The Development of the Drilling Fluid Rheological Meter

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Abstract. A set of on-line test equipment for drilling fluid rheological parameters is developed, which can realize real-time on-line monitoring. Design method: first of all let the drilling fluid to flow through the same shape and dimension of the section, in turn, change, will produce different velocity of different section, between all the pipe sections using pressure sensor real-time acquisition of differential pressure value, and the differential pressure and flow rate signals to the data acquisition system for transformation, such as display and processing, and then according to the rheology model to calculate the rheological parameters of drilling fluid to be measured. The final measurement results will be compared with the results of rotary viscometer measurement, shows the practicability and feasibility of the device have zero since the calibration function, measuring range is 5-150 mpa’s, measurement accuracy can satisfy the requirement of 5%.

Introduction

The harsh environment of oil drilling operation puts forward more stringent requirements for drilling fluid, that is, drilling fluid should complete suspension, pressure control, stability of exposed strata, buoyancy, lubrication and cooling, etc. The rheological parameters of drilling fluid include drilling fluid viscosity, static shear force, dynamic shear force and shear thinning property. This paper introduces an on-line drilling fluid rheology parameter test device of \([1,2]\), has the advantages of simple operation, short time, high accuracy, easy remote measurement results and other characteristics, which will fundamentally change the existing mode of measuring drilling fluid rheology, high precision and real-time measurement of the performance of drilling fluids.

System Design

System Hardware Design

Drilling fluid rheology parameters online testing device is composed of measuring system and data acquisition and processing system is composed of two parts of \([3]\), the measurement system is mainly composed of a constant flow pump, 4 different diameter tubes, Coriolis mass flowmeter \([4]\), 4 groups of pressure sensor and so on. Data acquisition and processing system consists of minimum system, data storage module, communication module, switch output module, analog input module and so on.
Measurement System Structure

![Diagram of the measurement system]

**Figure 1. Structure of measuring system.**

**Measuring Principle.** First of all to the mud pump as the power source, the drilling fluid into the tube in [5,6] cross section with different tube diameter to adjust the thin area, so as to realize the different velocity of flow in the same flow, so as to achieve different shear rate in the capillary fluid (the four tubes, respectively is 510 and 1020 s\(^{-1}\) rotary viscometer s\(^{-1}\), 340 s\(^{-1}\), 170 s\(^{-1}\), the shear rate). The flow meter was determined by capillary flow, measuring pH with pH meter installed in pH measuring tank pH, 4 tubes of different diameters were measured with 4 sets of pressure loss of pressure sensor, the 2 equation 4 contradictory equations established the pressure loss in pipe flow equation and then use Bingham fluid flow pressure loss equation and power law the fluid [7], solutions of 2 contradictory equations respectively, shearing force and plastic viscosity and flow index and viscosity, and their correlation coefficient.

Flow pressure loss formula of Bingham fluid in pipe:

\[
\Delta p = \frac{128LQ\mu_p}{\pi D^4} + \frac{4\tau_0 L}{D}
\]  

(1)

Power law fluid tube flow pressure consumption formula:

\[
\Delta p = \frac{4kL}{D} \left( \frac{Q}{\pi D^3} \right)^n \frac{24n+8}{n}
\]  

(2)

**System Software Design**

**Lower Computer Program**

This system adopts modularization design in the design of lower computer program, including the two part of the main program and subroutine, the main program is calling the subroutine system at the completion of each part according to the process after initialization, each subroutine is called. Subroutines include initialization subroutine, serial program, TLC2543 conversion program, control algorithm program, AT25256 storage program, real-time clock program, temperature sensor program, W5500 program. The lower computer program is shown in figure 2:
Host Computer Program

The upper computer interface is written by QT and the corresponding upper computer program is written by C++ realizes remote control of electromagnetic valve and mud pump and remote acquisition of data received by each sensor[9]. The PC application consists of 8 small files, each file contains the source files, header files, UI file interface, the main program, key program, start setting time key program, display program, variable time setting procedure, operation interface program, boot interface program, communication program.

Operation Process and Data Analysis

System Setup and Operation Display

The setting is mainly related to the acquisition time and washing time of PC system, special attention here is the execution cycle running time for several hours, the flushing time execution cycle can be 10min or longer. The relevant interface is shown in figure 3.

Running Demo: after the controller is powered on, let it warm up for half an hour. Open the upper computer software, enter the boot interface, countdown to five seconds after entering the monitoring interface, press the start button, the next opportunity to parse the data, and then extract
control command code, turn on the mud pump, turn off the solenoid valve, so that the liquid being measured into the pipeline. Then, the host computer program design delay, after a certain period of time to send data access command, after parsing, in accordance with the communication protocol, then the next opportunity to collect data uploaded to the host computer. The results of the dynamic shear force and the plastic viscosity are shown in figure 4.

Figure 4. Running interface.

After the acquisition time reaches the predetermined time, the system will flush the measuring system according to the set flush time. The upper computer sends the flushing instruction, the lower machine extracts the corresponding instruction, opens the electromagnetic valve, closes the mud pump, lets the clean water scour the pipeline.

Experiment and Data analysis of on Line Measuring Method of Rheological Properties

Viscosity measurements were carried out on using mud sample under different conditions [10], the test sample in the same mud, and measuring method of drilling fluid rheology online verification device and rotary viscometer to measure [11], the consistency of comparison of test results.

(1) The rotational viscometer operates at 100rpm, and the measurement results are shown in Table 1, corresponding to the test curve shown in figure 5.

Table 1. Test data under different viscosities.

<table>
<thead>
<tr>
<th>Rotational viscometer viscosity (mPa • s)</th>
<th>Flow rate (L/h)</th>
<th>Device display viscosity (mPa • s)</th>
<th>Deviation (mPa • s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>350</td>
<td>2.324</td>
<td>1.324</td>
</tr>
<tr>
<td>15</td>
<td>350</td>
<td>16.158</td>
<td>1.158</td>
</tr>
<tr>
<td>24</td>
<td>350</td>
<td>26.086</td>
<td>2.086</td>
</tr>
<tr>
<td>38</td>
<td>350</td>
<td>40.435</td>
<td>2.435</td>
</tr>
<tr>
<td>55</td>
<td>350</td>
<td>55.292</td>
<td>0.292</td>
</tr>
<tr>
<td>72</td>
<td>350</td>
<td>71.552</td>
<td>-0.448</td>
</tr>
<tr>
<td>88</td>
<td>350</td>
<td>86.761</td>
<td>-1.239</td>
</tr>
<tr>
<td>102</td>
<td>350</td>
<td>100.362</td>
<td>-1.638</td>
</tr>
</tbody>
</table>
Comprehensive analysis, under different viscosity effects, the results of two kinds of viscometer measurement deviation is relatively small, so as to achieve the desired results to meet the requirements.

(2) When measuring viscosity of $\alpha=14$ by rotary viscometer, the flow rate is gradually increased by controlling the regulating valve to verify the influence of flow rate on viscosity measurement. In order to make the result look more intuitive, the pressure difference of diameter $D=9.78\text{mm}$ and length $L=980\text{mm}$ straight pipe is used as the reference. The measurement results are shown in Table 2, corresponding to the test curve, as shown in figure 6.

Table 2. Test data and comparison results at $\alpha=14$.

<table>
<thead>
<tr>
<th>Rotational viscometer viscosity (mPa • s)</th>
<th>Flow rate (L/h)</th>
<th>differential pressure (kPa)</th>
<th>Device display viscosity (mPa • s)</th>
<th>Deviation (mPa • s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>46</td>
<td>2.135</td>
<td>37.468</td>
<td>23.478</td>
</tr>
<tr>
<td>14</td>
<td>64</td>
<td>2.725</td>
<td>32.457</td>
<td>18.457</td>
</tr>
<tr>
<td>14</td>
<td>98</td>
<td>3.465</td>
<td>27.516</td>
<td>13.516</td>
</tr>
<tr>
<td>14</td>
<td>132</td>
<td>3.82</td>
<td>23.86</td>
<td>9.86</td>
</tr>
<tr>
<td>14</td>
<td>163</td>
<td>4.365</td>
<td>20.765</td>
<td>6.765</td>
</tr>
<tr>
<td>14</td>
<td>245</td>
<td>4.865</td>
<td>18.736</td>
<td>4.736</td>
</tr>
<tr>
<td>14</td>
<td>300</td>
<td>5.635</td>
<td>16.763</td>
<td>2.763</td>
</tr>
<tr>
<td>14</td>
<td>370</td>
<td>6.145</td>
<td>14.728</td>
<td>0.728</td>
</tr>
</tbody>
</table>

Figure 5. Comparison of test curves.
Comprehensive analysis, when the flow rate is about 350L/H, the viscosity of the straight tube viscometer is basically the same as that of the rotational viscometer. Other deviations are relatively large, which is in line with the actual situation. Next, we perform error analysis:

\[
\mu = \frac{\Delta \rho \pi D^4}{128LQ} = \frac{(P_2 - P_1) \pi D^4}{128LQ}
\]  
(3)

From the test principle and the actual situation, we can think that P1, P2, D, L and Q are not related to each other, and the uncertainty of the synthetic standard of viscosity measurement is:

\[
u_u(\mu) = \left[ u_u^2(\mu) \right]^{1/2}
\]

\[
= \left[ \left( \frac{\partial \mu}{\partial P_2} \right)^2 u^2(P_2) + \left( \frac{\partial \mu}{\partial P_1} \right)^2 u^2(P_1) + \left( \frac{\partial \mu}{\partial D} \right)^2 u^2(D) + \left( \frac{\partial \mu}{\partial L} \right)^2 u^2(L) + \left( \frac{\partial \mu}{\partial Q} \right)^2 u^2(Q) \right]^{1/2}
\]

\[
= \left[ \left( \frac{\pi D^4}{128LQ} \right)^2 u^2(P_2) + \left( -\frac{\pi D^4}{128LQ} \right)^2 u^2(P_1) + \left( \frac{(P_2 - P_1) \pi D^3}{128LQ} \right)^2 u^2(D) + \left( \frac{(P_2 - P_1) \pi D^4}{128L^2Q} \right)^2 u^2(L) + \left( \frac{(P_2 - P_1) \pi D^4}{128LQ^2} \right)^2 u^2(Q) \right]^{1/2}
\]

(4)

In the formula, P1, P2 precision is 0.5%, namely U (P1) =0.5%, u (P2) =0.5%, the error of stainless steel tube diameter of D in terms of 0.01mm, u (D) max=0.03988/9.78 = 0.41%, the error of length L is calculated according to 2mm, u (L) max=4.988/980 = 0.51%, uncertain traffic the degree of U (Q) = [0.2%+ (zero stability / instantaneous mass flow]= x 100%) + [0.2%+ (0.0002/0.35 * 100%) =0.25714%]. The above parameters into the formula (4), pressure difference of P maximum, namely =60.9kPa=60900Pa (P2- P1), a
\[ u_c(\mu) = \left[u_c^2(\mu)\right]^{\frac{1}{2}} = \left[\left(\frac{\pi D^4}{128LQ}\right) u^2(P_2) + \left(\frac{-\pi D^4}{128LQ}\right) u^2(P_1) + \left(\frac{(P_2 - P_1)\pi D^4}{128LQ}\right) u^2(D) + \left(\frac{(P_2 - P_1)\pi D^4}{128L^2Q}\right) u^2(L) + \left(\frac{(P_2 - P_1)\pi D^4}{128Q^2}\right) u^2(Q)\right]^{\frac{1}{2}} \]

\[ = \left[\left(\frac{3.14 \times 0.018^4 \times 3600}{128 \times 0.98 \times 350}\right)^2 \times 0.5\% + \left(\frac{3.14 \times 0.018^4 \times 3600}{128 \times 0.98 \times 350}\right)^2 \times 0.5\% \right]^{\frac{1}{2}} \]

\[ + \left(\frac{60900 \times 3.14 \times 4 \times 0.018^3 \times 3600}{128 \times 0.98 \times 350}\right)^2 \times 0.41\% + \left(\frac{60900 \times 3.14 \times 0.018^4 \times 3600}{128 \times 0.98^2 \times 350}\right)^2 \times 0.51\% \right]^{\frac{1}{2}} \]

\[ + \left(\frac{60900 \times 3.14 \times 0.018^4 \times 3600}{128 \times 0.98 \times 350^2}\right)^2 \times 0.25714\% \right]^{\frac{1}{3}} \approx 1.5\% \]

(5)

This value is the result of the theoretical calculation and meets the requirement of accuracy. To sum up, the real-time measurement of rheological properties can be carried out by straight tube type online viscometer, which effectively avoids the defects of poor real-time measurement and poor control. In addition, in order to further improve the measurement accuracy, the measuring device can take steady flow measures.

Acknowledgement

Special thanks to my teacher Ming-jian Huang teacher, give me guidance in the development of this system, from the system development to the end in the process encountered many difficulties are he gave me encouragement and guidance, so that I can overcome the difficulties, the system is completed, we would like to Miss Huang with sincere thanks and regards. Thank you!

Conclusion

In this paper, aiming at measuring drilling fluid rheological parameters was designed based on the drilling fluid rheology measurement instrument STM32 processor, under different conditions respectively with straight line viscometer compared with rotary viscometer.

The experimental results show that compared with the off-line measurement method of the existing drilling fluid rheology measurement device can realize the remote on-line viscosity parameters on-line monitoring measurement through the network, the development of products has the advantages of simple operation, short time, easy remote measurement structure characteristics, improve the measurement efficiency of drilling fluid rheological parameters.

References


