Automatic Speed Control System Of Drilling Fluid Horizontal Screw Centrifuge

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***Abstract*—Aiming at the problem that the particle size distribution of solid particles in drilling fluid after centrifugal separation is difficult to control in the traditional horizontal screw centrifuge of drilling fluid treatment, an automatic control system of centrifuge based on particle size detection is proposed. The designed sample collection device is used to collect the image of the solid particles in the separation liquid sample, and the average diameter of the particles is obtained by contour extraction. The diameter data is sent to the controller by serial-port. The controller adjusts the centrifuge speed according to the particle size value to achieve the purpose of controlling the particle size distribution in the separation liquid. The system forms an automatic closed-loop control process through particle size detection and speed adjustment, realizes real-time online detection and control of the centrifuge, and improves the processing capacity and separation efficiency of the system.**

Keywords—Image sensing; Automation; Particle size measurement; speed regulating

Ⅰ. Introduction

In the process of oil and gas drilling, the solid control system of drilling fluid continuously circulates the drilling fluid between the solid control system and the mine, removes the unnecessary solid particles in the drilling fluid, and transports the cuttings. At the same time, it maintains the stability of the drilling fluid performance, cools and lubricates the drill bit and balances the formation pressure, so as to improve the working conditions of the drilling pump and other drilling equipment and improve the drilling efficiency[1,2]. Centrifuge as one of the solid control system of drilling fluid [3], the use of centrifugal force as a driving force to achieve the separation or concentration of liquid phase heterogeneous mixture, the basic principle is the use of mechanical methods, the mixture is placed in a certain force field, the use of the mixture of each phase in the force field by different forces to obtain a larger phase weight difference to separate it. Centrifuge is an important solid control equipment in the oil drilling industry, which is used to separate the drilling fluid with a particle size distribution of 2um-74um (the highest content) that cannot be processed by the vibrating screen. Drilling fluid centrifuge has become an indispensable solid control equipment for drilling operations, especially for medium-deep wells and horizontal wells. Its processing capacity and treatment effect can directly affect the mud quality [4]. Automated drilling is the ultimate development trend of the oil industry, but at present, most of the drilling fluid centrifuge equipment only has the functions of starting, stopping and stopping [5]. The common centrifuge control system has the following three categories : 1. Simple electronic control system, using conventional electrical controls (circuit breakers, servo motors, alarms, drive circuits, etc.) to build the control system, which can realize manual speed regulation, automatic feeding / unloading, abnormal operation alarm emergency stop and other functions ; 2.PLC control system, the system uses PLC as the main controller, with a variety of sensors to complete the detection, control and integration of the measurement and control process, because of its free programming according to the production needs of the characteristics of the major manufacturers are widely used ; the PC + PLC control system can manually issue instructions on the PC side to perform related detection and control tasks by the PLC, and can also complete the set measurement and control tasks by the built-in program[6]. In the aspect of intelligent control system of centrifuge, Dong Huairong et al. developed a fully automatic closed-loop control drilling fluid centrifuge[7]. According to the actual situation of drilling technology and the change of different drilling fluid performance and slag discharge in different formations and different drilling processes, the actual parameters such as load torque and processing capacity of centrifuge are collected in real time, and the closed-loop control is realized by frequency converter and automatic control system.

The particle size of the drill cuttings separated by the centrifuge is related to the speed of the centrifuge. As the speed increases, the particle size decreases, and as the speed decreases, the particle size increases. The existing centrifuge control system can only change the speed of the centrifuge by manually adjusting the controller parameters in the process of dealing with mud with different particle size distributions, which consumes too much labor and has the problem of adjustment lag, and it is difficult to ensure the accuracy of separation [8]. In order to solve this problem, this paper proposes a method to control the speed of centrifuge by measuring the particle size of drilling cuttings and bringing the difference between the detected value and the set value into the PID algorithm, so as to realize the function of automatically adjusting the speed of centrifuge in real time according to the change of particle size distribution of drilling cuttings in the process of separating cuttings. The system designs a sample acquisition device to collect samples of the drilling fluid after centrifugation. The industrial microscope head is used to collect sample images. The python programming language is used to program the OPENCV image processing platform on the PC side to preprocess the image and identify the contour to obtain the particle size distribution of the cuttings in the liquid. The particle size data is sent to the single-chip microcomputer through the serial port. After completing the data processing task, the single-chip microcomputer sends a control signal to the inverter drive module to adjust the speed of the centrifuge.

Ⅱ. System design

Since the diameter of more than 90 % of the drilling cuttings particles in the mud treated by the centrifuge is distributed within the range of 10.6 microns. And the order of magnitude of particulate matter is huge, so choosing a suitable particle size detection method is very important for the accuracy and efficiency of detection. At the same time, the accuracy of the detection results also directly affects the subsequent control links. Image recognition has the advantages of fast detection speed, convenient data reading and low difficulty in implementation. In the process of particle size detection, only a simple sample acquisition device can be used to complete the detection function. So image detection is the best choice for the system. The overall process of the system is shown in Fig.1.Firstly, the sampling device collects the processed drilling fluid samples from the liquid discharge port of the centrifuge according to the set sampling speed, and then dilutes the samples. Then, the microscope was used to collect images with high definition, no ghosting, moderate brightness and strong contrast at a set frequency, and the OPENCV image processing platform was used to detect the average diameter of particulate samples. Finally, after the diameter data is introduced into the controller, the difference is made with the set value, and the obtained difference is brought into the PID algorithm to adjust the duty cycle of the PWM signal and adjust the speed of the centrifuge through the frequency converter.

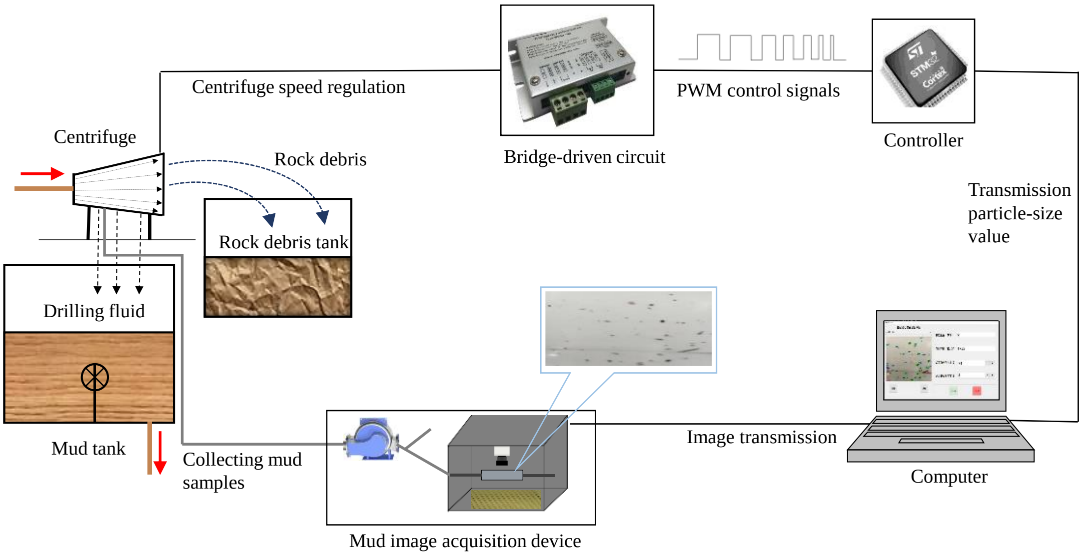


Fig.1 Control flow chart

III. Image capture and processing

A. image capture

The particle size of the particles in the sample is at the micron level, and there is mutual adhesion between the particles. Select a moderate dilution factor to disperse the particles, and also need to have sufficient number of particles in the field of view, so that the sample size is as large as possible to ensure the representativeness of the sample ; as shown in Figure 5, the distance *h* between the lens and the sample is set within 0.5cm, and the image is collected at a rate of 30 frames per second. In order to make the image edge clear without ghosting, it is tested that the flow rate V_3 of the diluted sample through the transparent pipe should be less than 0.15 m / s. It can be adjusted by adjusting the output speed V_1 of the micro pump, the injection speed V_2 of the diluent and the inclination angle α of the pipeline. The microscope and the transparent pipe are covered with a dark shell to prevent the external changing light from obliquely shining into the lens field of view to shadow the image. The light required for imaging is provided by a matrix light source arranged under a transparent tube, which ensures sufficient brightness and uniform distribution of light to improve image quality.

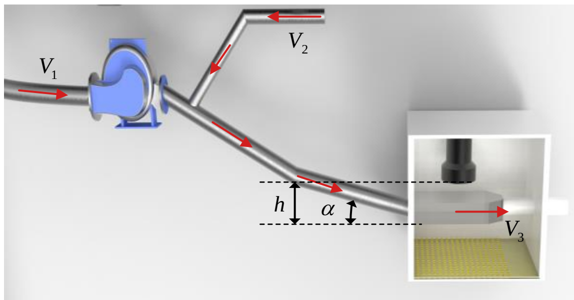


Fig. 2 Image capture system

B. image processing

The collected images are converted from analog to digital by D / A conversion and stored in matrix form. Before calculating the particle size value, the original image needs to be pre-processed to improve the image quality and then identify the edges of each particle to extract the contour. The entire execution process is shown in Figure 3.

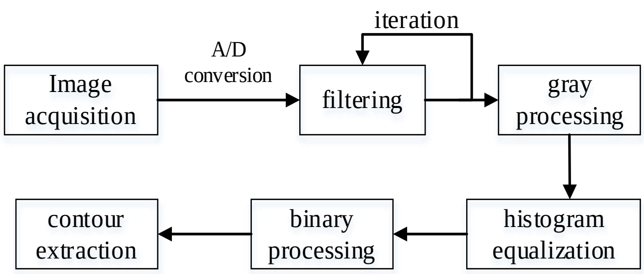
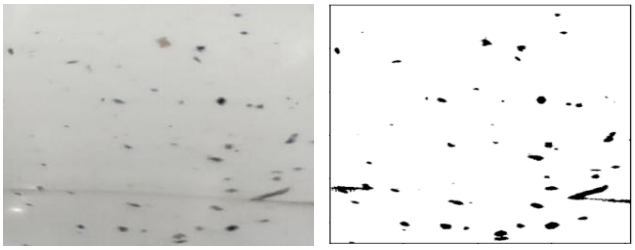


Fig. 3 Image pre-processing process

The lens imaging system will be disturbed by noise when generating images, resulting in distortion of the image. It is difficult to accurately predict the time and type of noise. Gaussian filtering can reduce this random error. Gaussian filtering is a process of weighted average. According to the denoising effect, after three iterations, most of the noise is eliminated, and the image structure is complete and presents a clear outline. The binarization processing is to re-assign the gray value of each pixel point according to the set threshold Z. The gray value of the pixel point greater than Z is reset to 255, and the pixel point less than Z is reset to 0. After the image is processed, there are only two gray values of 0 and 255, which are black and white, and are clearly divided into two parts : the target and the background. At this time, the image contrast reaches the maximum, as shown in Figure 4. Due to the large contrast of the binary image and the simple composition elements, the contour extraction can achieve higher extraction speed and accuracy, which greatly improves the efficiency of image recognition.



(a) original image　　(b) binary image

Fig. 4　pre-and post-process comparison image

- *C.* image recognition

Edge detection is to find out the pixel point whose gray value changes obviously in the image and calibrate it as the contour boundary of the target. Sobel edge detection is a detection method based on the maximum value of the first derivative of the gray function of the search image to determine the boundary. The algorithm structure is simple and easy to use, and the running speed is fast. At the same time, because the Sobel operator combines Gaussian smoothing and differential operation, it has strong denoising ability. The algorithm execution process is to use two three-row three-column matrices to perform plane convolution with image to obtain the approximate values G_x and G_y of the partial derivatives $f_x(x,y)$ and $f_y(x,y)$ of the image gray function $f(x,y)$ in the x-axis and y-axis directions. According to the partial derivative approximation G_x and G_y , the direction $\theta = \arctan(G_y / G_x)$ with the fastest gray scale change (gradient) can be obtained. If the gradient $G = \sqrt{G_x^2 + G_y^2}$ is greater than the threshold, the point is a point on the edge of the image. After the contour recognition is successful, the boundary of each target image is drawn with red lines, and the image contour is circumcircled and numbered in turn. The image diameter can be obtained by solving the circumcircle diameter, as shown in Fig.4.

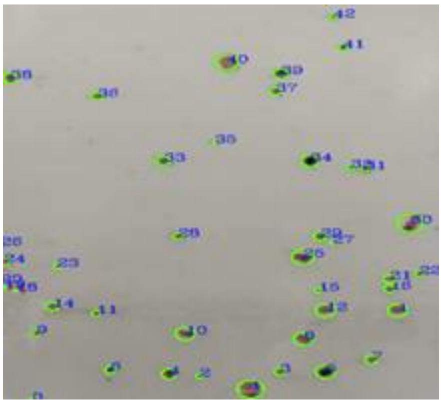


Fig. 5 Circumcircle of particle contour

- Ⅳ. Control

The main control chip of the control end is STM32 series single chip microcomputer. The controller processes the particle size detection value sent by the PC end and adjusts the speed of the centrifuge to control the particle size of the solid particles in the drilling fluid. At the same time, the encoder is used to collect the speed value and send it to the PC end. According to the production requirements, the upper and lower limits of the particle size in the centrifuge separation liquid are set to determine the distribution range of the particle size. The detected particle size value is sent to the controller, and the controller judges the two data. If the detection value is within a given range, the duty cycle of the output PWM control signal remains unchanged to maintain the current speed of the centrifuge. If the particle size value exceeds the given value, the two values are subtracted and the difference is brought into the PID algorithm to adjust the duty cycle of the PWM signal to achieve the purpose of speed regulation. The process is shown in Figure 6.

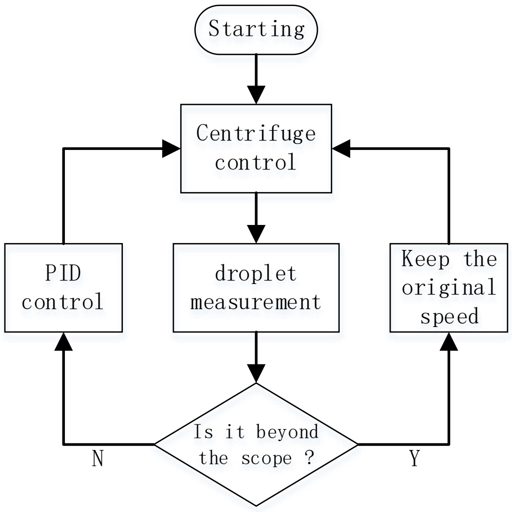


Fig. 6 Speed adjustment process

The feedback control algorithm is simple to use and has strong robustness. It dynamically adjusts the speed by inputting the real-time detection value and the set value. The algorithm performs proportional, integral, and differential operations on the error signals of past, present, and future three items. The position-based PID discretization algorithm is as follows:

$$u_{(k)} = K_p * err(k) + K_i \sum_{i=0}^{k} err(i) + K_d \left(err(k) - err(k-1) \right) \quad (1)$$

Where, $u_{(k)}$ is the control variable, $err(k-1)$, $err(k)$ is the difference between the k-1 and k-2 detection values and the set value, and K_p 、 K_i 、 K_d are the proportional coefficient, integral coefficient, and differential coefficient. The proportional term multiplies the current error by a proportional coefficient and adds it to the current output control signal. Using only the proportional term will result in a steady-state error. The integral term accumulates every instance of the error, multiplies it by an integral coefficient, and adds it to the control signal. This term can eliminate steady-state error. The derivative term calculates the difference between the current error and the previous error, multiplies it by a derivative coefficient, and uses this to predict the next error and prevent output from exceeding the setpoint and causing system oscillations.

In the centrifuge control system based on particle size detection, since the particle size distribution of the solid phase in the treated separation fluid depends on the separation effect of the centrifuge, and the separation effect is related to the rotational speed, the solid phase particle size distribution control of drilling fluid can be transformed into the control of the rotational speed of the centrifuge. The sample particle size value is obtained by particle size detection, and the error value is obtained by making a difference with the set particle size value, which is brought into the PID algorithm to control the variable frequency drive to adjust the centrifuge speed, so that the control of solid phase particle size in drilling fluid can be realized.

Ⅴ. Simulation analysis and experiment

A. System equivalent analysis

A motor equivalent model in this section is built for analysis and calculation. R is defined as the effective resistance, L is expressed as the equivalent inductance, and E is defined as the counter-electromotive force. The dynamic voltage and the current flows of the circuit can be determined as:

$$U_d - E = RI_d + L\frac{dI_d}{dt} = R(I_d + T_l \frac{dI_d}{dt}) \quad (2)$$

$$I_d - I_L = \frac{T_m}{R}\frac{dE}{dt} \quad (3)$$

Where T_l is the electromagnetic time constant (s), $T_l = L/R$; U_d is the input voltage (V); I_d is the armature current(A); T_m is the system electro-mechanical time constants (s), $T_m = GD^2 R / 375 C_e C_m$; I_L are the loads current (A), $I_L = T_L / C_m$; C_m is the torque coefficient at rated flux; C_e is a counter-electric potential coefficient(V *min/r); T_L is load torque applied to motor shaft (N/m); GD^2 is the converted inertia on the motor shaft ($Kg * m^2$).

B. Transfer function of motor system

With Laplace transforms, the transfer function between voltage and current is obtained:

$$G_1(s)=\frac{I_d(s)}{U_d(s)-E(s)}=\frac{1/R}{T_l s+1} \quad (4)$$

Simultaneously, the transfer function between electric potential and current can be determined as:

$$G_2(s)=\frac{E(s)}{I_d(s)-I_L(s)}=\frac{R}{T_m s} \quad (5)$$

According to the relational expression $E=nC_e$, the transfer function between electromotive force and rotational speed can be obtained:

$$G_3(s)=\frac{n(s)}{E(s)}=\frac{1}{C_e} \quad (6)$$

The transfer function model of the motor control system is obtained by connecting (4), (5) and (6), as shown in Fig.7

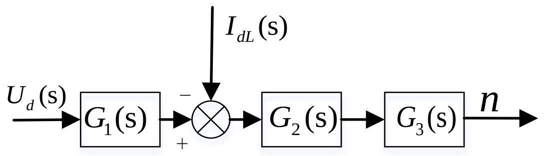


Fig. 7 Transfer function model

- *C.* Simulation analysis of motor control output

To further verify the possibility of the control method and the stability of the control system, an electromechanical coupling control model of the system is established by applying the Runge–Kutta method. DC motor Z4-132-1 is selected for control simulation, the parameters of the control system are shown in Table 1.

Table 1 Motor parameters

Parameter	Value
Rated voltage U/V	400
Rated current I/A	52.2
Rated speed n/(r/min)	2610
Back-EMF coefficient Ce/(V*min/r)	0.1459
Overload capacity ratio λ	1.5
Equivalent resistance R/Ω	0.368
Electromagnetic time constant Tl/s	0.0144

Taking the medium-speed centrifuge as a research object, we set the target rotational speed with 1500 rpm and a 40%load rating. According to the speed formula $n=U_d-I_dR_a/C_e$, the input voltage is set to 238V.

The control circuit adopts the H-bridge driving circuit as the driving device, PWM wave is used to modulate the pulse signal in the g-end of the H-bridge so as to control the output signals of the bridge circuit. The control voltage Uc is compared with the triangular wave which can produce a square wave signal with an adjustable pulse duration ratio (pulse width). Take the PID algorithm into error signal to calculate and adjust the value of the control voltage so as to change the duty ratio of the PWM wave, and achieves the purpose of adjusting the average output voltage of the driving circuit. In this simulation part, the comparison voltage is converted to the speed by a relational equation, i.e., the product of the given rotational speed and the rotational speed feedback coefficient as the control voltage, the gain value of the feedback link is set as the speed feedback coefficient, and a double close loop control system is formed by directly inputting the speed (N) and the feedback speed value, as shown in Fig.8

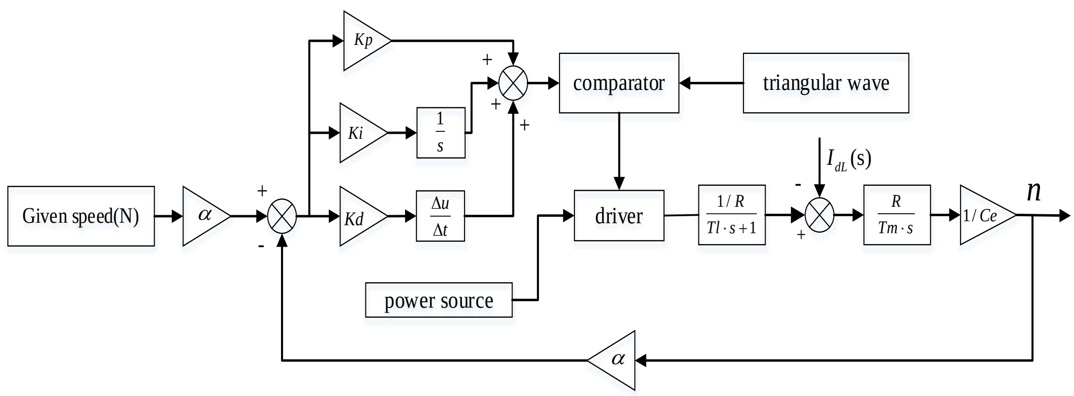


Fig. 8 PID control speed feedback model

The speed change of the PID control speed feedback model in the simulation process is shown in Fig.9. It is demonstrated that the speed is increased dramatically before 0.2 s, and a minor overshoot occurs around 0.2s. The error gradually reduced with time going and eventually stabilized at the given speed of 1500 rpm. The steady response is an important index for evaluating the control system. After 1.4s, it gradually fits with the given speed, eliminating the steady-state error.

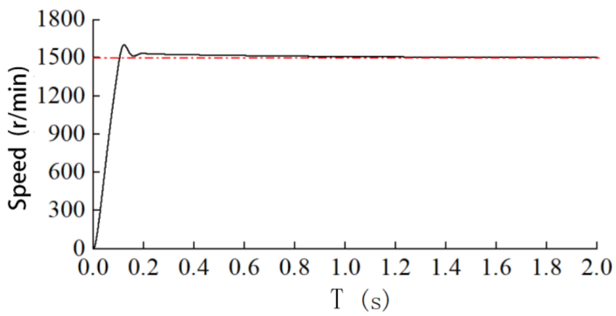


Fig. 9 Speed change of PID control speed feedback model

Fig.10 shows the speed change curve of PID speed feedback control under no-load and abrupt load variations. The reference speed was set to 1500r/mi at startup and kept no-load operation, and an abrupt load with a 40% rated load is added at 0.5s. It can be found that the two-speed curves are approximate and unanimous after 0.2s, the static difference is reduced, close to the given speed, and the centrifuge can be started smoothly. An abrupt load is added at 0.5s, the load speed curve decreases slightly at first, then increases compared with the no-load speed curve. Finally, it tends to be stable, and the final speed of the no-load and load state reaches the given speed. The proposed PID algorithm can be applied to the speed control of the centrifuge with zero steady-state error.

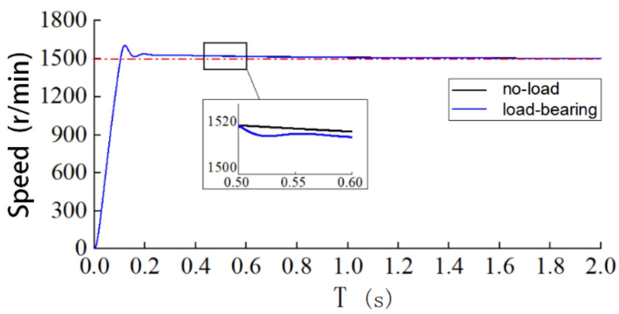
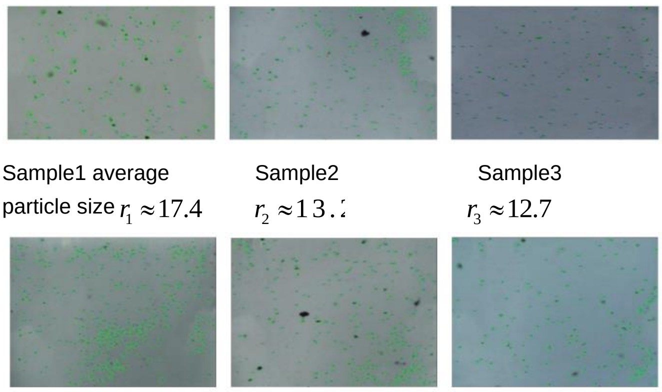


Fig. 10 Speed comparison diagram of PID control under different loads

- *D.* Experimental results and discussion

The upper limit of the centrifuge separates is set to 15um at the control interface in the experiment period. Then start the centrifuge, and we can grab real-time image acquisition at regular intervals of 10s, as shown in Fig.11. The average particle size of the particles is obtained by the image contour recognition. Simultaneously, the particle sample is collected and the particle size value of the sample is detected by the laser particle size detector in collecting samples of the particles. The resulting error is calculated and compared with the given separation range to evaluate the reliability of the control system.



Sample1 average particle size $r_1 \approx 17.4$ | Sample2 $r_2 \approx 13.$ | Sample3 $r_3 \approx 12.7$

Sample4 $r_4 \approx 13.9$ | Sample5 $r_5 \approx 14.2$ | Sample6 $r_6 \approx 16.3$

Fig. 11 Sample contour extraction

- Ⅵ. Conclusion

A centrifuge control system with detecting particle size is proposed to apply in oil and gas drilling engineering. The sample images of the drilling fluid after being separated by the centrifugal are collected, and the particle size values of the cuttings in the sample are obtained through image recognition. The separation range of the centrifuge is customized, and the deviation between the detected particle size value and the particle size set value is used in the PID algorithm to achieve real-time and dynamic adjustment of the centrifuge speed, which enables the control of the solid-phase particle size distribution in the drilling fluid to be within the set range. By inputting the detection value into the feedback control output system in the system, a closed-loop system for detection and control is formed, which enhances the performance and reliability of the drilling fluid centrifuge, and improves the separation efficiency of the centrifuge. The improvement in the informatization and convenience of the centrifuge has increased its adaptability and reduced the difficulty of operation. This has significantly reduced the need for manual operation while ensuring normal operation. All these study results will provide a new idea for developing and designing drilling fluid centrifuge of automation, intellectualization, and effectiveness with high efficiency and energy-saving in engineering.

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