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The Reliability Evaluation of Heavy Nc Machine Tool Based on Fuzzy Theory

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The reliability system evaluation of heavy nc machine tool is the guarantee of safety production. And the reliability evaluation index system is the important premise in evaluating. In this paper, the reliability evaluation system of heavy nc machine tool is determined on the basis of scientific principle, systematic principle, comprehensive principle, hierarchical principle, dynamic principle, fuzzy principle, and feasibility principle. According to the linear membership function to determine the fuzzy comprehensive evaluation matrix, the evaluation of heavy nc machine tool is carried out by establishing the fuzzy comprehensive evaluation model. In the end, through the given data the simulation experiment is carried out to show that the method is scientific and practical.

1. Introduction

Nc machine tool is the work foundation of manufacturing industry while its reliability is an important research content. Analytic hierarchy process (AHP) and the entropy method are often used in evaluating the reliability of nc machine tool. There are many index factors which need to be considered and the calculation is much too complicated. In this paper, the fuzzy comprehensive evaluation model of heavy nc machine tool reliability is established using fuzzy theory(Cai et al., 2015). The relatively small amount of index is used to carry on the reasonable and scientific evaluation of heavy nc machine tool reliability(Lin et al., 2013).

2. The establishment of heavy nc machine tool reliability evaluation system

Nc machine tool reliability evaluation system has different treatment for different situation. The evaluation index reflects the reliability level of heavy nc machine tool from different angles and different sides. According to the selection principle above, we select the following five indexes as the evaluation index of heavy nc machine tool reliability comprehensive evaluation such as the mean time between failures (MTBF), mean time to repair (MTTR), inherent availability (A), first failure time (TTFF), equivalent failure rate(D). Each index corresponds to the subsystem of heavy nc machine tool. The specific subsystem and the code can be seen in table 1.

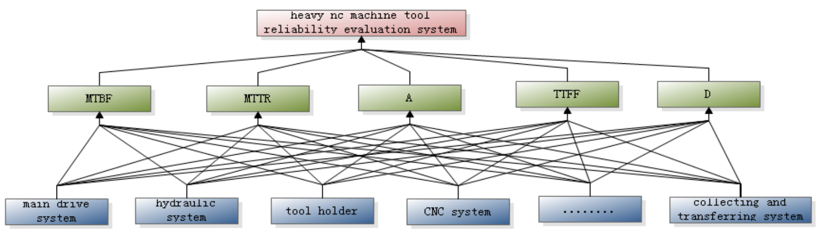

Figure 1: The hierarchy analysis diagram of heavy nc machine tool reliability evaluation system

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Table 1: The name of heavy nc machine tool subsystem and the code

subsystem name	code	included parts
main drive system	S	Spindle, motor, belt, spindle box, Spindle encoder and ect.
hydraulic system	D	hydraulic station, hydraulic valve and ect
tool holder	M	tool holder, cutter head and ect
CNC system	CNC	cnc system, display, control panel and ect
electrical system	V	power supply, wire, cable, electronic components and ect
feed system	F	X/Z axis servo motor, travel switch, silk pole, silk pole encoder and ect
lubrication system	L	Lubrication Oil Pipeline, oil pump, valve body and ect
cooling system	W	cooling pump, air-conditioning and ect
protection system	Q	Hood, protective door and ect
collecting and transferring system	K	Cuttings Removal pipeline, spiral thruster and ect

The hierarchy analysis diagram of nc machine tool reliability evaluation system is shown in figure 1.

3. The structure of heavy nc machine tool reliability evaluation model

3.1 The establishment of heavy nc machine tool reliability evaluation factor set and the determination of the weight

The fuzzy comprehensive evaluation system of heavy nc machine tool reliability level is determined by heavy nc machine tool reliability evaluation index system. The specific details are shown in table 2.

Table 2: The fuzzy comprehensive evaluation system of heavy nc machine tool reliability level

Evaluation objective	Evaluation index	Weight	Subsystem	Weight
heavy nc machine tool reliability level (RL)	the mean time between failures(MTBF)	P1	main drive system S	ω_1
			hydraulic system D	ω_2
	mean time to repair(MTTR)	P2	tool holder M	ω_3
			CNC system NC	ω_4
	inherent availability(A)	P3	electrical system V	ω_5
			feed system F	ω_6
	first failure time(TTFF)	P4	lubrication system L	ω_7
			cooling system W	ω_8
	equivalent failure rate(D)	P5	protection system Q	ω_9
			collecting and transferring system K	ω_{10}

From table 2 we know that the fuzzy comprehensive evaluation index factor set of heavy nc machine tool reliability level is RL=(MTBF,MTTR,A,TTFF,D),and the weights are P=(P1,P2,P3,P4,P5). Each evaluation index is influenced by ten subsystems, of which the weights are $\omega=(\omega_1,\omega_2,\omega_3,\omega_4,\omega_5,\omega_6,\omega_7,\omega_8,\omega_9,\omega_{10})$.

P1, P2, P3, P4, P5 is determined by AHP, and comparison matrix is

$$\begin{pmatrix} 1 & 1/3 & 1/7 & 1/9 & 1/5 \\ 3 & 1 & 1/5 & 1/7 & 1/3 \\ 7 & 5 & 1 & 1/3 & 3 \\ 9 & 7 & 3 & 1 & 5 \\ 5 & 3 & 1/3 & 1/5 & 1 \end{pmatrix}$$

Maximum eigenvalue is 5.24, CR=0.053<0.1. Through consistency check, the weights we can obtain are P1=0.5076, P2=0.2642, P3=0.0698, P4=0.0382, P5=0.1201.

Subsystems about reliability weight are determined by expert evaluation method. The results are as follows: $\omega_1,\omega_2,\omega_3,\omega_4,\omega_5,\omega_6,\omega_7,\omega_8,\omega_9,\omega_{10}$=(0.2,0.08,0.1,0.15,0.09,0.08,0.04,0.09,0.11,0.06).

3.2 The establishment of heavy nc machine tool reliability evaluation set and the determination of fuzzy evaluation decision matrix

Divide the comprehensive evaluation of heavync machine tool reliability into five dimensions(Angel Garrido.2010), namely

$N=(n_1,n_2,n_3,n_4,n_5)$=(excellent, good, medium, poor, very poor)

The corresponding score to its level is (0.9, 0.7, 0.5, 0.3, 0.1).
According to the five determined dimensions, carry out a fuzzy evaluation to index factors, establish membership function and determine membership matrix, which forms a fuzzy mapping(Li, 2015):

$$f: P \to F(N),\ P_i \to \frac{r_{i1}}{n_1} + \frac{r_{i2}}{n_2} + \frac{r_{i3}}{n_3} + \frac{r_{i4}}{n_4} + \frac{r_{i5}}{n_5},$$

And $0 \le r_{ij} \le 1$, i=1,2,…,10; j=1,2,…,5. The fuzzy evaluation decision matrix is

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{15} \\ r_{21} & r_{22} & \cdots & r_{25} \\ \vdots & \vdots & & \vdots \\ r_{10,1} & r_{10,5} & \cdots & r_{10,5} \end{bmatrix},$$

And $r_{ij} = A(P_i, n_j)$ indicate that evaluation factor P_i is evaluated as the membership function of level n_j (or called possibility)
The determined membership functions of five dimensions are:

excellent: $r_{i1} = \begin{cases} 1, & 9 \le y \le 10, \\ \frac{1}{2}(y-7), & 7 \le y < 9, \\ 0, & y < 7. \end{cases}$ Good: $r_{i2} = \begin{cases} -\frac{1}{2}(y-9), & 7 \le y < 9, \\ \frac{1}{2}(y-5), & 5 \le y < 7, \\ 0, & y < 7, y \ge 9. \end{cases}$

Medium: $r_{i3} = \begin{cases} -\frac{1}{2}(y-7), & 5 \le y < 7, \\ \frac{1}{2}(y-3), & 3 \le y < 5, \\ 0, & y < 3, y \ge 7. \end{cases}$ Poor: $r_{i4} = \begin{cases} -\frac{1}{2}(y-5), & 3 \le y < 5, \\ \frac{1}{2}(y-1), & 1 \le y < 3, \\ 0, & y < 1, y \ge 5. \end{cases}$

very poor: $r_{i5} = \begin{cases} 1, & y < 1, \\ -\frac{1}{2}(y-3), & 1 \le y < 3, \\ 0, & y \ge 3. \end{cases}$

y is the score the expert given to ten subsystems under the corresponding evaluation index, substitute the score into the membership function, and we get the fuzzy evaluation decision matrix of each level factors

$R_1=(r_{ij})_{10\times5}$, $R_2=(r_{ij})_{10\times5}$, $R_3=(r_{ij})_{10\times5}$, $R_4=(r_{ij})_{10\times5}$, $R_5=(r_{ij})_{10\times5}$

3.3 The comprehensive evaluation results of heavy nc machine tool reliability

Using weight average model $M(\bullet,+)$, according to the obtained weights of10 subsystems and its evaluation matrix, the fuzzy evaluation decision matrix of heavy nc machine tool reliability level could be calculated.

$$R = \begin{pmatrix} \omega \bullet R_1 \\ \omega \bullet R_2 \\ \omega \bullet R_3 \\ \omega \bullet R_4 \\ \omega \bullet R_5 \end{pmatrix},$$

According to the corresponding weights of evaluation index, the comprehensive evaluation results of heavy nc machine tool reliability level can be calculated:

$$Q = P\bullet R = \left(P_1, P_2, P_3, P_4, P_5\right)\bullet\begin{pmatrix} \omega\bullet R_1 \\ \omega\bullet R_2 \\ \omega\bullet R_3 \\ \omega\bullet R_4 \\ \omega\bullet R_5 \end{pmatrix} = \left(q_1, q_2, q_3, q_4, q_5\right).$$

Combined with the five dimensions of heavy nc machine tool reliability level comprehensive evaluation $N=(n_1,n_2,n_3,n_4,n_5)$, the final score of heavy nc machine tool reliability level evaluation is:

$$S = Q\bullet N = \left(q_1, q_2, q_3, q_4, q_5\right)\bullet\begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \\ n_5 \end{pmatrix}.$$

Evaluating heavy nc machine tool reliability need comprehensive consideration. If the final score of heavy nc machine tool reliability level evaluation $S\geq 0.7$, heavy nc machine tool reliability is excellent; If the final score of heavy nc machine tool reliability level evaluation $0.5\leq S<0.7$, heavy nc machine tool reliability is good which needs proper correction; If the final score of heavy nc machine tool reliability level evaluation $0.3\leq S<0.5$, heavy nc machine tool reliability is medium which means we should consider comprehensively whether the performance, economic benefit and modification cost of heavy nc machine tool need to be repaired or not. If the final score of heavy nc machine tool reliability level evaluation $0.1\leq S<0.3$, heavync machine tool reliability is poor which means it should be repaired widely. If the final score of heavy nc machine tool reliability level evaluation $S<0.1$, heavy nc machine tool reliability is very poor which means it could be given up.

4. The simulation application of heavy nc machine tool reliability

On the basis of experimental data, using the calculated value of five evaluation indexes such as the mean time between failures (MTBF), mean time to repair (MTTR), inherent availability (A), first failure time (TTFF), equivalent failure rate(D), the expert evaluation method is used to evaluate(Mark Ndubuka NWOHU.2007). And the results are shown in table 3.

The evaluation results the expert scored are used into the membership function. We can obtain that:

$$R_1 = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{pmatrix} R_2 = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{pmatrix} R_3 = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$R_4 = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 \end{pmatrix} R_5 = \begin{pmatrix} 0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 \end{pmatrix}.$$

Table 3: The expert evaluation results of heavy nc machine tool reliability evaluation index

Subsystem code	MTBF	MTTR	A	TTFF	D
S	10	9	10	10	8
D	8	6	10	8	10
M	8	8	9	6	8
CNC	10	9	9	10	8
V	8	8	9	8	5
F	10	10	10	8	10
L	8	8	8	8	8
W	8	6	8	8	8
Q	10	8	10	10	8
K	10	10	9	4	8

Using weight average model $M(\bullet,+)$, according to the obtained weights of 10 subsystems and its evaluation matrix, the fuzzy evaluation decision matrix of heavy nc machine tool reliability level could be calculated.

$$R=\begin{pmatrix}\omega\bullet R_1\\ \omega\bullet R_2\\ \omega\bullet R_3\\ \omega\bullet R_4\\ \omega\bullet R_5\end{pmatrix}=\begin{pmatrix}0.8 & 0.2 & 0 & 0 & 0\\ 0.66 & 0.255 & 0.085 & 0 & 0\\ 0.9 & 0.1 & 0 & 0 & 0\\ 0.755 & 0.135 & 0.08 & 0.03 & 0\\ 0.685 & 0.225 & 0.09 & 0 & 0\end{pmatrix},$$

According to the corresponding weights of evaluation index, the comprehensive evaluation results of heavy nc machine tool reliability level can be calculated:

$$Q=P\bullet R=\left(0.5076,0.2642,0.0698,0.0382,0.1201\right)\begin{pmatrix}0.8 & 0.2 & 0 & 0 & 0\\ 0.66 & 0.255 & 0.085 & 0 & 0\\ 0.9 & 0.1 & 0 & 0 & 0\\ 0.755 & 0.135 & 0.08 & 0.03 & 0\\ 0.685 & 0.225 & 0.09 & 0 & 0\end{pmatrix}$$
$$=\left(0.7543815,0.2080505,0.036322,0.001146,0\right).$$

Combined with the five dimensions of heavy nc machine tool reliability level comprehensive evaluation $N=(n_1,n_2,n_3,n_4,n_5)$, the final score of heavy nc machine tool reliability level evaluation is:

$$S=Q\bullet N=\left(0.7543815,0.2080505,0.036322,0.001146,0\right)\begin{pmatrix}0.9\\ 0.7\\ 0.5\\ 0.3\\ 0.1\end{pmatrix}=0.8430835.$$

Due to the comprehensive evaluation score of heavy nc machine tool reliability S=0.8430835,it means that heavy nc machine tool reliability is excellent. And heavy nc machine tool could be carried out the reliability evaluation repeatedly by multiple expert evaluation.

5. Conclusion

Following the scientific principle, systematic principle, comprehensive principle, hierarchical principle ,dynamic principle, fuzzy principle, and feasibility principle to select the evaluation index of heavy nc machine tool reliability, determining its evaluation system, using the fuzzy theory to establish comprehensive evaluation model, doing quantitative score to evaluation results, determining the dimensions of heavy nc machine tool reliability according to the scores, the method is simple, scientific, reasonable and feasible, providing a novel evaluation way for heavy duty nc machine tools reliability.

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