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The Applied Research on b-Value in the Fault Prediction of the CNC Machine Tools

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Abstract: G-R curve is an important analysis curve on seismic prediction and b-value can reflect the degree of seismic activity of an area. The paper uses G-R curve to analyze the relations between the fault levels and fault frequency of some series of the CNC machine tools. According to the results, we can draw the relations between b and faults occurrence. Thus we can use b-values to predict the faults of the CNC machine tools.

Keywords: G-R curves; B-value; CNC machine tools; Failure prediction

1. Introduction

In the paper Failure Rate Evaluation of CNC Machine Tools Based on G-R Curves Analysis, we adopted least-squares fitting method to calculate b values in G-R curves of a series of CNC machine tools. We got that b values are low during the frequent faults periods and b values are higher and higher with the reliability improvements and implements. During the years' reliability research, the reliability of the CNC machine tools has been improved and the fault rates keep stable. B values are increased gradually and keep 1.0 at last.

Since $\lg N = a - bM$ was put forward by the scientists, G-R curve has been used widely in the application and research in the Earth Science. It's also the majority of academic research areas at present. The subjects such as how the earthquake levels deviation affects the b values [1,2] and how b values change before large earthquake[3] and so on are all in the research stage. There is still a lot of work needed to be done.

Liu Zheng-rong[4] thinks that the mean value of b is very important in the seismic research and gives a reasonable explanation on the so-called earthquake rhythm using the mean value of b.

Huang Wei-qiong etc.[5] think that b curves have great difference on the linearity for different time and space regions. They got the best b-value statistics when they discussed the regions with some high level earthquakes. They speculated the probability of different level earthquakes in different areas. They think they can use b values to forecast all kinds of earthquakes.

Duan Hua-chen etc.[6] think that the formulation of b value[7] should be improved.

$$b = \frac{\sum M_i \sum \lg N_i - n\sum (M_i \lg N_i)}{(\sum M_i)^2 - n\sum M_i^2} \tag{1}$$

In order to clearly reflect the changes of the faults rate of recurrence of the CNC machine tools and significantly show the differences in the magnitude, something must be done to improve the calculation of b values. Here we adopt the improved formula of b value to predict the faults of the CNC machine tools.

2. The Improved Calculation Formula of b-value

In order to increase the role of the changes of the faults rate of recurrence of the CNC machine tools in the calculation of b-value and make the calculated b-values significantly reflect the significant changes, at the same time assure the liner relationship between faults levels and rates, we adopt normalized and standardized methods to calculate the parameters of faults levels and rates of b-values respectively. The formulas are given as below:

Normalized method:

$$\begin{cases} M_i' = M_i / M_{\max} \\ \lg N_i' = \lg N_i / \lg N_{\max} \end{cases} \tag{2}$$

Where: $M_{\max}$ and $\lg N_{\max}$ refer to the largest fault level and logarithm of the largest fault frequency.

Standardized method:

$$\begin{cases} M_i' = M_i / \bar{M} \\ \lg N_i' = \lg N_i / \lg \bar{N} \end{cases} \tag{3}$$

Where: $\bar{M}$ and $\lg \bar{N}$ refer to the average fault levels and the average fault frequencies. $\lg N'$ and M' keep linear relationship after being normalized and standardized. When the structure of fault level frequency changes clearly, b values reflect significantly. Thus we can draw the characteristics and rules from quantitative analyzing the abnormal faults according to the changes of b-values with time.

In order to make b-values as accurate as possible, we select 100 fault events as the samples to make b-values stable and comparable. We refine the fault levels that we add half levels on the original basis. Because the fault time of the same samples at different phases is different, we add time density factor p_{ft} which reflects the times faults occurred during the unit time. We analyze the abnormal fault activities combined p_{ft} and b.

3. The Calculation of B-values

We need a long time to accumulate the faults data after the CNC machine tools being put into use. The paper analyzes the faults data according to the phases given as below and calculates b-values of G-R curves of different phases (the Least squares fit method is used to calculate b-values). The results are shown in table 1 to 5.

Table 1. b-values of a series of CNC machine tools (data from Jan. 1995 to Dec. 1996)

No.	M	N	b	ρ	N(5)	$N_C(5)$	N(6)	$N_C(6)$
1	2.0	131	0.49	0.945	25	20.3	3	2.1
2	2.5	66	0.51	0.966	13	10.3	1	0.9
3	2.0	114	0.52	0.972	21	18.5	0	0.5
4	2.0	138	0.48	0.969	26	20.9	2	1.1
5	2.5	74	0.49	0.956	16	10.7	1	0.6
6	2.5	59	0.53	0.981	15	10.2	0	0.3
7	2.0	125	0.50	0.963	22	19.4	2	1.7
8	2.5	74	0.49	0.952	15	11.6	0	0.6
9	2.0	158	0.45	0.987	29	22.6	5	4.5
10	2.5	79	0.48	0.979	18	16.3	3	2.7
11	2.0	144	0.47	0.981	29	23.1	6	5.2
12	2.5	59	0.53	0.979	13	9.8	2	1.2
13	2.0	109	0.53	0.954	16	13.8	3	2.7
14	2.5	63	0.52	0.982	14	11.5	1	0.8
15	2.5	74	0.49	0.991	15	11.8	1	0.9
16	2.0	131	0.49	0.953	23	21.8	4	2.9
17	2.0	120	0.51	0.965	20	19.5	3	2.0
18	2.0	114	0.52	0.968	19	17.6	3	1.9
19	2.5	66	0.51	0.963	14	12.8	2	1.1
20	2.5	70	0.50	0.979	14	12.5	2	1.2

Table 2. b-values of a series of CNC machine tools (data from July 1997 to Dec. 2000)

No.	M	N	b	ρ	N(5)	$N_C(5)$	N(6)	$N_C(6)$
1	3.0	177	0.85	0.957	29	26.5	5	4.7
2	2.5	251	0.80	0.972	35	32	6	5.1
3	3.0	107	0.79	0.965	16	10.9	3	2.3
4	3.0	66	0.86	0.971	11	9.2	2	1.6
5	2.5	199	0.84	0.963	31	30.3	7	5.6
6	2.5	188	0.85	0.974	30	29.4	5	3.9
7	3.0	100	0.80	0.976	15	13.4	4	2.9
8	2.5	158	0.88	0.956	25	20.1	3	2.7
9	3.0	61	0.87	0.978	10	9.2	3	2.1
10	2.5	199	0.84	0.991	32	29.5	6	5.6
11	3.0	75	0.84	0.993	12	10.3	4	2.3
12	2.5	188	0.85	0.949	31	27.2	6	5.2
13	3.0	81	0.83	0.965	13	10.8	2	2.1
14	2.5	177	0.86	0.971	27	23.3	5	3.6
15	2.5	177	0.86	0.978	25	21.3	5	2.9
16	3.0	75	0.84	0.967	12	10.5	3	2.5
17	3.0	61	0.87	0.977	9	7.8	2	1.5
18	3.0	70	0.85	0.989	10	8.5	3	2.4
19	2.5	188	0.85	0.979	31	29.6	6	5.6
20	2.5	188	0.85	0.963	31	28.6	6	5.2

Table 3. b-values of a series of CNC machine tools (data from Jan. 2001 to Dec. 2003)

No.	M	N	b	ρ	N(5)	$N_C(5)$	N(6)	$N_C(6)$
1	3.5	35	0.93	0.965	7	5.3	0	0.4
2	3.5	38	0.92	0.973	7	5.2	1	0.7
3	3.0	125	0.90	0.981	18	15.6	6	4.5
4	3.0	95	0.94	0.949	14	13.2	4	3.5
5	3.0	102	0.93	0.976	15	13.7	4	3.7
6	3.5	32	0.94	0.973	6	4.3	2	1.6
7	3.5	35	0.93	0.967	6	4.5	2	1.7
8	3.5	32	0.94	0.965	5	3.9	2	1.5
9	3.0	109	0.92	0.978	16	14.5	4	3.1
10	3.0	109	0.92	0.969	15	13.4	4	3.0
11	3.0	109	0.92	0.975	17	15.4	4	3.7
12	3.0	102	0.93	0.982	16	14.6	4	2.3
13	3.0	109	0.92	0.967	15	13.9	4	2.8
14	3.5	38	0.92	0.975	6	4.8	2	1.6
15	3.5	32	0.94	0.978	5	4.6	2	1.5
16	3.5	32	0.94	0.969	5	4.6	2	1.4
17	3.5	35	0.93	0.978	5	4.3	2	1.1
18	3.0	109	0.92	0.979	16	14.6	5	4.5
19	3.0	109	0.92	0.974	16	14.3	6	4.8
20	3.0	117	0.91	0.956	18	15.7	7	5.8

Table 4. b-values of a series of CNC machine tools (data from Jan. 2004 to Jan. 2006)

No.	M	N	b	ρ	N(5)	$N_C(5)$	N(6)	$N_C(6)$
1	3.5	68	0.99	0.976	8	6.9	5	4.2
2	3.5	74	0.98	0.986	8	6.7	4	3.5
3	4.0	31	0.95	0.983	5	4.1	3	2.6
4	4.0	26	0.97	0.978	5	3.9	3	2.5
5	4.0	23	0.98	0.965	4	2.8	2	1.6
6	3.5	53	1.02	0.992	6	5.2	3	2.4
7	3.5	58	1.01	0.976	6	5.3	4	3.5
8	3.5	63	1.00	0.965	6	5.5	4	3.3
9	4.0	19	1.00	0.976	3	2.1	1	0.9
10	4.0	21	0.99	0.973	3	2.2	0	0.6
11	4.0	23	0.98	0.993	3	2.7	0	0.6
12	4.0	19	1.00	0.972	3	2.5	0	0.5
13	4.0	16	1.02	0.966	2	1.9	1	0.3
14	3.5	49	1.03	0.979	3	2.6	1	0.8
15	3.5	49	1.03	0.976	3	2.4	1	0.6
16	3.5	53	1.02	0.965	3	3.6	1	0.7
17	3.5	53	1.02	0.972	3	3.7	1	0.7
18	4.0	16	1.02	0.979	2	1.8	1	0.6
19	4.0	16	1.02	0.974	2	1.7	1	0.5
20	4.0	18	1.01	0.989	2	1.6	1	0.4

Table 5. b-values of a series of CNC machine tools (data from Feb. 2006 to Feb. 2010)

No.	M	N	b	ρ	N(5)	$N_C(5)$	N(6)	$N_C(6)$
1	4.0	19	1.00	0.965	3	2.2	0	0.5
2	4.0	16	1.02	0.981	2	1.7	0	0.3
3	4.0	21	0.99	0.971	2	1.5	0	0.3
4	4.5	7	0.98	0.957	1	0.4	0	0.2
5	4.5	8	0.97	0.969	1	0.4	0	0.3
6	4.5	9	0.96	0.966	1	0.5	0	0.3
7	4.5	7	0.99	0.992	1	0.5	0	0.3
8	4.0	26	0.97	0.973	3	2.3	1	0.9
9	4.0	18	1.01	0.997	2	1.7	1	0.8
10	4.0	16	1.02	0.965	2	1.6	1	0.9

11	4.0	20	1.00	0.992	2	1.7	1	0.7
12	4.0	18	1.01	0.986	2	1.6	1	0.6
13	4.5	5	1.02	0.971	1	0.6	0	0.6
14	4.5	6	1.01	0.991	1	0.5	0	0.5
15	4.5	7	0.99	0.9891	1	0.4	0	0.4
16	4.0	24	0.98	0.956	2	1.1	1	0.9
17	4.0	26	0.97	0.976	2	1.2	1	0.8
18	4.0	24	0.98	0.978	2	1.2	1	0.7
19	4.0	22	0.99	0.976	2	1.3	1	0.6
20	4.0	20	1.00	0.982	2	1.3	1	0.7

Notes: No. refers to the sample number of the CNC machine tools. M refers to the fault levels fitted. ρ refers to the correlation coefficient. N(5) and $N_C(5)$ refer to the actual times of faults the times from G-R formula respectively.

Table 6. Statistical results of samples analysis

Samples		The fist stage	The second stage	The third stage	The fourth stage	The fifth stage
p_{ft}		1.08	1.16	1.14	1.12	1.09
b	Max.	0.53	0.87	0.94	1.03	1.02
	Deviations	1.2△	1.4△	1.0△	1.8△	2.1△
	Decline	30%	25%	7.9%	29%	36%
b_{NM}	Max.	1.72	1.92	1.65	1.46	1.86
	Deviations	1.2△	1.3△	1.3△	2.0△	2.5△
	Decline	28%	21%	15%	22%	32%
b_{ST}	Max.	3.24	2.99	2.43	2.16	2.86
	Deviations	1.25△	1.23△	1.5△	1.5△	1.56△
	Decline	39%	50%	28%	35%	22%

Notes: p_{ft} refers to time density factor. b refers to the original value. b_{NM} refers to the normalized value. b_{ST} refers to the standardized value. △ refers to the standard deviation corresponding to the b-values.

The averages of b during the five phases of the twenty samples are different from 0.50 to 0.85 to 0.90 to 1.00. In the fifth phase, b values fluctuate near 1.00. The low level faults occur frequently at first and keep stably at last with the reliability improvement carried out. MTBF is over 500 hours during the stable stage.

One of the greatest usefulness of b is to estimate the relapse cycle of the earthquake of six, seven and eight grades of a region. Chen pei-shan etc.[8] utilized the fixed b-value(the result is the best with b of 0.85) to calculate the possibility of the earthquake relapse in the near future. For the CNC machine tools, we can collect the faults data to calculate the possibility of the large faults occurred.

4. The Possibility to Calculate the Faults Occurred of the CNC Machine Tools with b-value

CNC machine tools are mainly composed of information carrier, CNC system, servo system and machine body. The design reliability of the CNC machine tools depends on the parts mentioned above which the reliability of the CNC system is especially important. During the process of the reliability improvement, Module optimized design of the CNC system has greatly improved the reliability of the CNC system and increased the whole reliability. To decrease the numbers of the parts is to decrease the frequencies of the faults. Adopt software to replace the hardware to realize the functions needed as much as possible during design for the low cost of the software with higher reliability. During the reliability research of the CNC machine tools, the departments related adopt great amount of reliability improvement technique and significant results have got.

We read no papers about faults prediction of the CNC machine tools at present.

The faults are affected by many factors with certain randomness. The samples of the CNC machine tools are obviously different from the normal distribution samples which are common. The majority and the mean of the normal distribution samples are in intermediate positions. The greater the deviation from the average, the smaller the probability appears.

Here, we try to predict the probability of the faults occurred with b-values of the CNC machine tools.

We look for the representative intervals of the faults occurrence during the five stages where b-values are unusual high. These b-values are obviously higher than the average adding its standard deviation. We find that b-values decrease significantly with 10 percent following the large level faults. The results are shown in Table 6.

From the results we can see that time density factor obviously increases before the large level faults. p_{ft} is greater than 1.08. B-values change abnormally. Because the fault data about one CNC machine tool are incomplete, the large level faults occurs not many. The samples we selected are not representative. So the analysis above may be with considerable degree of error.

5. Conclusions

B-values can reflect the faults states of the CNC machine tools. The paper puts forward utilizing the changes of b-values and time density factors to predict the probability of the large level faults based the improved b calculation. Because the data is limited, the prediction above is only preliminary. The refined and accurate prediction will be practical with the increased perfect data.

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