Development of Automatic Control System for Cutting Fluid Filtration

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Abstract. Cutting fluid by which the cutting tools and workpieces can be cooled and lubricated play an important role. The filtration and recycling for cutting fluid will effectively remove the iron filings, dust and impurities from the cutting fluid, reduce the secondary pollution to the processing site in the process of recycling, and improve the result of cutting fluid recycling. The paper provides a kind of the design of automatic filtering control system for cutting fluid, the system can recycle and filter the cutting fluid which has been used in the process of production, and recycle again, so as to save energy greatly, protect the environment and increase economic benefits. meanwhile the whole recycling and filtering process can be controlled automatically or manually on the touch screen, and the status of each working part of the system can be displayed in real time, and the judgment algorithm for filter belt replacement has been optimized, so as to improve the operating efficiency of the system further, enhance the convenience, stability and reliability.

Keywords: Cutting Fluid; Filtration and Recovery; Control System; Replacement of Filter Belt; Touch Screen; PLC.

1. Introduction
Nowadays, every country in the world will regard modern machining technology as the main approach to improve productivity, and it is also the representation of the important competitive ability for the enterprise development. Whether it is the traditional machining facilities such as lathe, milling machine and drilling machine, or the modern machining facilities with higher degree of automation such as CNC lathe and CNC milling machine, cutting fluid should be indispensable in the process of processing and manufacturing. Cutting fluid which can reduce cutting temperature, decrease tool wear, increase tool life, and improve the quality of machining surface of workpieces plays an important role in ensuring machining accuracy and improving production efficiency [1]. Moreover the cutting fluid can clean the impurities such as iron powder, wear debris and greasy dirt remained on the surface of workpieces and tools, so as to improve the cutting effect. It is imperative to recycle cutting fluid in order to comply with the trend of saving energy and protecting environment. When the cutting fluid is used for the tools, workpieces and machines, impurities including a large number of iron filings, dust and greasy dirt will inevitably be mixed into it [2], the pollutants of the recycling cutting fluid without filtering treatment
will be brought back to the processing site again. The impurities of the cutting fluid without filtration will reduce the tool life, increase the tool wear, and affect the processing quality of the workpieces, decrease the production efficiency, therefore the control technology of cutting fluid recovery and filtration will be the key factors to improve the effect of cutting fluid recycling. With the constant progress of enterprise production system, especially with the increasing requirements for environmental protection, energy saving and civilization, the technology of cutting fluid recycling treatment will be applied more and more widely [3].

2. System Overview

2.1. Model of filtration and recovery for cutting fluid
At present there are two main recycling modes for cutting fluid including filtration by single machine and centralized filtration [4]. Filtration by single machine means that the machine is equipped with recycling and filtering system, which is suitable for the environment where the number and scale of equipment are small and the specifications of cutting fluid are different. Centralized filtering which is aimed at all machines within a certain area can recycle and output the cutting fluid concentratively, which is widely used by large-scale machining enterprises, it can save costs and reduce pollution.

The filtration forms used in the recovery and filtration system of cutting fluid include the type of filter element, the type of adsorption, the type of roller, the type of gravity and the type of vacuum. Gravity filtration mainly depends on the gravity of cutting fluid to flow through the filter belt. The iron filings and impurities of cutting fluid can not pass through the holes of filter belt through which the clean fluid filtered can pass, so as to realize solid-liquid separation and filtration. It has the advantages of simple mechanical structure, low cost, easy control and convenient maintenance. Therefore this paper establishes the model of filtration and recovery for cutting fluid as shown in Fig. 1 based on the mode of centralized recycling and gravity filtration.

As shown in Fig. 1, the model is mainly composed of top water tank and bottom water tank. After the cutting fluid has been used is pumped into the bottom water tank by the pump, the fluid has been filtered by the filter belt will sink into the bottom of the bottom water tank and then will be pumped into the top water tank by another pump. The cutting fluid has been cooled will be discharged from the top water tank by the drainage pump to supply the equipments in the plant again and keep always recycling. The holes of the filter belt which has been used for a period of time will be gradually blocked by solid particles, and the filtration efficiency will be reduced [5]. The blocking of the filter belt will cause the poor circulation of cutting fluid, the liquid level of which will rise. Right now it is necessary to move the filter belt to remove the blocking part of the filter belt and replace the old one with the new one, so as to ensure the filtering effect.

Fig.1 Model of filtration and recovery for cutting fluid
1- Bottom water tank  2- Top water tank  3- Filter belt  4- Upper limit of liquid level for top water tank  5- Lower limit of liquid level for bottom water tank  6- liquid level of filter belt blocked  7- Normal liquid level of top water tank

2.2. Control system of Filtration and recovery for cutting fluid

![Control system diagram](image)

The control system shown in Fig.2 mainly includes PLC controller, touch screen, sensor, contactor, motor, etc. The PLC controller is connected internally with communication unit, digital input unit and digital output unit. The touch screen is connected with the communication unit by RS485 communication cable; the temperature sensor, level switch block, detection switch of filter belt replacement and the normally closed auxiliary contacts of the thermal relay block are connected separately to the digital input unit and collect the signals; the digital output unit is used to drive every excitation coil of the contactor block; every main contact of the contactor block are connected separately with the three-phase windings of hydraulic pump block, conveying motor of filter belt and coolant pump which are also connected separately with every main terminal of the thermal relay block in order to provide three-phase AC power supply; the thermal relay block can function as the overheating detection.

3. Work Principle

PLC controller which can achieve the data processing and logical operation is the core unit of the system. Touch screen is the equipment of automatic filtering control system which can interact with the operators. The system operation can be started and stopped automatically by the operators, who also can manually operate each equipment of the filtration system and monitor the operation state of every equipment during the filtering process. When the operator sends the operation command to the PLC controller by touch screen, the external input components which should be connected with the digital input units will be scanned firstly based on PLC instructions, including level switch block, detection switch of filter belt replacement and the normally closed auxiliary contacts of the thermal relay block. The level switch block includes the detection switches of lower limit and upper limit of liquid level for top water tank, the detection switches of lower limit and upper limit of liquid level for bottom water
tank and the detection switch of liquid level for filter belt blocked. If there is no signal detected by the detection switch of upper limit of liquid level for bottom water tank and the detection switch of liquid level for filter belt blocked, it means that there are still enough spaces to place the cutting fluid in the bottom water tank, and there are not many impurities on the filter belt, which can continue to be used. The thermal relay block is used to detect whether the hydraulic pump block, conveying motor of filter belt and coolant pump are overheated and overloaded. The hydraulic pump block includes the recovery pump of bottom water tank, the pump from bottom water tank to top water tank and the drainage pump of the top water tank. If the normally closed auxiliary contacts of the thermal relay block do not act, it means that all pumps and motors connected to the thermal relay block can work properly without breakdowns. The detection switch of filter belt replacement is used to detect whether the filter belt is used up and remind to replace the coil of filter belt in time. When the start-up conditions are met, the PLC controller will ask the digital output unit to send a signal to power up the excitation coil of the corresponding contactors of the contactor block, so as to make the recovery pump of bottom water tank work, and the cutting fluid has been used will be recycled to the bottom water tank, in the meantime the impurities will be filtered by the filter belt. Until there is a detection signal of upper limit of liquid level for bottom water tank, it means that the bottom water tank has been full, what can feed back to the PLC controller by digital input unit, and finally the recovery pump of bottom water tank will be stopped. When the liquid level is standing still after a short delay according to the program setting, the PLC controller will ask the digital output unit to send a signal to drive the hydraulic pump which can deliver the cutting fluid from bottom water tank to top water tank, and the cutting fluid has been filtered will be cooled in top water tank by coolant pump if the top water tank of which there is a detection signal of upper limit of liquid level is full, at the same time the pump for bottom water tank to top water tank should be stopped. When the temperature of cutting fluid has dropped to the set temperature which can be scanned by the temperature sensor, the coolant pump will be stopped by PLC in time. After a time delay, the digital output unit will drive the related contactors to make the drainage pump of top water tank work, and finally the cutting fluid which has been cooled and filtered will be outputted again for supplying to the equipments. When the cutting fluid of top water tank of which there is a detection signal of lower limit of liquid level has been outputted completely, the drainage pump of the top water tank will be stopped. The system will stop operating immediately and keep the standby status during the process of filtering operation, if the stop operation is executed or the overheating and overload signals are detected by the thermal relay block.

4. Optimized Judgment Algorithm For Filter Belt Replacement

As mentioned above, after the cutting fluid has been filtered circularly for a period of time, the filtering effect will be seriously reduced due to the accumulation of impurities on the filter belt of which the holes have been blocked. So the cutting fluid will also accumulate on the filter belt, what can cause the liquid level of cutting fluid to rise until it can reach the position of the detection switch of liquid level for filter belt blocked in the bottom water tank. And the filter belt should be moved based on a detection signal scanned by PLC to replace the old part of filter belt with a new one in order to ensure the health of the system. Because the detection switch of liquid level for filter belt blocked can be interfered by the fluctuation and dynamic change of liquid level, the traditional judgment method is to prolong the detection time, called ‘eliminating jitter’. After the detection switch of liquid level for filter belt blocked has detected continuously the liquid level signal for a period of time, it can ask the filter belt to move. The selection of the detection time which is hard to grasp can be influenced by the different flow rate of cutting fluid and the different size of the tank carrying the cutting fluid, so it is particularly necessary to implement the replacement of filter belt with a set of optimized judgment algorithm.

In summary the quantities of detection switches of liquid level for filter belt blocked are increased to four by optimized setting, of which two are placed with different heights between the filter belt and the inlet in the bottom water tank, and the height difference is \( h_1 \), the other two are placed with different heights between the upper limit of liquid level and lower limit of liquid level in the bottom water tank, and the height difference is \( h_2 \).
Assuming that the flow of cutting fluid recovered to the bottom water tank is $Q$, the base area of the bottom water tank is $S$, the change speed of cutting fluid level in the bottom water tank is $v$, the height difference between each two detection switches of liquid level of the bottom water tank is $h$, and the time of liquid level change between each two level detection switches is $t$, then the calculation formula is as follows [6]

$$Q = S \times v \quad (1)$$

$$v = \frac{h}{t} \quad (2)$$

It can be gotten based on formula (1) and (2)

$$Q = \frac{S \times h}{t} \quad (3)$$

Then the filtration flow of cutting fluid above the filter belt is

$$Q_1 = \frac{S \times h_1}{t_1} \quad (4)$$

Then the filtration flow of cutting fluid below the filter belt is

$$Q_2 = \frac{S \times h_2}{t_2} \quad (5)$$

Assuming that the power of the inlet and outlet pumps of the top and bottom water tanks are the same and the diameters of the main pipes are equal, the input and output flow of the bottom water tanks should be equal. If the distance of detection switches of the liquid level can be adjusted to get $h_1=h_2$, then it can be gotten from formula (4) and (5)

$$\frac{Q_1}{Q_2} = \frac{t_2}{t_1} \quad (6)$$

At this moment the change of filtering flow can be judged directly by comparing the corresponding time of filtering flow of cutting fluid with one of the output flow of cutting fluid which also is the input flow, so as to master the condition of the filter belt.

Now the filter belt provided by most suppliers can reach the filtering accuracy of 30 ~ 80 $\mu$m, which can meet the production needs of most machining types [7]. Taking a machining factory as an example, the impurities of cutting fluid below 80 $\mu$m can account for 85%, the total impurity content is 150mg / L, the inlet and outlet flow of water tank is 1650 L / min, and the bottom water tank is 22m$^3$. The time interval of traditional replacement of filter belt is generally set as 750s [8]. It can be obtained by calculation that the impurity which can be filtered out is about 464g when the filter belt is replaced each time. Then the optimized judgment algorithm will be used, and the experimental analysis is shown in Table 1.
Table 1. Experimental analysis of optimized judgment algorithm

| $\frac{t_2}{t_1}$ | Turnover time (s) | Filtered impurities (g) | \begin{tabular}{l} Time efficiency \\ (%) \end{tabular} | \begin{tabular}{l} Filtration efficiency \\ (%) \end{tabular} |
|-------------------|-------------------|-------------------------|-------------------------------------------------|-------------------------------------------------|
| 0.8               | 353               | 229                     | -52.9                                          | -50.6                                           |
| 0.618             | 478               | 298                     | -36.3                                          | -35.8                                           |
| 0.5               | 611               | 396                     | -18.5                                          | -14.7                                           |
| 0.382             | 656               | 455                     | -12.5                                          | -1.9                                            |
| 0.2               | 778               | 468                     | 3.7                                            | 0.9                                             |

It can be seen from Table 1 that the time efficiency and filtering effect are not the same when different $\frac{t_2}{t_1}$ are selected as the standards of filter belt replacement. By comprehensive comparison, when the ratio is between 0.5 and 0.382, the effect is better. It can not only ensure the filtering effect, but also reduce the replacement time of filter belt, which will not cause waste of filter belt, but also improve the rate of filtering and recycling.

5. Function Description Of Hmi

5.1. Automatic filtration

The control interface of touch screen is shown in Fig.3, the operator can enable the auto start and stop of the filtration system by this interface to provide the automatic operation with security guarantee. When the operator selects the auto mode on the touch screen and presses the auto start, the filtration system will run with automatic sequence according to the established technological procedure [9]. If there is no signal detected by the detection switch of upper limit of liquid level and the detection switch of liquid level of filter belt blocked for bottom water tank, and the thermal relay works properly, then the automatic filtering process will start. Firstly the recovery pump of the bottom water tank works until there is a signal detected by the detection switch of upper limit of liquid level for bottom water tank, the recovery pump of the bottom water tank will be stopped immediately and the cutting fluid has been filtered completely. Then the pump from the bottom water tank to the top water tank will work, and the cutting fluid filtered will be delivered to the top water tank. When there is a signal detected by the detection switch of upper limit of liquid level for top water tank, the pump from the lower water tank to the upper water tank will be stopped immediately, and the coolant pump will be started. Until the temperature of cutting fluid detected by the temperature sensor can match the setting temperature, the coolant pump will not work anymore and the cutting fluid has been cooled. Finally the drainage pump of the top water tank should work for the recycling of cutting fluid which has been filtered and cooled. The equipments in the system can be coordinated each other automatically during the whole filtering process without manual intervention, what can save labor and raise working efficiency. If the problems are caused in any working procedure, the filtering system can be manually stopped by the emergency stop button to improve safety.
5.2. Manual filtration

The operator can manually control and adjust the equipments of each procedure in the filtration process according to the actual filtration requirements and production conditions. When the operator selects the manual mode, the start and stop of the recovery pump of the bottom water tank, the pump from the bottom water tank to the top water tank, and the drainage pump of the top water tank can be independently controlled by the touch screen. According to the specific situation, the corresponding pumps can be started to meet the actual needs. The operator can independently control the conveying motor of filter belt to move the clean filter belt to the bottom water tank from which the contaminated filter should be removed. When there is a signal detected by the detection sensor for replacing the coil of filter belt, it means the filter belt roll should be replaced necessarily. At this moment the forward and reverse rotation of the conveying motor for filter belt can be manually controlled to assist the roll replacement. Manual filtration mode will bring more convenience and flexibility to the operators, what can adapt to different production conditions and filtration requirements.

5.3. Monitor of filtration status

The status interface of touch screen is shown as Fig.4, whether it is automatic filtering or manual filtering, the operator can observe the status of each procedure in real-time by the touch screen, master the operation sequence during the filtering process, know the operation status of each equipment during the filtering process, and get warning in time. Detection switch of liquid level, thermal relay, hydraulic pump and other components and equipments are configured to be associated with the display components of the touch screen by PLC controller. Therefore the operator can clearly read the on-site information in real time on the touch screen, and can get the alarm reminding in time. It is conducive to the operator to grasp the operation status of the system in time, and improve the stability and safety for system operation.
6. Conclusion
A control system of automatic filtration for cutting fluid can effectively improve the usage effect of the recycling and filtration for cutting fluid by necessary control functions including automatic filtering, manual filtering, monitoring in real time and breakdown warning. By optimizing the judgment algorithm of filter belt replacement, the use efficiency of filter belt and the circulation efficiency of cutting fluid are further improved. The system application during the process of recycling and filtration of cutting fluid will greatly save labor, improve the operation efficiency of equipment, promote economic benefits, and meet the requirements of energy saving and environmental protection.

Acknowledgements
The work was supported by Scientific Research Project of Nanjing Communications Institute of Technology, Nanjing, Jiangsu Province, China No.JZ1910.

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