Design of a New Structure for Rotary Viscometer

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Abstract. The existing rotary viscometers on the market mostly adopt the single-blade transmission structure, which cannot eliminate the end-effect of the fluid viscosity test and affect the test accuracy. In order to solve this problem, a new structure of rotary viscometer is designed. The blade of the rotary viscometer is divided into upper and lower parts, and the parallel transmission scheme is adopted to prevent the upper blade from being subjected to additional torque, thereby eliminating the end-effect.

1. Introduction
Rotational viscometer is widely used for fluid viscosity testing because of its ease of use and ability to test fluid viscosity at different rotational speeds [1, 2, 3, 4]. The mainstream rotary viscometers on the market include DV series viscometers produced by Brookfield company, RB series viscometers produced by Toki company and ROTAVISC series viscometers produced by IKA company, etc., as shown in Figure 1.

Figure 1. The mainstream rotary viscometers on the market.

These rotary viscometers are generally single-blade motion transmission structure [4, 5], as shown in Figure 2. The motor drives the blade to rotate through coupling and torque sensor. The blade’s torque and rotational speed can be measured by the torque sensor. By substituting the torque and speed data into formula (1) [6], viscosity of fluid can be calculated.

\[
\eta = \frac{M}{4\pi h\Omega} \left( \frac{1}{R_1^2} - \frac{1}{R_2^2} \right)
\] (1)
The torque $M$ in formula (1) is formed by the shear stress of the fluid on the side of the blade. However, when the blade rotates, the fluid under the blade moves relative to the bottom surface of the blade. The resulting shear stress causes additional torque $M'$ at the bottom surface of the blade. Additional torque results in inaccurate torque measurements, which affects the accuracy of viscosity test result of the single-blade rotary viscometer. This is called the end-effect of fluid viscosity testing [6].

The structure of rotary viscometer designed in this paper divides the blades into upper and lower parts. By the scheme of parallel motion transmission, the additional torque of the upper blade is eliminated and the end-effect of viscosity test is eliminated.

2. Design of structure for rotary viscometer

According to the analysis in the chapter 1, when the fluid under the blade moves relative to the bottom surface of the blade, additional torque is generated on the bottom surface of the blade, which affects the viscosity test results. Therefore, in order to eliminate the end-effect, it is necessary to eliminate the relative motion between the fluid under the blade and the bottom surface of the blade.

The structure of the rotary viscometer designed in this paper is shown in Figure 3. The blade consists of upper blade and lower blade. The upper blade is test blade and the lower blade is auxiliary blade. The torque sensor collects the torque and speed data of the upper blade, and outputs them to the computer to calculate the viscosity of the fluid.
In order to eliminate the relative motion between the fluid under the blade and the upper blade, the motion parallel transmission scheme is adopted. The upper blade is fixed on the large gear II by welding. The motor drives it to rotate through “Reducer - Coupling I - Large gear I - Small gear I - Shaft II - Coupling II - Torque sensor - Coupling III - Shaft III - Small gear II - Large gear II”. The lower blade is fixed to Shaft I by screw connection. The motor drives it through “Reducer - Coupling I - Shaft I”. Since the gear ratio of the gear train is designed to be 1, the rotational speeds of the upper and lower blades are equal. When the blade rotates in fluid at the rotational speed $\Omega$, fluid under blade rotates at the rotational speed $\Omega$ driven by the lower blade. There is no relative motion between the fluid under blade and the bottom surface of upper blade. Therefore, the fluid under blade does not cause additional torque at the bottom surface of the upper blade. When the lower blade drives the fluid under it to rotate, it is subject to additional torque. However, since the shaft I and the big gear II are connected by bearings, the additional torque will not be transmitted to the motion transmission path where the torque sensor is located. The torque sensor measures only the torque generated by the fluid on the side of the upper blade. The viscosity of the fluid can be obtained by substituting the torque and speed data of the upper blade into formula (1). By using the double-blade motion parallel transmission structure, the additional torque in the viscosity test is eliminated, and then the end-effect is eliminated.

![Figure 4. Three-dimensional model of the double-blade motion parallel transmission structure.](image)

3. **Experiment verification**  
After detailed design such as motor and torque sensor selection, motor speed control, data processing program writing, etc., the rotary viscometer with double-blade motion parallel transmission structure is produced, as shown in Figure 5.

![Figure 5. The rotary viscometer with double-blade motion parallel transmission structure.](image)
To verify the accuracy of the rotary viscometer with the double-blade motion parallel transmission structure, the viscosity of the cement paste was tested at 10r/min and 20r/min using this rotary viscometer and the DV-2T rotary viscometer manufactured by Brookfield Company. In order to avoid the influence of the type of cement or the stirring method on the experimental results, the double-blade rotational viscometer and the commercial viscometer use the same pot of fresh cement paste and start testing at the same time.

The test results of 10r/min are shown in Figure 6. The average error between the viscosity test results of the double-blade rotary viscometer and the DV-2T is 3.15%. The test results of 20r/min are shown in Figure 7. The average error of the test results of the two instruments is 1.15%. The experimental results show that the measurement error between the double-blade rotary viscometer and the DV-2T is small, which can verify the accuracy of the rotary viscometer with the double-blade motion parallel transmission structure.

![Figure 6. Test results at rotational speed 10r/min.](image)

![Figure 7. Test results at rotational speed 20r/min.](image)

4. Conclusion
In order to eliminate the end-effect in viscosity test of the rotary viscometer, the double-blade motion parallel transmission structure for rotary viscometer is designed. The structure eliminates the additional torque at the bottom surface of the upper blade by eliminating the relative motion between the bottom surface of upper blade and the fluid under blade. The rotary viscometer with double-blade
motion parallel transmission structure tested viscosity of the cement paste at 10r/min and 20r/min, and the results were in good agreement with the DV-2T viscometer.

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