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Research on Soft Fault of Computer Numerical Control System

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Computer Numerical Control (CNC) system can be seen as the core of manufacturing and its reliability should be paid much attention to. Soft fault of CNC system occupies a large proportion in failure, but it is hard to diagnose. In this paper, the definition of soft fault of CNC system is studied, and based on the abnormal data of multi-sample CNC systems, the induction and classification of soft fault is made. Moreover, Failure mode and effects analysis (FMEA) method is used to analyze failure module, failure mode, failure cause and failure effect of soft fault of CNC system. Defects which influence reliability of CNC system most are found out at last and it has a positive impact on CNC system products design, manufacture and use.

1. Introduction

Nowadays, great efforts have been given to develop advanced manufacturing technology and CNC equipment worldwide to improve manufactural ability, which is seen as an important way to accelerate economic development and improve national power and status. As the center control of CNC equipment, CNC system can be called the soul and brain of CNC machines (Zhang and Wang, 2011). Its failure rate and reliability has become a significant factor restricting the development of advanced manufacturing technology and equipment. Furthermore, it is of great importance to the use of CNC equipment, the improvements of the level of product technology, enhancement of product competitiveness and extension of market share.

According to the fault modes, the faults of CNC system can be classified into two kinds (Bandler, and Salama, 1985): hard fault and soft fault. Hard fault can also be called catastrophic fault (Qi, Ganesan, Pecht., 2008) which is a structural damage usually referring to the short circuit or open circuit of an element. Characteristic of this kind of fault is the parameter of the product change to extreme bounds. Soft fault can also be called deviation fault which means the faulty element deviates from its nominal value without reaching extreme bounds.(Zhou and Shi, 2009) This will cause chaos of the module data and make CNC system stop responding. Most of the case will not result in the total failure of the system, but may cause degradation and deviation of system performance.

As for soft fault, though it is hard to predict and repeat manually during maintenance and repair, its impact can be profound. If CNC manufacturers ignore this kind of fault, CNC system may have a higher return rate, reduced customer confidence and increased potential safety hazards. According to the definition and phenomenon observed from usual process, four features can be summarized of soft fault (Pecht, Ramappan. 1992): trouble-not-identified (TNI), can-not duplicate (CND), no-trouble-found (NTF), and retest OK (RTOK). That is to say a soft fault may occur without being verified or replicated, nor can it attributed to a specific root cause or failure mode.

Based on the definition and characteristics of soft fault above, abnormal data of 10 types of CNC system is traced and recorded. Besides, failure mode and effects analysis is used to analyze the record data and indicate the weak links thus providing the basis for designing and analyzing the reliability of CNC system.

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2. Test method and data collection

In order to obtain the reliability test data of CNC system, experience of CNC system is carried out which uses type-I censored data (test time is determined and unit can be repaired and replacement). 10 types of CNC system are taken from actual usage and they are observed for more than 1 year. From the observation record, 170 pieces of error data are obtained, including the time when error happen, description of error, process of diagnosis, etc. Failure mode, effect analysis will be taken as follows.

3. FMEA method to assess soft fault

FMEA method is a qualitative reliable analysis technique (Rausand et al., 2010). Its purpose is to analyze all possible failure modes and their effects. In traditional FMEA method, the analysis of failure mode mainly concentrates on the effects from functional modules to the whole product. Whether it is an effect to later failure has not been analyzed. Therefore, this article puts both soft fault and hard fault in time order, trying to find out the effect of soft fault to later hard fault.

According to the definition from Section 1, 10 types of CNC system is observed and recorded, gaining more than 70 pieces of abnormal data. For the data recorded, criteria are shown as following three aspects:

a. Past failure history Trying to find out the same failure mode as the current soft fault from the past history of hard fault.

b. Future failure history For some soft faults which their failure cause cannot be found immediately, observing hard faults which appear in the future and find out the hard fault with same failure mode. This kind of soft fault can be considered as a process of degradation and deviation of system performance (Joseph V R and Yu T. 2006). Therefore, to infer the cause of soft fault, analyzing the hard fault with the same failure mode is necessary.

c. Expert system For the soft fault which occurs infrequently, expert system can be established and used to diagnose. Expert system knowledge derives from the element function given by the manufacturer instructions and troubleshooting manual.

According to criteria above, 148 faults are gained from the error data, and the statistical data is shown as Table 1 and Figure 1.

Table 1 The statistical data of test

	The times of soft failure	The times of hard failure	The times of transitive failure
Frequency	25	64	59

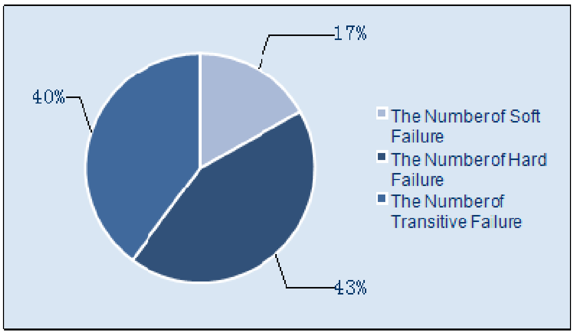

Figure 1 The distribution of hard failure and soft failure

There are 25 soft failures among 148 failures, particularly, new definition is given for the failure except soft failure and hard failure: transitive failure. Transitive failure is a process of degradation and deviation of system performance, it appears to be soft fault first and with time goes by it turns into hard fault making certain modules fail completely. Therefore 50 % of the failure is soft fault at first in the record, but most of the anomalies can recover after the operation of reset.

In order to analyze the 84 soft failures which includes transitive failure, FMEA method is used to analyze the failure of CNC system which includes four aspects: failure parts analysis which points out the weakness of CNC system, failure mode analysis which provides a basis to the failure cause of CNC system, failure cause analysis which points out the reason of soft fault and failure effects analysis which gives final effects to the system.

3.1 Failure parts analysis of CNC system

Based on the distribution of failures, the structure (Sun, 2000) of CNC system and the use situation, modules are divided, an inductive analysis of the frequency of failure module is shown in Table 2 (Zhang and Jia, 2004).The histogram of failure module of CNC system is shown in Figure 2.

Table 2: Frequency of soft failure module of CNC system

code	sub system	times	frequency
H1	Motherboard	11	13.41 %
H4	Hard Disk	2	2.44 %
H5	Power Supply	3	3.66 %
H6	Operation Panel and Display	5	6.10 %
H11	Feed Servo System	23	28.05 %
H12	Spindle Servo System	5	6.10 %
H13	I/O Unit	4	4.88 %
H15	Spindle Motor	2	2.44 %
H16	Feed Motor	4	4.88 %
S5	Position Control Module	2	2.44 %
S7	Real-time Management Module	16	19.51 %
	Others	5	6.10 %

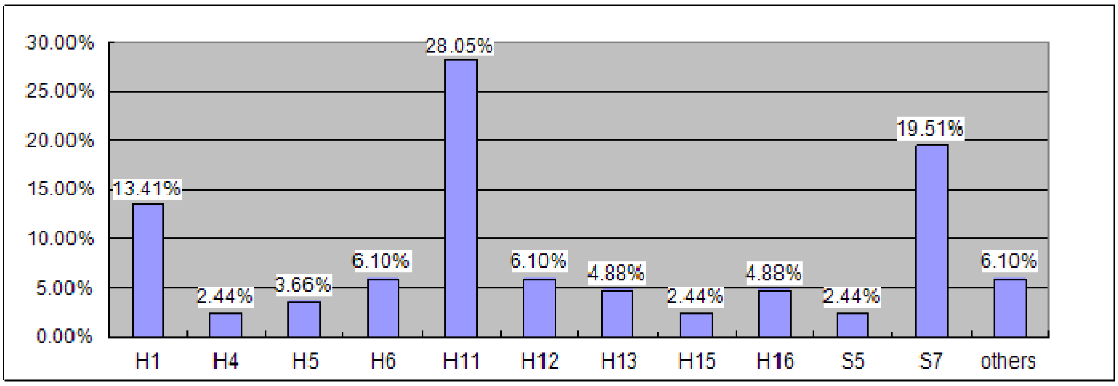

Figure 2 The histogram of soft failure module of CNC system

From Table 2, the weak modules is listed as follow: feed servo system (28.05 %), which includes X, Y, Z axis feed servo controller, servo encoder etc., real-time management module (19.51 %), Motherboard (13.41 %). Other parts in the table occupies much less than the three parts above. Therefore, how to decrease the soft fault rate of feed servo system, real-time management module and motherboard are the key to increase the reliability of CNC system.

3.2 Failure mode analysis of CNC system

Failure mode can be identified by components (Hardware Law) or function which usually can be observed (Ebeling and Kang et al., 2010). Study every failure mode of CNC system that may exist can provide a basis for the analysis of failure cause. For the soft fault studied above, the frequency of failure mode is shown in Table 3. The histogram of failure mode of CNC system is shown in Figure 3.

Table 3: Frequency of failure mode of CNC system

code	failure mode	times	frequency
1105	The failure of system	24	30.4 %
401	Motor cannot work normally	11	13.9 %
101	Component damage	7	8.9 %
104	Open-circuit of line or cable	6	7.6 %
202	Poor connection of line or cable	5	6.3 %
105	Short-circuit of line or cable	4	5.1 %
406	Failure of sensing component	3	3.8 %
404	Function loss of component	3	3.8 %

Table 3: Frequency of failure mode of CNC system (continued

code	failure mode	times	frequency
203	Component loose	3	3.8 %
1102	Parameter Modified	2	2.5 %
411	Too high temperature	2	2.5 %
1101	Loss of program	2	2.5 %
others	others	5	6.3 %

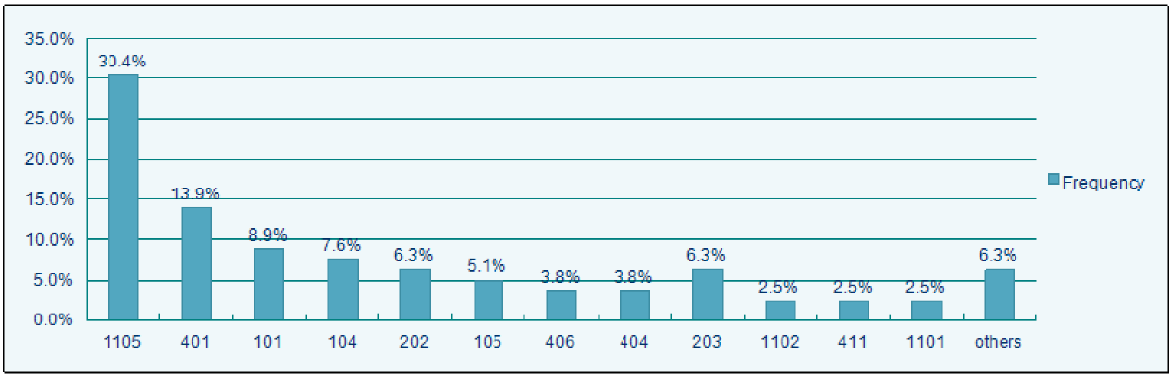

Figure 3 Histogram of failure mode

Therefore, the weak failure mode can be put in order from more to less as follows: the failure of system (30.4 %), motor cannot work normally (13.9 %), component damage (8.9 %), open-circuit of line or cable (7.6 %), etc. It can easily be seen that there is a big gap between the failure of system and motor cannot work normally.

3.3 Determine the cause of failure

Generally the cause of failure mode is divided into two kinds: one is to find the direct cause of the failure modes from functional failure modes or potential failure modes of physical, chemical or biological changes, another is to find the indirect cause of failure modes from external factors (such as failure from other product, environment and human factors, etc.). Considering there is no qualitative change when soft fault happens, a new type of classification of soft fault cause of CNC system is put forward and shown in Table 4.The histogram of failure cause of CNC system is shown in Figure 4.

Table 4: The classification of failure cause

code	the classification of failure cause	code	the classification of failure cause
01	aging	06	assembly not good
02	component damage	07	poor line connection
03	design	08	purchasing
04	improper adjustment	09	environmental stress
05	environmental interference	10	vibration

Furthermore, according to the failure data of 9 types of CNC system and the classification from Table 4, the cause of soft fault is analyzed and its frequency is shown in Table 5 and the histogram of failure cause of CNC system is shown in Figure 5.

Table 5: Frequency of classification of failure cause

code	the classification of failure cause	times	frequency
03	design	36	45.57 %
05	environment interference	4	5.06 %
07	poor line connection	12	15.19 %
08	purchasing	15	18.99 %
09	environment stress	8	10.13 %
10	vibration	4	5.06 %

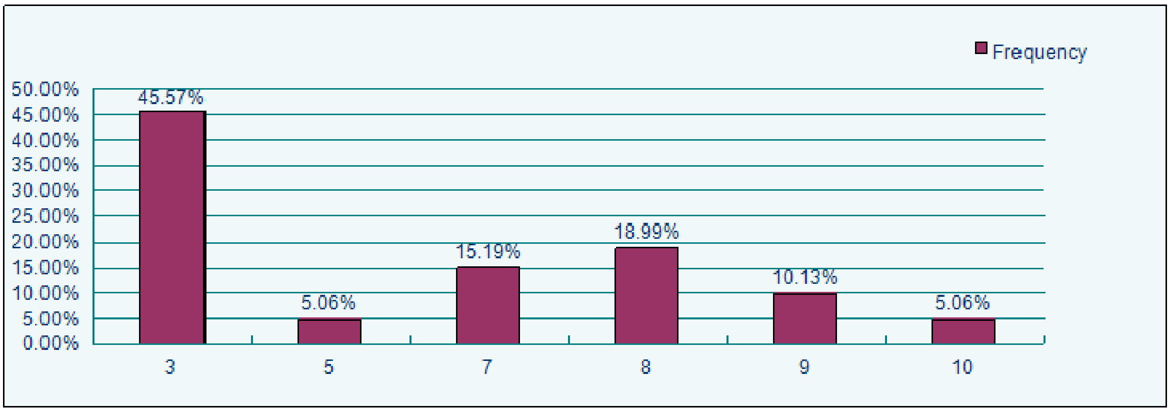

Figure 4 Histogram of classification of failure cause

From Table 4, the cause of design occupies 45.57 % of the failure cause. That is mainly because there are defects in the process of design, causing components cannot satisfy the demand of environment which result in the driving unit damage. Next is purchasing (18.99 %) which is also caused by the defects of components. In addition, poor line connection which causes poor connection between servo drive and host computer resulting alarming of CNC system makes the system out of service in a short time.

3.4 Final failure effects

Failure effect is the effect of failure mode to the usage, function and status of product. For soft faults, they can be solved after restarting CNC system, but cannot be repeated at will. Some of them rarely recur, this kind of fault can be considered has little effect to the performance of CNC system and it is caused by random stress or error. There is less effect to CNC system and it can be considered in deviation range from the definition.

Table 6: Failure effect of fault-prone module

failure module	failure mode	classification of failure cause	failure effect	final effect
feed servo system	parameter modified	Design	Loss of function	N/A
	PLC unit disorders	Poor line connection	Loss of function	N/A
	overload	Environmental stress	Feed motor cannot work	N/A
	motor can not work normally	Design	Feed motor cannot work	Feed motor damage
	Sensing components disorders	purchasing	Loss of function	Feed servo system damage
	Open-circuit of line or cable	Design	Feed motor cannot work	Feed servo system damage
	Sensing components disorders	purchasing	Feed motor work incorrectly	Feed motor damage
	Component loss of function	purchasing	Loss of function	Feed servo system damage
	Component improperly adjusted	Environmental interference	Loss of function	N/A
	short-circuit of line or cable	Environmental stress	Feed motor cannot work	Feed servo system damage

However, others recur in a period of time. Though same method can solve the fault temporarily and make the system back to work, this kind of fault will become hard fault at last and make certain modules fail completely like the transitive failure mentioned above. It can be considered as a process of degradation and deviation of system performance, so they can be summarized from the failure tendency.

For the 18 faults observed and sorted above, the module soft fault happens most has been analyzed as follows in Table 5. The final effect is a result compared and analyzed with hard fault.

From the analysis above, when soft fault happens in feed servo system, its failure effect will appear to be out of work of feed motor, loss of function of system. If the fault affects slightly, CNC system can be recovered by restarting and will not have a loss in performance. However, most of the fault will result in the damage of servo motor or servo system and will not recover until the motor is repaired or replaced.

4. Conclusions

Soft fault of CNC system is a kind of failure which will not immediately make components fail completely and it can be solved easily by restarting. However, if root cause is not determined and let the machine work as usual, probability of potential hazards will be increased. This paper studies the criteria to distinguish soft fault data from abnormal data of multi-sample CNC systems, and uses FMEA method to analyze soft fault, including failure parts analysis, failure mode analysis, failure cause analysis and failure effects analysis. In the end, the weak module, main reason and fault effect of CNC system are given, which has certain significance for the reliability growth technology of CNC system.

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