on a precision traverse stage so that the sensor position can be adjusted by based on the estimated diverter timing error.

Even if a diverter is designed on the principle of the double wing method, some tests for estimating diverter timing error must be conducted, for adjustment

of the timing. In the previous double wing method, the wings must return to the start position under a liquid jet for next diversion, because these wings travel linearly in the same direction. On the way to the start position, the liquid jet drops into the weighing tank. In the bursts test under ISO4185, this mechanism involves a problem in practical operation. If an additional diverter is set between a main diverter and a weighing tank to prevent this unnecessary inflow, some liquid which must not drop into the weighing tank may wet the wall of the collection side. A large wet area lengthened a waiting time for dropping down fully. In the case of oil, the wet area should be made as small as possible, since the waiting time is apt to increase drastically, because of high viscosity.

Determining a method of checking for leaks presents another problem. Providing this additional device only for the test will reduce accuracy in usual calibration; in addition, ISO4185 tests are seldom carried out.

In contrast the new design offers many advantages: the wet area can be minimized; the diverter wings do not have to return, because the end position is the same as the start position; the wet area of the collection side is completely separated from the bypass side; bursts test of ISO4185 can be run consecutively without any waiting time; usual calibration can be carried out accurately; and the mechanism of this rotating motion is simple and robust. However, tests should be carried out in order to confirm that the rotating motion of the diverter poses no problem.

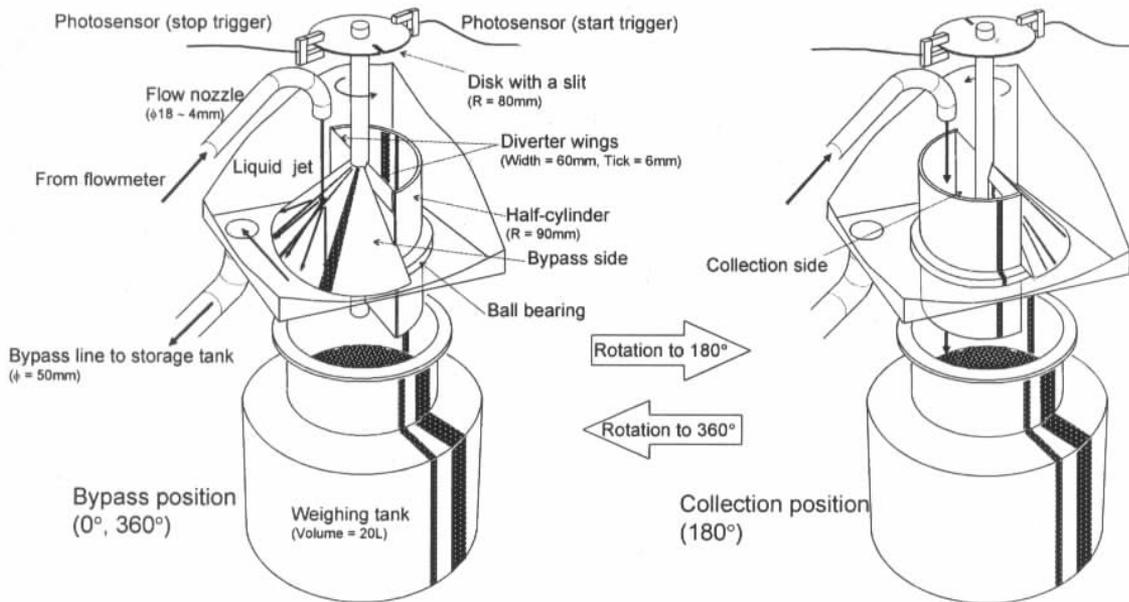


Fig. 1 Design of diverter with rotating double wing.

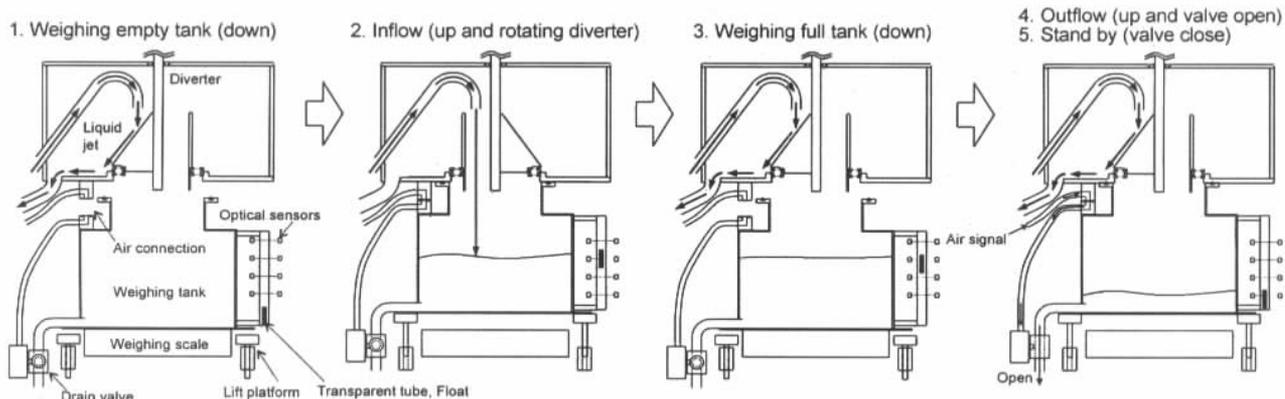


Fig. 2 Sequence of operation of the weighing system.

3.2. Weighing tank and weighing scale system

In many cases, a weighing tank system has an open section at the inlet, through which vapor might escape from the collected mass. A weighing tank is often linked by electric wires to detect liquid level, and by air tubes to actuate a drain valve. These can be sources of error. Especially in case of a small weighing tank having a small scale, even if the tension is small, these errors could exert greater influence on measurement than the resolution of the scale.

This weighing tank system has devices for accurately measuring a mass of the collected liquid. The weighing tank in the present system has no open section from which vapor and mist are ejected to the atmosphere, except for a short time during weight measuring. Figure 2 shows the sequence of operation of the weighing system. The weighing tank is placed on a lift-platform which is elevated by air actuators. The tank is lifted up from the scale and pushed tightly to the bottom of the diverter box, in order to protect the scale against sudden impact by the jet, and to prevent the escape of vapor. Although the air inside of the tank flows from the weighing tank to the diverter box as the tank is filled by liquid, the air inside the box has already been saturated with mist or vapor. Therefore, diffusion and evaporation hardly progress. Even in the event of unexpected overflow due to malfunction of the diverter, the liquid will flow to the bypass line through the diverter box. This tight sealing at the inlet functions as a fail-safe mechanism.

The weighing tank is placed on the scale completely free during weighing, because no electric wire is connected to the weighing tank. In order to avoid any mechanical connection to the tank, the liquid level is detected by optical sensors and a float inside a transparent tube. The system also features automatic connection of an air tube for the drain valve. Only when the tank is pushed up, the connection is established so that the valve can be operated by an air signal. When the tank is placed on the scale, the connection is completely separated. These devices are also adaptable and useful in a hydrocarbon flow facility. Oil vapor ejection to the atmosphere is unfavorable, in view of measurement accuracy and the environment of

the room. The air connection is safe in a hazardous area. Of course, in case of an oil facility, a ground wire to be connected must be as flexible as possible.

3.1. Experimental apparatus

Figure 3 shows a schematic of the experimental apparatus and flow circuit. The flow rate is maintained by means of a pump and a control valve. The water is automatically maintained at a constant temperature by a heat exchanger, which has another pump. The inner diameter of main piping is about 25 mm. Downstream of the control valve, the piping branches into 4 nozzles which feed water jet to the diverter. The inner diameters of the nozzles are 18, 13, 7, and 4 mm, respectively. Many calibration facilities equipped with a diverter adopt a variable-width nozzle in order to maintain a jet flow stable over a wide range of flow rate. However, such a device has a complicated mechanism and may be prohibitively expensive, especially in the case of a small size. When flow rate is low, removing bubbles from the top of the variable-width nozzle is difficult. In this prototype, independent multi-nozzles of different inner diameters are employed, in order to simplify the mechanism and to lower cost. In addition, this nozzle is nothing more than a cutting pipe edge. According to the theory of the double wing method, the diverter timing error is not dependent on the position and the flow velocity profile of the liquid jet from the nozzle^[2]. The weighing system has a capacity of 20 kg for the collected liquid and a resolution of 0.1 g. Atmospheric pressure and ambient temperature were measured for buoyancy correction.

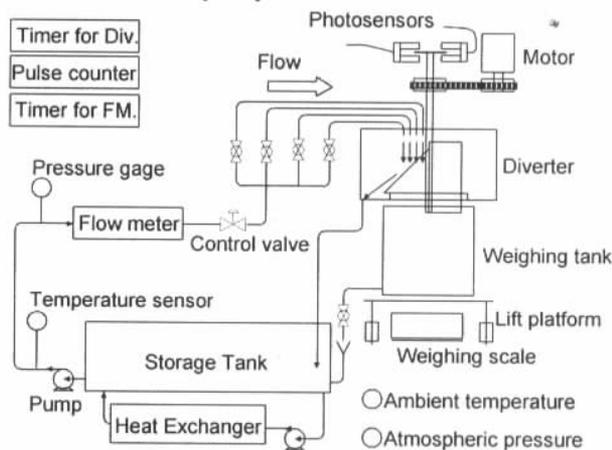


Fig. 3 Schematic diagram of the prototype.

4. Experiment

In our experiments, diverter timing error was estimated by Eq. (2) of the bursts test recommended in ISO4185. We set the diversion number at $n = 25$. Flow rate was measured by a Coriolis flowmeter. The angular velocity of the wing was set to $360^\circ/\text{s}$. In some experiments simulating a single wing diverter, only one wing goes and returns across the liquid jets. In order to investigate the influence of flow rate profile and that of nozzle position, two nozzle locations were tested: straight location, and oblique location, as shown in Fig. 4. In practical calibration, valves of larger nozzles are closed as the flow rate becomes small. In the present experiments, all 4 valves were always open.

Diverted flow rates against the angle of the diverter wing were measured as follows. The diverter wing enters the liquid jet and is stopped at an arbitrary angle. During a constant time (30 s), a portion of the liquid jet is divided and dropped into the weighing tank. The flow rates were calculated from the weight of liquid and the time. The angles were set from 80° to 130° in increments of 0.5° .

5. Results and Discussion

5.1. Adjustment of diverter timing error

The results of the estimation test of the diverter timing error are shown in Fig. 5. Nozzle location A was used in this experiment. First, the photosensor for the start signal was set at 90° , as set by the encoder of the servo motor. Diverter timing error was measured by using only one wing, in order to simulate a single-wing-type diverter. The averaged diverter timing error was about 7.5 ms, because the nozzles are not set exactly on the line of 90° . Second, from the time of error and the angular velocity of the wing, an adjustment angle of the photosensor was calculated. This corresponded to -1.4° . After the photosensor position was adjusted near 88.6° , the estimation tests were again carried out by the single wing method. Third, while the position of the photosensor was maintained near 88.6° , the other photosensor was set at 270° . Then the diverter timing error was measured by the double wing method. Average error time and correction angle were -2.1 ms and -0.8° , respectively.

Fourth, after the other sensor position was adjusted to 269.2° , estimation of timing error was carried out with two wings. After adjustment of the sensors, the diverter timing error falls within 1 ms, for the double wing method regardless of flow rate. The results of the single wing method suggest that the diverter timing error is somewhat dependent on flow rate.

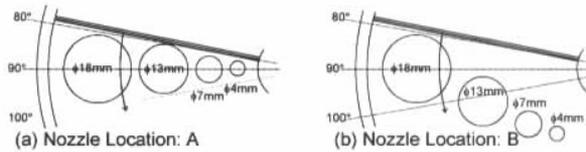


Fig. 4 Location of multi nozzles.

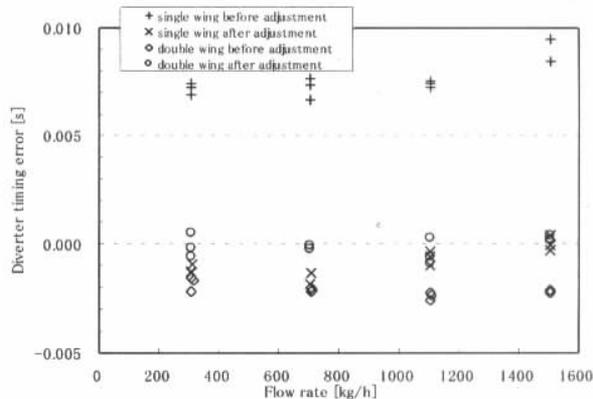


Fig. 5 Variation of diverter timing error in the adjustments.

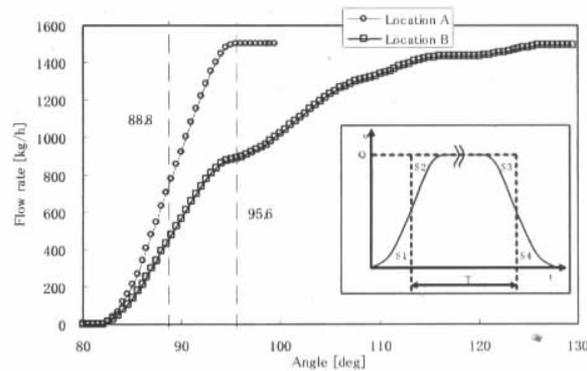


Fig. 6 Diverted flow rate versus position of the diverter wing.

5.2. Effect of nozzle location

Figure 6 shows measurement result of diverted flow rate (1500 kg/h) versus diverter wing angle. The flow rate pattern of location A is relatively symmetric. The pattern of location B is quite bumpy. In the case of the single wing diverter, the diverter timing error theoretically becomes zero^[3] under the conditions of $S1=S2$ and $S3=S4$, as illustrated in Fig. 6. The angle

which satisfies $S1=S2$ was calculated from the flow rate data under the premise that the velocity of rotation is constant. The calculated angle for the location A is 88.8° , which is close to the adjusted angle in the single wing method. The angle for location B was 95.6° .

Figure 7 shows the results for location B. Although the jet condition was changed remarkably, the results confirm that in the case of the double wing method the diverter timing error is not dependent on the flow profile. A conspicuous difference from the single wing method is observed. The value of diverter timing error at 1500 kg/h is -39.8 ms, which corresponds to an angle of 95.8° for the sensor position. These close values obtained by different methods indicate the high reliability of these experiments.

5.3. Effect of the seal at the inlet

In order to investigate the efficiency of the seal at the inlet of the weighing tank, the weights were measured after the weighing tank was filled, in both the case where the tank was moved up and the case where the tank was moved down. Figure 8 shows transition of the weight of the filled weighing tank. In case where the inlet remained open, the collected mass was lost at a rate of about 0.13 g/min, because of evaporation, and diffusion of vapor. Even if the weighing tank is filled at a low flow rate, thereby requiring a long time, the evaporation effect is illustrated to be negligibly small, so long as the lift platform is in the raised position.

6. Conclusion

A new diverter based on the rotating double wing method has been developed. The weighing tank system has been improved by some contrivances. Experiments using the prototype have shown that the design has many advantages, and that the rotation motion raises no problem. By rotation of two wings, the double wing method enables easy implementation of the test under ISO4185. In the weighing tank system, a single action of the platform can prevent the escape of vapor, ensure connection of the air tube, provide protection against impact, and provide a system that is fail-safe against overflow.

We are able to use a large flow rate with a small

tank, which makes the collection time short, because the diverter timing error is certain to fall within 1 ms. In addition, this design avoids drawbacks of long-time calibration conducted at a low flow rate. Therefore, the prototype has a very wide range of flow rate. The devices employed in this design offer high accuracy, low cost, a simple robust mechanism, and easy maintenance.

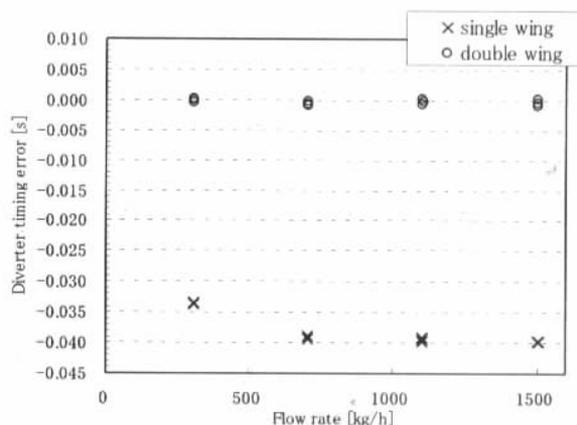


Fig. 7 Diverter timing error at different nozzle locations.

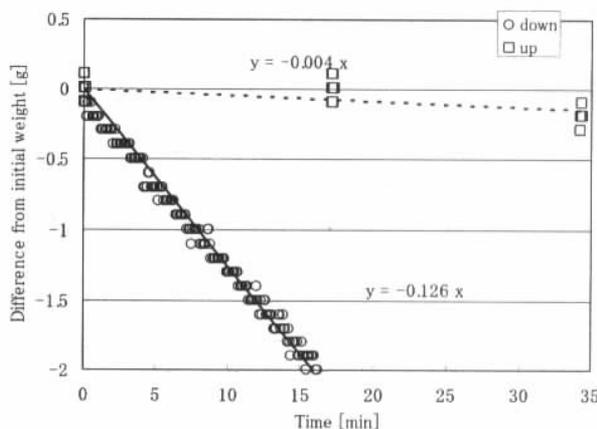


Fig. 8 Transition of the weight of filled weighing tank.

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