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Failure Mode Analysis of a CNC Machine by FMEA and Grey Relational Analysis Approach

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Abstract – Computer numerical controlled (CNC) machines play an important role in the new machining industry; product abilities also production become main issues. Therefore, the optimum turning conditions have to be set. Throughout the entire production processes, the product needs to be monitored in order to meet the overall specifications

The aim of the present work was to depict the importance of failure modes of CNC hydraulic machines for specifying its relation to key competitive factors and performance indicators. Research in the present work has principally addressed technical issues related to failures of the CNC hydraulic machines. The aim of this research was to synthesize the multidisciplinary nature of CNC machine failures from a performance perspective and highlight some of the more important aspects. The method was presented for calculating Risk Priority Number based on FMEA, which can be used to prioritization of failure modes of CNC hydraulic machines. Optimization of various failure modes have been depicted in the present work based on conventional FMEA approach. And further, the calculated values have been optimized by using Grey Relational Analysis Approach (GRA).

Keywords: CNC Machine, Risk Priority Number, Grey Relational Analysis, FMEA

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I. INTRODUCTION

The extent to which results are consistent over time and an accurate representation of the total population under study is referred to as reliability. Reliability is an issue of high significance in engineering. Estimation of reliability plays an important role in performance assessment of any system. Reliability predictions are necessary for varied functions, like production designing, maintenance designing, reliableness assessment, fault detection in manufacturing processes, and risk and liability analysis of many processes. Modeling of machine reliableness has been one among the most necessary problems in mining industries. Information of reliableness beforehand permits a lot of correct forecast of acceptable preventive and corrective maintenance.

Reliability is one among the most necessary characteristics of parts, products, and enormous complicated systems. Producing will be defined because the method of converting materials from one kind to the form that customer's need. Products are manufactured consistent with customer or style specifications. Quality of a producing company will be measured by the organizations ability to provide defect-free, reliable parts or product. Defect may be a smaller the better (STB) kind quality measure. Reliability additionally contains a great impact on the consumers' perception of manufacturer. Consumers' experiences with recalls, repairs and warranties can affect the longer term sales of a manufacturer.

A. CNC Machine

Computer numerical controlled (CNC) machines play an important role in the new machining industry; product abilities also production become main issues. Therefore, the optimum turning conditions have to be set. Throughout the entire production processes, the product needs to be monitored in order to meet the overall specifications.

Fig. 1. CNC machines

II. LITERATURE REVIEW

(Yang *et al.*, 2018) presented a novel improved maximum likelihood estimation method (IMLE) through increasing changed failure data. Moreover, the correction factor of mean ratio to extend censored time has been designed. Verification by the orthogonal experiment has been simulated to verify the proposed model. Compared to the ICM and MLE methods, the EMLE method is more suitable for the reliability modelling for CNC machine tools with a short test time and a large truncated ratio.

(Ran, Zhang and Pang, 2017)A new assembly reliability control method was proposed for CNC machine tools in this paper; based on the assembly faults and reliability control flow analysis, key assembly processes were extracted quantitatively by the new integration method of QFD, FMECA, and fuzzy theory; and then, assembly reliability monitoring system is established using information technology to realize real-time key assembly process control and analysis, along with models and examples given to illustrate the correctness and effectiveness of this method.

(Salvi, 2017) proposed to synthesize the multidisciplinary nature of CNC machine failures from a performance perspective and highlight some of the more important aspects. The method was presented for calculating Risk Priority Number based on FMEA, which can be used to prioritization of failure modes of CNC machines.

(Desnica *et al.*, 2017)showed that FMEA method can be successfully applied in complex technical system, such as in the case of the casting machines under high pressure, and that their use can achieve significant results in providing the reliability and quality of operation of the mentioned technical system with minimum maintenance costs. Also, the results of analysis can be used as feedback to designers, but also those who are engaged in maintenance.

(Kraynev *et al.*, 2017) considered the problem of improving the effectiveness and reliability of the adaptive control systems for the CNC machining centers due to the on-line diagnostics of machining process. The research results of the impact of the surface layer properties on the characteristics of the cutting process are given. The possibility of on-line diagnostics of the cutting process due to measurements of the cutting forces and the magnitude of the thermo-EMF signal is analyzed.

(H. Li *et al.*, 2016)proposed a new method for NC machine tools' reliability evaluating. The Cox proportional hazards model is employed to determine the relation model between the NC machine tools' reliability and also the corresponding operating conditions. The probability ratio check is employed to eliminate the operating condition covariates that have no effects on the reliability of NC machine tools. Within the parameter estimating method, a two-step estimation technique is applied. That is, the coefficients of operating condition covariates are first calculable by the partial probability estimation technique, and then the maximum probability estimation technique is employed to estimate the parameters of the baseline failure rate operate.

(Lad and Kulkarni, 2010b) designed Improved fault tree diagram based framework found useful in provided that enhanced insight into the failure and their effect. Two methods have been developed to support the analysis through the above framework. The first method will help the machine tool manufacturers in obtaining the time-to-failure distribution parameters using expert judgment, thereby allowing them to carry out further reliability studies when data is either not available or not sufficient. The approach can be further extended to combine it with the Bayesian approach. First, the expert judgment based method can be used to construct a prior distribution model for the time to failure. As and when data becomes available, it can be used to derive the posterior distribution model for time to failure using Baye's formula.

(Lad and Kulkarni, 2010a) In the absence of field failure records, the knowledge of the maintenance personnel is used in this paper for estimating the time to failure distribution parameters for both repairable and non-repairable components. Practical use of the proposed methodology is demonstrated by two examples, and the results show that the proposed method is a promising and efficient approach with the potential to become useful in industry. The methodology is validated and goodness is tested for the error and uncertainty in the expert judgment by comparing the same against the statistical method at different number of the data points available with the designer. It is expected that the methodology will alleviate the problem of data availability, thus, help designers to use reliability-based approaches to design more reliable machine.

(Keller, Kamath and Perera, 1982) some following analyses are:

1) The Weibull and lognormal distributions offer appropriate vehicles for the analysis of the failure characteristics of CNC machines.

2) The lognormal distribution provides the simplest fit to describe repair time distributions.

3) The availability of CNC machines studied is in the range of 82 ~o to 85 ~o.

4) About two thirds of the total system down time is due to non-active repair times.

5) The Duane plot provides a convenient means to monitor the reliability growth for the CNC system.

6) A new damped oscillatory phenomenon of the Duane growth curve is observed for the hydraulic and mechanical systems.

(Zhang *et al.*, 2011)a non-fatal shocked reliability model is planned supported failure interaction. Weibull distribution is often utilized in reliability analysis; therefore a special case of the reliability model for this is often given after, and so applied to research the failure information of a particular variety of CNC machine. The analysis result will illustrate the natural failure rates of mechanical and electrical subsystems, and even show the failure interactions between them.

(Zhang, Zhang and Ran, 2014)focused on CNC machine reliability technologies, and a reliability analysis method of CNC machine based on element action was put forward in it. The mathematical models of e-action reliability were studied. Meanwhile, the FMECA method using e-action as the element level was expounded by taking the grinding carriage feed movement as an example. This paper researched on CNC machine reliability in a newly different angle, which provided a new direction in reliability study and helped a lot in perfecting the reliability technology system.

(Karyagina, Wong and Vlacic, 1995)presented suggest that a manufacturer using CNC machinescan expect that 26% of failures will be caused by mechanical parts, 26% byelectrical components, 13% by hydraulics, 12% by human error and 12%operating environment. MTBF differ significantly between machines rangingfrom 150 to more than 1000 operating hours (i.e from 9 working days to 2 months). However, MTBF for more complex machines (machining centers) wason average half of that for autonomous machines.

(Chen *et al.*, 2015)provided reference and basis for the growth of reliability and maintainability to designer, depending on the repair degree, failure reason and indexes of related reliability. In view of that the reliability model of CNC machine is not improper without repair effect considered; we set up a modified reliability model for subsystems of CNC machine considering repair degrees. Combined with Kijima I model, the repair degree can be calculated, and the critical point of earlier-failure-period and random-period could be estimated. In order to prove the model, we use this model to an application example which collected data in field tests for a type of CNC lathes. According to this method, we can calculate the repair degree and other reliability parameters properly.

(Kim *et al.*, 2015)proposed a new condition monitoring method consideringthe machine capability. In fact, reliabilityand quality have been dealt separately in the field ofconventional machine tools. This study willcontribute to designing high-quality and highreliablemachine tools by successfully combiningthe two highly correlative indices.

(Yingjie and Liling, 2015)a novel approach has been planned for the reliability analysis of a machining system by using MTBF of machines. During this scheme, the time used for calculation of machine's MTBF relies on its actual cutting time. Once all machines are selected, the required repair time for the machining system can also be determined during a given period of time. Then the lifecycle price of the system has additionally been calculated. By comparison totally different machining system schemes, an optimal configuration has been determined by trading off the system reliability and its lifecycle price. However, because of the quality of the particular machining system, it not only includes the machines however additionally includes controller, robot and material handle system. All of those have their own characteristics, and totally different models ought to be selected for reliability analysis. Within the planned methodology, only the contribution of machine on the system reliability has been thought-about, that isn't appropriate for the reliability analysis of the opposite parts like controllers, robot and material processing system.

III. METHODOLOGY

The present work is on the failure mode analysis of the CNC machines used in a manufacturing industry. The CNC machines used for the study are CNC HYDRAULIC TUB BENDING and NCX HYDRAULIC TUBENDING type. The failures of CNC machines normally occur in the failure of mechanical or electronic components which results in reduction in production rate. The failures of hydraulic CNC machine components are due to accident, faulty power supply or mishandling of machine operator etc. Therefore, the prediction of equipment failure is inevitable particularly for CNC machine. The failure of hydraulic CNC machines during operation not only reduces the production rate but also leads to wastage of resources.

A. Description details of CNC machine-1

The following parameters pertaining to the failures of the hydraulic CNC machines are record for the failure mode analysis.

- Electrical Connections
- Oil Leakage
- Solenoid Valve
- Input Voltage
- Push Button
- Greasing
- Hydraulic Pressure
- Pressure Gauge,
- Homing Position
- Limit switch,
- Manual & Auto Mode. Cleaning of Contactor PCB Cards
- Oil Filter

MAKE	ELECTRO PNEUMATICS
SR. NO.	MC-8-1810
MACHINE	CNC HYDRAULIC TUB BENDING
MODEL	65 CNC X
MINIMUM CAPACITY (O/D)	25 MM
MAX: CAPACITY (O/D)	65 X 6.0 MM
MINIMUM BEND RADIUS	24 MM
MAX: BEND RADIUS	300 MM
BEND ANGLE	5 TO 180 DEGREE
BENDING SPEED	18 DEGREE / SECOND
HY: TANK. CAPACITY	300 LITTER
MOTOR	10 P

B. Analysis Approach

The Failure Mode and Effect Analysis (FMEA) is widely used technique due to enhance reliability and safety of complex system to identify and eliminate known or potential failure modes. The FMEA is also intended to provide information for making risk management decisions. The predicting failure on CNC machine is complicated, and it is not easy to keep in good working condition. The failure, especially the failure of key equipment and systems, may cause accidents even disaster to the CNC machines. Therefore, the prediction of failure based on FailureMode and Effect Analysis (FMEA) is necessary for failure mode analysis of CNC machines, as safety is critical to the well-being and reputation of the industry. In the present work, the Failure Mode and Effect Analysis were performed with two approaches which are given below:

1. Conventional FMEA Approach
2. Grey Relational Analysis Approach

IV. RESULT

From the study, it was observed that the failure mode with lower frequency has lesser effect on the production process as compared to the failure modes with higher frequency. The frequencies which were more than 20% of the highest frequency were considered as major failures.

Further the RPN number was calculated based on the values of Severity, Occurrence and Detection in reference to the failure datasheet of the CNC machine.

Table 5.2: Calculation of RPN number

S. No.	Failure Mode	S	O	D	RPN	RANK
1	24 V DC Connector	4	2	7	56	V
2	Oil O-ring pipe	6	4	5	120	IV
3	Push buttons 4 in No.s	6	2	3	36	VII
4	Oil leakage	4	2	4	32	VIII
5	Machine break down	7	3	4	84	I
6	Oil seal damage	5	2	3	30	III
7	O-ring replacement	6	2	4	48	II
8	Emergency push buttons	1	2	6	12	VI

Example illustration:

Failure mode : 24 V DC connector with severity, (S)=5,

Occurrence (O) = 1

Detection (D) = 8

Now, **RPN =SxOxD**

Putting up the values RPN = 4x2x7

= 56

Hence the Risk Priority Number is 40 for the first failure mode. Similarly the RPN number for other Failure Modes has been calculated.

A. Results of Grey RPN number

Based on the equation number [3] we have the following values of Grey RPN

Table 5.3: Results of the values for Grey RPN

S. No.	Failure Mode	S	O	D	GREY RPN	RANK
1	24 V DC Connector	4	2	7	0.4074	III
2	Oil O-ring pipe	6	4	5	1.0000	I
3	Push buttons 4 in No.s	6	2	3	0.2223	V
4	Oil leakage	4	2	4	0.1851	VI
5	Machine break down	7	3	4	0.6667	II
6	Oil seal damage	5	2	3	0.1667	VII
7	O-ring replacement	6	2	4	0.3334	IV
8	Emergency push buttons	1	2	6	0.0000	VIII

Example illustration:

The grey RPN is calculated from the equation

$X^*_i(k) = X_i(k) – \min X_i(k) / \max X_i(k) - \min X_i(k)$

Putting the values in the above equation for 1st failure mode

$X^*_i(k)$= (56-12) / (120-12)

= 0.4074

Similarly, based on the above equation, the Grey RPN has been calculated for all the cases

B. Results of deviation sequence or Degree of Grey analysis

The Degree of Grey Analysis is calculated by using equation [4]

Table 5.4: Result values for Degree of Grey analysis

S. No.	Failure Mode	Grey RPN Number	Degree of Grey Analysis	Rank (GRA)
1	24 V DC Connector	0.4074	0.5953	III
2	Oil O-ring pipe	1.0000	0.0000	I
3	Push buttons 4 in No.s	0.2223	0.7777	V
4	Oil leakage	0.1851	0.8149	VI
5	Machine break down	0.6667	0.3333	II
6	Oil seal damage	0.1667	0.8333	VI
7	O-ring replacement	0.3334	0.6666	IV
8	Emergency push buttons	0.0000	1.0000	VII

Example Illustration:

The values of degree of Grey Analysis is calculated by equation

$\Delta_{0i}(k) = | X_0^*(k) - X_i^*(k) |$

X_0^* (k) is the reference sequence, which is 1 in the present case

X_i^* (k) is the comparability sequence, which is **0.4074** in the present case

Putting the values in above equation for 1st failure mode

$\Delta_{0i}(k) = 1 – 0.4074$ (is the deviation sequence)

= 0.5953

Similarly, based on the above equation, the Degree of Grey Analysis has been calculated for all the cases.

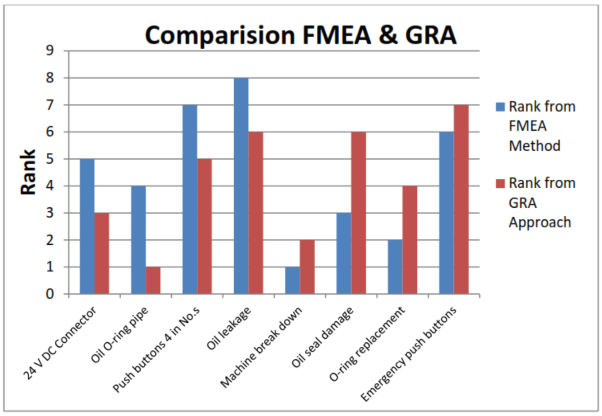

Fig.2 Comparison Graph for Hydraulic CNC-1

IV. CONCLUSION

The aim of the present work was to depict the importance of failure modes of CNC machines for specifying its relation to key competitive factors and performance indicators. Research in the present work has principally addressed technical issues related to failures of the CNC machines. The aim of this thesis was to synthesize the multidisciplinary nature of CNC machine failures from a performance perspective and highlight some of the more important aspects. The method was presented for calculating Risk Priority Number based on FMEA, which can be used to prioritization of failure modes of CNC machines.

The principal approach that has been proposed throughout this work to increase production rate performance through the prioritization of the failures occurs in CNC machines. The main findings and conclusions are stated here under.

- The conventional FMEA approach has a lower duplication rate than the GRA approach.
- The results obtained from the GRA approach are similar to the results of conventional approach.
- Risk factors and relative importance weight is evaluated in a linguistic manner rather than in precise numerical values. This makes the assessment easier to be carried out.
- Both conventional FMEA and GRA approach confirm failures are more prominent and component failures are least prominent.
- The GRA approach is proven to be best choice because it involves all the possible combination of parameter values and gives minimum error rate hence shows accuracy of the failure modes and RPN values can be predicted up to close level of accuracy and precision.

- Depending on the rank value for CNC-1, the failure mode for Oil O-ring pipe is ranked I and the failure mode for Emergency push buttons is ranked VIII.

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