Electrical control design of CNC equipment fault based on part quality

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Abstract. Aeronautical structure component has high value and complex shape, normally manufacturing by advanced five-axis CNC machine tools, but sometimes random failures also occur. Therefore, this research focuses on how to predict the failure, imply redundancy design technique and minimize part quality risk as much as possible. This article first analyses quality risk caused by device failure in manufacturing and introduces several axis movements during alarm occurring, then studies the influence of accuracy in movements and optimizes by the electrical and external power grid redundancy design. At last this article carries out engineering verification though practice application and reduces the quality risk from device failure in order to prepare quality insurance system in intelligent manufacturing.

1. Introduction
With the rapid development of domestic manufacturing industry, computerized numerical control (CNC) machine tools continuously develop to flexible production line or intelligent manufacturing[1,2]. It does not only need higher reliability, efficiency and performance, but also much higher quality requirement. If high value parts are scrapped due to equipment failure, besides economic loss, the customer will also receive reputation damage.

At present, most of the original equipment manufacturers (OEMs) do not consider the influence of machine reaction to part quality when the equipment fails. The fundamental method to solve the problem is to design preventive measures in the design stage. However, the customer often realises the need of equipment failure control in the time of suddenly facing the part quality problem caused by the alarm. Its design has been finalized after the machine installed, so some improvement methods are urgently needed to avoid quality risk.

In this paper, according to the quality risk caused by the equipment failure in the parts machining process, the action and state of the machine tool when the alarm occurs and is cleared are analysed based on the view of machine alarm design. Then the corresponding design principles are carried out. The examples are given for electrical and external auxiliary design.

2. The effect of alarm on parts machining
At present, there are very few researches on alarm control of CNC machine, mainly focusing on the diagnosis and processing of fault alarm[3]. Some scholars study programmable logic controller (PLC) control system [4] and other methods to protect device safety and prevent operation errors, but there is almost no research on alarm design for part quality. In order to study alarm control, the alarm classification method is analysed first.
2.1 Alarm classification
Alarm information can be divided into system alarm and OEM alarm. CNC system manufacturers such as Siemens, Fanuc and other companies classify the fault information according to the structure or function of the system. The OEMs do the same thing. According above, it is obviously that the design of the alarm information has nothing to do with the safety or quality assurance. The alarm information is only used for reminding, and will not bring direct damage to the quality.

2.2 Alarm state
During the alarm, the machine tool may have five action states: “alarm prompt”, “pause”, “emergency stop”, “fault stop” and “abnormal stop”. At present, there is no design standard for them.

“Alarm prompt” means that the operation panel displays alarm information, but the machine status is not affected and still in normal. It is often used for safety door opening and closing, abnormal liquid level warning or overtemperature warning, etc. This kind of information will not cause damage in a short time or need to be dealt with immediately. Some process informations, such as normal tool change, generating opening and closing information do not even need to be considered.

“Pause” means the pause of the machine tool axis movement, including the machine coordinate axis, the spindle and some auxiliary axes. Common axis pause methods include activating the spindle or coordinate axis pause key in the panel, or switching the feedrate to zero and so on. The common reasons of pauses are such as no flow of coolant, the spindle temperature reaching the warning value, etc. Some “Pause” alarms require later operation or maintenance by authorized person.

“Emergency stop” is an alarm generated when the machine tool is in an emergency situation. All the axes immediately stop and all the power to drive devices are cut off. It can be activated by manually pressing the emergency stop button or by some faults from the machine. Emergency stop normally means there is serious situation such as people in danger, spindle bearing damage or servo drive error, etc. At this time, the axis movement is forced to stop, so the coordinate axis with brake and spindle should immediately stop, but the coordinate axis without brake may still move because of inertia.

“Fault stop” is the stop caused by equipment failure, which may be controlled by CNC system, relay or drive module. Because it does not force the machine to stop or turn off power, some subsystems may still work. The response may be slower, so there is a certain part quality risk in “fault stop” state.

“Abnormal stop” refers to the sudden machine action stop due to the failure of machine tool or external reasons. At this time, the CNC system is out of control and unable to control mechanical system. For example, if the coordinate axis with damaged brake suddenly stops, failing to brake at this time will inevitably lead to out of control, resulting in serious quality and safety risks. To sum up, when the machine tool is in the four states of “alarm prompt”, “pause”, “emergency stop” and “fault stop”, the control of the equipment is still effective and their actions are under the control of the system. When the equipment stops abnormally, the system will lose control, so the quality and safety risk of abnormal stop is the highest.

2.3 The influence of alarm state on the part quality
The machining quality of parts includes machining accuracy and surface quality. The machine tool failure mainly affects the accuracy. If the alarm affects the parts, it must first be in the condition that alarm occurs in the machining process. At this time, the tool is cutting the parts or the distance between them is small. Once the axis or spindle deviates abnormally due to fault may damage the parts.

In the moment of alarm during part machining, if only alarm prompt information appears, the machine tool status will hold and still execute the numerical control (NC) program, which will not affect part machining, so there is no quality risk. But in order to clear alarm prompt information the accompanying alarm action and reset action may cause the machine tool axis movement, leading to the part accuracy risk.
The keys on the operation panel such as the axis feedrate control are controlled by the PLC system. If the “pause” state is activated, the sudden change in the cutting process may form a trace which is normally less than 0.02mm, which only has a slight impact to the surface quality. However, if the relay or servo drive is used to activate the “pause”, some large marks may be largely formed due to the inertia or the axis brake, so there is a quality risk.

After troubleshooting, the alarm information must be cleared. Some information must be cleared through machine restart or system reset. Then there may be some influences such as the impact on the coordinate axis during the hydraulic start-up, the axis adjustment caused by the resynchronization, the offset of the coordinate axis caused by the brake releasing, etc. All the influences may cause slight axis movement. The effect is between the “pause” and the “emergency stop”.

If emergency stop appears, the coordinate axis with brake will stop immediately. The coordinate axes without brake may move which would have a impact on the parts accuracy due to inertia. If fault stop occurs, the machine response is controlled by the system and hardware components. It is slower than emergency stop and has a greater impact on the part quality. When abnormal stop appears, the coordinate axis may not be able to brake, so the abnormal axis movement could reach several millimetres due to inertia. The gravity axis without balance pressure may even fall to the lowest due to gravity, resulting in parts scrapping and machine damage.

To sum up, the alarm prompt has no direct impact on the part quality. In most cases, pause and return do not affect part accuracy, but in high-precision machining such as boring, shape accuracy may be affected and surface pattern or steps may appear. Emergency stop has a great influence on the machining that the coordinate axes abnormally move due to inertia or brake delay, resulting in accuracy problem. Abnormal stop is most likely to creat scrapped parts, which shall be avoided with all efforts. In short, the ability to protect the part quality from high to low is followed by alarm prompt, pause, return, reset, emergency stop, fault stop and abnormal stop. There are some cases to guarantee the part quality shown in the examples of electrical alarm design and external auxiliary alarm design.

3. Electrical alarm design case
The electrical design can work if the control system of the machine tool is effective. In the state of “alarm prompt”, “pause”, “return”, “emergency stop”, “reset” and “fault stop”, the CNC system is still under control, so they can be optimized through the control of electrical components or PLC.

A five-axis horizontal machining centre includes a linkage mechanism between machine and guard door. The Y axis balance pressure was at the low limit position then. When the operator opened the door, the Y axis dropped about 0.2mm at the moment, leading to part damage. The guard door switch controls the enable signal in the servo drive. When the guard door is opened, the enable signal is cut off and its message is generated. The drives do not output the driving power and the enable display on the panel is cancelled. Then the physical delay from enable relay and brake relay may produce axis deviation due to preload. When the driving power is turned off in Y axis, there may be a slight drop or rise due to the fluctuation of the balance pressure. This time the original control of the guard door opening and closing is applied by the design method of fault stop.

The machine tool is under the control during alarming, so the guard door control program can be modified in the PLC system. First disconnecting the door opening switch wirings from the drive hardware, then by modifying the PLC program the door opening switch signal links axis and spindle feedrate enable keys. When the door is closed, the system clears the "spindle and axis stop" message and other messages. Both the before and after optimized control flow charts are as shown in Figure 1:
It can be seen from the above flow chart that after the safety door is opened, the PLC system activates the spindle and axis pause and display pause message. When the door is closed, the pause message is automatically cleared and the operator can manually start the spindle and axis again. In this case, stop control by the hardware drive with high risk is successfully changed into stop control by the PLC program with low risk, which reduces the risk of part quality.

4. External auxiliary design case

Some external factors such as compressed air supply or abnormal power grid may still cause equipment failure and abnormal stop alarm. In this condition it is difficult to guarantee the machining accuracy only by applied electrical or mechanical hydraulic design, so it is necessary to consider adding external auxiliary devices. The below takes power problem because it is hard to deal with.

The main causes of abnormal power grid are harmonic, voltage flash and power failure, which may be caused by lightning stroke, short circuit, reclosing or misoperation, etc. The harmonic problem is small due to good quality inductors and filters. The main problems are voltage flash and power failure.

Voltage flash means that the supply voltage deviates from the rated voltage large in a short time due to system failure, which belongs to the transient voltage quality problem\[6\]. Voltage flash includes voltage sag, voltage short-time interruption and voltage transient rise. It has been found that the main cause of CNC equipment failure is the short-term interruption. If there is a serious voltage flash, dynamic voltage restorer (DVR) is needed to ensure the quality.

DVR\[7\] is a voltage source power electronic compensation device which is connected in series between the power supply and the equipment. It has excellent dynamic performance. When the power grid is down, it can restore the power supply at the load side. When the voltage flash change to power cutting, a signal is sent to the machine tool. The NC equipment start emergency stop or return action to maintain machining accuracy of parts. The electrical diagram is as shown in Figure 2:
When the power grid is normal, the external power supply provides power to the CNC machine tool through QF1, SCR rectifier and QF3. DVR is equivalent to a current source at that time. When the power grid is abnormal and beyond the DVR setting value, DVR will close the relay KM3 and activate the ultracapacitor. At this time, the DVR equals to a voltage source. After the power grid voltage flash disappears, DVR stops and the machine is powered by the external network again. When the voltage transient becomes to power cutting, DVR will send a signal to the machine tool after the setting time. Then the machine tool will respond based on the signal. The control flow chart is as shown in Figure 3:

Figure 3. Control flow chart of DVR

Because the design is carried out and the above DVR application fixes the power grid problems such as power cutting and voltage flash, the parts quality problems are basically solved in a large horizontal five-axis machining centre. meanwhile, the high-value equipment itself also has been protected.
5. Summary
CNC equipment is developing rapidly towards intelligent manufacturing and flexible production line, and the quality insurance ability of equipment directly determines the products quality. In CNC equipment there must always be a certain amount of failures, which would directly determine the machining quality, so the design of equipment failure control needs higher requirements. This paper mainly analyses the machining accuracy of parts in the cutting process when alarm occurs. Through the electrical design and the external auxiliary design of the machine tool, the NC equipment is fully ensured and the part quality problems caused by the equipment failure are minimized.

The fault control design of machine tool based on the machining accuracy of parts is to eliminate the quality risk by preventive methods. It is a important basic technology for the future flexible production line to ensure product quality. However, the manufacturing facilities do not only include machine tools, but also logistics equipment, robots and other device. These equipments may also have many contacts with parts, so there may be quality risks if an alarm occurs. Fault control design requirements must be needed then. This paper does not give the example for mechanical hydraulic design which is needed in future research. The fault design and analysis in this paper can be used as a reference to other equipment fault design.

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