A Novel Motor-driven Flow Diverter with an Enclosed Structure

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Abstract

In order to reduce the uncertainty and improve the calibration with oil flows or hot water flows, an electric motor driven flow diverter with an enclosed structure was developed. The structure, performance parameters and characteristics of the novel flow diverter are described in the paper. The details of the enclosed mechanical structure for fluid diversion and the measures taken to control vaporization of volatile oils or hot water are presented. The principle of the integrated electric control subsystem together with the strategy of turn speed control are also presented. Experimental data together with analyses on a prototype flow diverter using water flows are introduced. According to the test data, the standard uncertainty of the flow diverter is better than 0.0006% using the method of transfer time difference.

1. Introduction

Static gravimetric method is widely used in flow meter calibrations and experimental tests since it is able to reach low uncertainty, and it is convenient to directly get mass flow rate. Static start-and-stop method is usually applied to the accumulated flow rate calibrations of the flow meters as the initial and end values of the meter should be recorded. Flying start-and-stop method is more popular than static start-and-stop method because the flow rate is stable during the test process. Flow diverters are essential components of a liquid flow calibration facility using the flying start-and-stop method. The uncertainty related to the flow diverter can significantly affect the overall flow rig uncertainty to achieve better calibration and measurement capability. The movement repeatability of the actuation mechanism and the time symmetry of transfer actions are key factors for improving flow diverters.

The electric actuation mechanism was gradually applied in the flow diverters because it has better controllability of movement speed, time symmetry of transfer in and out, and repeatability of many times transfer action than traditional pneumatic cylinder. The standard uncertainty of motor-driven flow diverters in water flow facility at Physikalisch-Technische Bundesanstalt (PTB) were better than 0.004% that were controlled by a programmable logic controller (PLC), driven by a motor and linear gear, and monitored by an absolute angle encoder [1, 2]. A single-direction rotating double wing flow diverter was developed by National Metrology Institute of Japan that reached a standard uncertainty better than 0.0019% driven by a servo motor [3, 4]. The liquid flow diverters, at UME Fluid Mechanics Laboratories in Turkey, were driven by servo motor and precise ball screw that were controlled by PLC [5]. Type A and B uncertainties of a single-direction rotating flow diverter, which was actuated by motor and reducer, were better than 0.005% and 0.0005% respectively [6]. ITRI developed a water flow diverter that was composed of a horizontal movement flow distributor, a linear gear and a servo motor controlled by PLC [7]. A water flow diverter, whose flow distributor was directly driven by a step motor, was developed by Tianjin University in China, as a result, a standard uncertainty 0.007% was achieved, moreover the noise and vibration of transition were reduced effectively [8]. The transition time of a water flow diverter was reduced to 4 ms by direct driving a flow conveyor by a motor on the water flow facility at INRIM [9].

For a traditional flow diverter, it typically has an open structure and this may present problems for volatile oil or hot water flows. The vapour of oil or hot water will make the test environment smelly or moist, and the weight of emission will impact the uncertainty of flow metrology. A flow diverter with an enclosed structure was adopted on the hot water flow facility at PTB, the temperature of the water up to 90 ℃, and the effect of water weight in expelled air during filling process on flow uncertainty was considered [10].

In order to reduce the uncertainty and improve the calibration with oil flows or hot water flows, an electric motor driven flow diverter with an enclosed structure was developed. The motor-driven and enclosed mechanical structures of the novel flow diverter are described in the paper. The principle of the integrated electric control subsystem together with the strategy of turn speed control are presented. Experimental data together with analyses on a prototype flow diverter using water flows are introduced. According to the test data, the standard uncertainty of the flow diverter is better than 0.0006% using the method of transfer time difference.

2. Structure

2.1 Enclosed mechanical structure

Traditional flow diverter has a nozzle or a furcate tube working as a flow distributor, like the part 8 shown in Figure 1, driven by a pneumatic or electric actuation mechanism to transfer the flow directions between the weighing tank and the bypass pipe [1, 9]. The top and bottom sides of the flow distributor are open because it has to rotate in a range of angle and let the liquid flow in and out at the top and the bottom, respectively. Vapour of volatile oils or hot water will escape out from the open area and the gaps between the distributor and the pipe or the weighing tank.

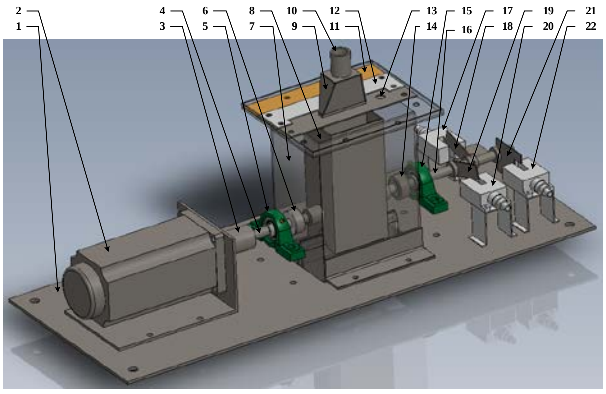

Figure 1: Motor-driven flow diverter with an enclosed structure.
1 Mounting plate; 2 Step motor; 3 Coupling; 4, 16 Shafts;
5, 15 Bearings; 6, 14 Seal covers; 7 Flow director; 8 Flow distributor;
9 Nozzle; 10 Feeding pipe; 11, 12 Cover boards; 13 Venting hole;
17, 20, 22 Optoelectronic switches; 18, 19, 21 Trigger boards.

The novel enclosed flow diverter structure is composed of seal covers (6, 14), flow director (7), flow distributor (8), nozzel (9), feeding pipe (10) and cover boards (11,12), as indicated by Figure 1. The flow distributor (8) is a furcate tube enclosed by the flow director (7), whose shape is samilar to the distributor but the size is larger. The director (7) is static because the bottom of it is connected to the weighing tank and the bypass pipe. The water flowing out from the bottom of the distributor (8) can be guided to the weighing tank and the bypass pipe by the two-ways structure of the director (7). The nozzle (9) is installed on the flow director (7), and the outlet of the nozzle is dived into the flow distriutor (8) to avoid the cutting board spilling the liquid out during the process of transition. The shafts (4, 16) pass throuth the wall of the flow director (7) and connect with the flow distributor (8). Seal covers (6, 14) are desinged to prevent the vapour from going outsisde through the gaps between the shafts and the walls. The cover boards (11, 12) can be fixed on a square platform at the top of the flow director (7) after the flow distributor (8) has been mounted inside. Considering the air inside the weighing tank will be expelled out together with the vapour of liquid, a venting hole (13) is set on the top of the flow director (7) that can guide the mixture of air and vapour to another tank or a predesigned area using a tube.

2.2 Motor-driven structure

The driving shaft (4) is supported by the ball bearing (5), and connected with the step motor (2) by the coupling (3), as displayed in Figure 1. The motor (2) actuates the flow distributor (8) directly since there is no moveable parts and gap between the connection parts. There is no time delay induced by the gaps between the mechanical connection parts as the flow distributor (8) reverses its rotating direction. The rotation of the flow distribution (8) is conveyed to three trigger boards (18, 19 and 21) by the output shaft (16) which is supported by a ball bearing (15) also. The movement of the trigger board will change the light conditions of the optoelectronic switches and generate the electric signals for start and end timing.

A three-phase hybrid step motor with step accuracy ±5% is used in the flow diverter. The maximum resolution of the motor driver is 60000 step/r so the minmum step angle is 0.006°, and the maximum response frequency can reach 200 kpps (kilo pulse per second). The number of the signal pulse, the pulse frequency and the variation of the frequency can precisely regulate the rotation angle, rotation speed and acceleration of the step motor, respectively. As a result, the swing angle, the transfer velocity, the acceleration, the start and stop positions of the flow distribution can be controlled. Keeping the turn speed stable during the transition can make the cutting board of the flow distribution smoothly cuts the flow below the nozzle outlet, as presented in Figure 3. The symmetry of transfer in and out and the repeatability of many times transition can be ensured by the performance of the step motor.

3. Electric control subsystem

3.1 Structure and working principle

The control subsystem consists of DC power, optoelectronic switches, Single Chip Microcomputer (SCM), Industrial Personal Computer (IPC), motor driver, step motor, as shown in Figure 2. DC power supplies electric power to the optoelectronic switches and the SCM. The optoelectronic switches detect the positions of the flow distributor and output signals for start and stop timing and safety protection. After receiving instructions from the IPC, the SCM control the motor driver to execute corresponding actions according to the signals output by the optoelectronic switches. For example: judge and reset the positions of the flow distributor, transfer the flow to the weighing tank or the bypass pipe. In different working modes the SCM is able to automatically achieve the calibration of the flow diverter using the method of transition time difference or flowmeter calibration through gravimetric method and send the test data to the IPC.

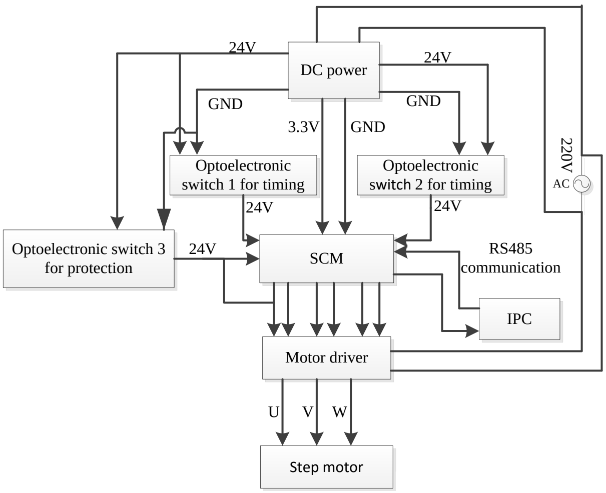

Figure 2: Structure of the control subsystem.

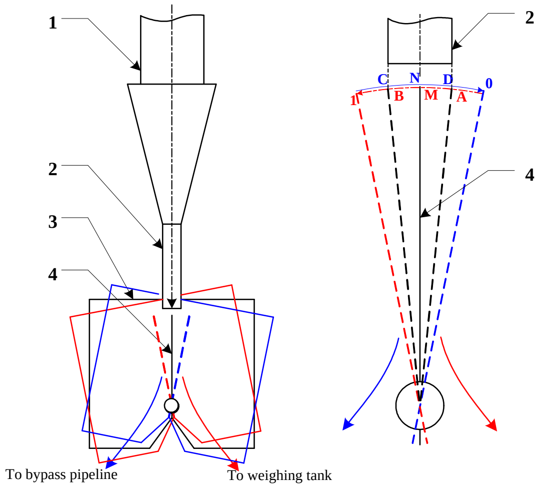

Figure 3: Transfer processes of the flow diverter.
1 Feeding pipe; 2 Nozzle; 3 Flow distributor; 4 Cutting board.

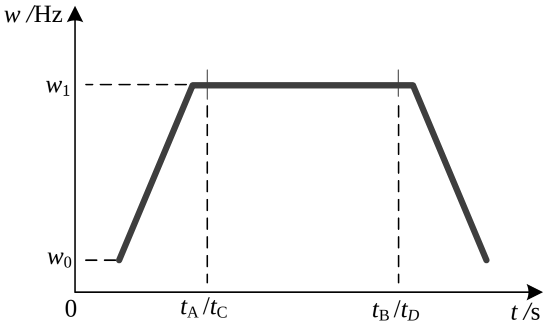

Figure 4: Control strategy of motor speed in the transfer process.

3.2 Control strategy

3.2.1 Motor speed control

The process of transfer in means the flow distributor turn left from the point 0 to 1 and change the flow direction from the bypass pipe to the weighing tank, as indicated in Figure 3. The transfer out is a process reverse to the transfer in.

In order to reduce the transition time, it is necessary to make the step motor rotate in a high speed. Step loss or blocking will appear in the step motor if the pulse frequency of control is too high at the beginning stage. A constant acceleration is set to increase the turn speed gradually, as illustrated in Figure 4. Rotation angle overshoot of flow distributor will occur before the motor stop while the turn speed is high. The control strategy in Figure 4 makes the step motor reduce the speed slowly. The pulse frequency of control should not be set as zero at the start and stop points because of the vibrations of the step motor under very low turn speeds. Intend to ensure the consistency of flow distributor transferring in and out the weighing tank, the turn speed of the step motor should be stable at a constant value in the effective stages of transitions from t_A to t_B or t_C to t_D. Turn speed of the step motor starts from a low value, gradually rises to high speed, keeps at a constant point over a period of time, then slow down and stop in the whole process.

3.2.2 Position judgement and reset

After power on, the SCM will reset the position of the flow distributor making the flow diverter ready to start work. The meaning of position reset is to make the flow distributor go back to the initial point 0 and let the liquid flow into the bypass pipe no matter wherever it was previous. Two optoelectronic switches (17, 20) are designed to genenrate the signals for start and stop timing, and the third one (22) is used to control the step motor preventing from the flow distributor (8) collides the flow director (7), as shown in Figure 1. The position judgement of the flow distrubutor is realized throuth the conditions of both the switches for timing.

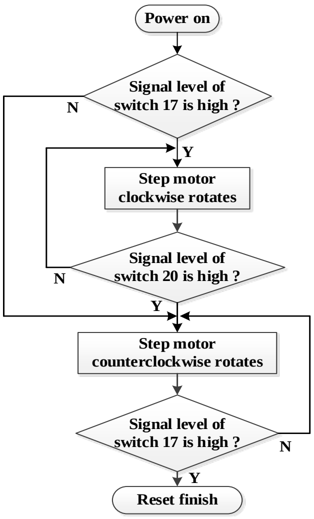

Figure 5: Process of the flow diverter reset.

Assuming the optoelectronic switch (17) is obscured by the trigger board (18) with high level electric voltage signal output, and the liquid flows into the bypass pipe. Then, as switch (20) is obscured the liquid will flow into the weighing tank. If both switches (17, 20) are not obscured that means the flow distributor is in the middle region, and the liquid flows into both the bypass pipe and the weighing tank. The process of reset is illustrated in Figure 5. As the signal level of switch (17) is high, the step motor clockwise (view from the step motor to the switches) rotates until the trigger board (19) covers the switch (20), then reversely rotates in counter-clockwise direction till the trigger board (18) covering the switch (17). If the signal level of switch (17) is low the motor counter-clockwise rotates until the trigger board (18) covers the switch (17).

4. Test and analysis

The test results of the flow diverter using flowmeter method include the effect of the flow velocity profile asymmetry in the cross section of the nozzle outlet. That is good for evaluation the overall performance of weighing system including the nozzle. The uncertainty of flow diverter calibrated by the flowmeter method based on reference flowmeter and electronic balance is related to the repeatability error of the flowmeter and the uncertainty of the balance. The uncertainty of a motor-driven flow diverter is ususally better than 0.005%. Therefore, there is a very high requirement for the reference flowmeter if the uncertainty of the flow diverter is actually presented. The transition time difference method [11] is only related to the behaviour of the actuation and movement parts that can avoid other influences on the test results.

A DN25 prototype motor-driven flow diverter with an enclosed structure was fabricated, as shown in Figure 6. The prototype of motor-driven flow diverter is calibrated using the transition time difference method for mainly evaluate the performance of the actuation and movement parts. The SCM controls the flow distributor to transfer in and out for n ($n \geqslant 10$) times and records the transition times t_{1i} for transfer in and t_{2i} for out after the flowrate has been regulated to the pre-set point.

The mean times of n times transfer in and out are t_1 and t_2, respectively. The type A uncertainty of t_1 and t_2 are u_{A1} and u_{A2}, respectively, and type B uncertainty of the flow diverter is u_B. In the formulas, $t_{\min}$ is the shortest measuring time of the flow facility.

$$t_1 = \frac{\sum_{i=1}^{n} t_{1i}}{n} . \tag{1}$$

$$t_2 = \frac{\sum_{i=1}^{n} t_{2i}}{n} . \tag{2}$$

$$u_{A1} = \frac{1}{t_{\min}} \sqrt{\frac{\sum_{i=1}^{n} (t_{1i} - t_1)^2}{n-1}} \times 100\% . \tag{3}$$

$$u_{A2} = \frac{1}{t_{\min}} \sqrt{\frac{\sum_{i=1}^{n} (t_{2i} - t_2)^2}{n-1}} \times 100\% . \tag{4}$$

$$u_B = \frac{t_1 - t_2}{4 t_{\min}} \times 100\% . \tag{5}$$

The uncertainty of DN25 prototype motor-driven flow diverter is shown in Table 1, assuming the $t_{\min}$ of the flow rig is 30 s. The uncertainty of the DN25 prototype flow diverters is better than 0.0006% tested in the flow rate range of 1.2 m^3/h to 12 m^3/h.

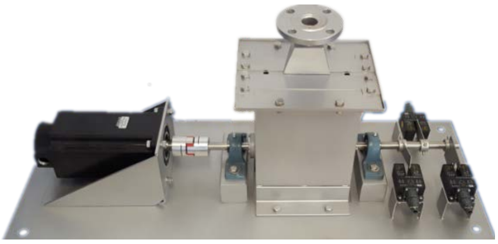

Figure 6: DN25 prototype motor-driven flow diverter with an enclosed structure.

Table 1: Test data of a DN25 prototype motor-driven flow diverter with an enclosed structure

Q (m^3/h)	1.2	6	12
Mean time of transfer in t_1 /ms	205.185	205.680	207.124
Mean time of transfer out t_2 /ms	205.512	205.987	207.094
Average time difference /ms	0.327	0.307	0.030
Maximum time difference /ms	0.541	0.580	0.294
Uncertainty of u_{A1} /%	0.0004	0.0004	0.0005
Uncertainty of u_{A2} /%	0.0002	0.0003	0.0004
Uncertainty of u_B /%	0.0003	0.0003	0.0000
Total uncertainty /%	0.0005	0.0006	0.0006

5. Conclusions

A novel flow diverter driven by step motor with an enclosed structure was developed to improve the calibration with oil flows or hot water flows. The vapour of the volatile liquid can be controlled through the enclosed structure during the process of meter calibrations. The electric control subsystem using single chip microcomputer realized turn speed control of transfer process, position reset of flow distributor and automatic calibration of the flow diverter. The uncertainty of the DN25 prototype flow diverter is better than 0.0006%, tested using water flows and the method of transfer time difference.

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