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Applied Research on Cmsr Method Used in Reliability Evaluation of the CNC Machine Tools

[1]Jie Yu, [2]Hai-Long Zhang, [3]Wu-sheng Tang, [1]Ting-ting Wang, [1]Zhan-guo Li and [4]Li Qiao-chan
[1]Mechanical Engineering College of Changchun University, 130022, China
[2]Information Center of Sino-Japanese Friendship Hospital of Jilin University, 130033, China
[3]Department of Scientific Research of Changchun University, 130022, China
[4]Xianyang Jingwei Textile Machinery Co., Ltd., 712000, China

Abstract: CMSR method synthesizes the advantages of MML method and SR method. The paper applies this method to evaluate the reliability of the subsystems of CNC machine tools and each unit of each subsystem is regarded as success or failure and exponent, respectively. From the results we can see that exponent type cannot evaluate the reliability of the CNC machine tools fairly.

Key words: Reliability Evaluation, CMSR, CNC machine tools, confidence limit

INTRODUCTION

Among the methods of classic approximate confidence limits, we usually use MLE, MML, SR and CMSR. Only with large samples and unbounded symmetric normal distribution, MLE can get better precision. MLE is in common use because of simple calculation with accurate results. But it cannot evaluate the reliability of the systems without failure units. We usually use SR and CMSR methods with the series connection without failure units. CMSR is the connection of MML and SR which owns the advantages of MML and avoids the disadvantages of SR. So we adopt CMSR to evaluate the reliability of the CNC machine tools (Dong, 1990; Reliability Engineering. Beijing).

MML

We suppose that the CNC machine tool is composed of m connected units. The No. i unit is tested n_i times and x_i times are succeeded. We record as $i=\overline{1,m}$. The equivalent test times of the system is recorded as $\hat{n}$. The successful times is recorded as $\hat{x}$ and the failure times is recorded as $\hat{F}$. These times can be got from the Eq. 1. The variance of the evaluated sub-samples is equal to the variance of the binomial distribution because it comes from the data of the success or failure sub-samples (He, 1993, The Management and Reliability of the Electronic Products). (Hu, 1999, Reliability Engineering Design Test Analysis Management). male. Information Center of Sino-Japanese 130022, China. Email: yu99jie99@sohu.com.

$$\hat{n} = \frac{\prod_{i=1}^{m} \frac{n_i}{x_i} - 1}{\sum_{i=1}^{m} \frac{1}{x_i} - \sum_{i=1}^{m} \frac{1}{n_i}} \quad (1)$$

$$\hat{x} = \hat{n} \prod_{i=1}^{m} \frac{x_i}{n_i} \quad (2)$$

$$\hat{F} = \hat{n} - \hat{x} \quad (3)$$

We can search the classic approximate confidence limits of the system reliability according to the confidence level γ and the calculated $\hat{n}$ and $\hat{F}$. It is with simple calculation and accurate results with MML method. From the results we can see that when x_j is equal to n_j, the equivalent test data is unrelated to x_j and n_j. When x_j is equal to n_j and n_j is less than n_i ($i=\overline{1,m}$ and $i \neq j$), it is obviously unreasonably. We should use CMSR method (IEEE Recommended Practice for The Design of Reliable Industrial and Commercial Power Systems, IEEE Standards Association, 1997).

CMSR

CMSR method is compressed once when the minimum unit of the test times has no failure and is amounted with MML formula. If the connected units has no minimum invalid unit, CMSR method is equal to MML method (IEEE Toutorial Course Text. Power System Reliability Evaluation, No. 82, IEEE, 1982).

We suppose that the CNC machine tool is composed of m success or failure connected units. The No. i unit is

Corresponding Author: Hai-Long Zhang, Information Center of Sino-Japanese Friendship Hospital of Jilin University, 130033, China

tested n_i times and x_i times are succeeded. We record as $i = \overline{1,m}$. Among the units, there are non-failure units (that is, the test times is equal to the success times). The steps to calculate the reliability confidence limits with CMSR method are given as below:

- Sort the numerical numbers of n_i from the largest to the smallest of m units
- Reject the units with intermediate non-failure and select the minimum non-failure recorded as (n_1, x_1). Then select the units that the times are larger than the minimum failure rates recorded as (n_i, x_i). That is, $n_{i_s} \geq n_1$, $n_{i_s} > n_1$, $n_{i_s} = n_1$. We compress and integrate the test information of these two units.

As:

$$x_i > n_1,\ (n_i, x_i) \to (n_i n_1 / x_i, n_1)(n_1, x_1) \to (n_1, x_1)$$

That is:

$$(n_i, x_1) \to (n_1, x_1) \to (n_i n_1 / x_i, n_1) \tag{4}$$

As $x_i = n_1$, we can get similarly:

$$(n_i, x_i),\ (n_1, x_1) \to (n_1, x_1) \tag{5}$$

As $x_i < n_1$, we can get:

$$(n_i, x_i),\ (n_1, x_1) \to (n_i, x_1 x_i / n_1) \tag{6}$$

We divide the hydraulic system of the CNC machine tools into five units according to the functions. The reliability data is given in Fig. 1. The calculating process of the reliability confidence limit of the hydraulic system is given as below.

The system has non-failure units and adopts CMSR method to solve the problems.

- List the sequence as (104, 105), (103, 103), (102, 101), (96, 96), (95, 94)
- Remove the unit (103, 103). Select the minimum times unit (96, 96) and the smaller times unit (102, 101) and compress. Because $x_i > n_1$, that is 101>96. From the Eq. 4, we can get (102, 101), (96, 96)→ (102×96/101,100) = (96.95,96). The equivalent system of the diagram 1 is shown as Fig. 2

- $\hat{n}, \hat{x}, \hat{F}$

  From Eq.1-4, we can get $\hat{n} = 99.65$, $\hat{x} = 96.65$, $\hat{F} = 3$.

- R_L

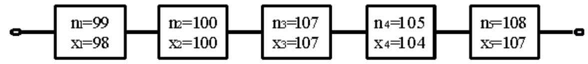

Fig. 1: Reliability diagram of the hydraulic system

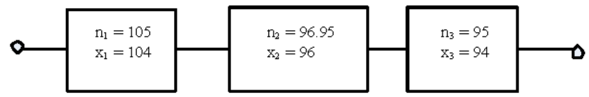

Fig. 2: Equivalent reliability diagram of the hydraulic system

Table 1: Reliability confidence limits of the other subsystems

Subsystems	Reliability confidence limits
Spindle assembly	0.9351
Clamping attachments	0.9345
Main drive system	0.9343
Turret system	0.9340
Electrical systems	0.9345
Protective equipment	0.9355
Cooling system	0.9353
Lubrication system	0.9349
X-axis feed system	0.9344
Chip system	0.9341
Hydraulic system	0.9342
others	0.9359

According to $\gamma = 0.9$, when n = 99, F = 3, we can get $R_L = 0.9338$, when n = 100, F = 3, $R_L = 0.9344$. When $\hat{n} = 99.65$, $\hat{F} = 3$, we use interpolation to get R_L = 0.9398+(09344-0.9338)×0.65 = 0.9342. That is, the reliability confidence limit of the hydraulic subsystem $R_L = 0.9342$.

From the above algorithm, we get the reliability confidence limits of the other subsystems of the CNC machine tools as given in Table 1.

CMSR OF EXPONENTIAL LIFE TYPE SERIES SYSTEM

Exponential life type unit products are used extensively on the CNC machine tools. Firstly, we convert the exponential life type units into the success or failure units and then use MML and CMSR to evaluate the reliability on the converted equivalent system.

Convert the No. i exponential life type unit (Z_i, η_i) into success or failure unit $(\hat{\eta}_i, \hat{x}_i)$. The equivalent test times $\hat{n}_i$ and the equivalent success times $\hat{x}_i$ of the converted units are given as below:

$$\hat{n}_i = \frac{(1 - e^{-Z_i/\eta_i}) \cdot \eta_i^2}{e^{-Z_i/\eta_i} \cdot Z_i} \tag{7}$$

$$\hat{x}_i = \frac{(1 - e^{-Z_i/\eta_i}) \cdot \eta_i^2}{Z_i} \tag{8}$$

where, η_i refers to the equivalent tasks converted, $\eta_i = T/t_0$ (T is the total test time and is t_0 the task time.

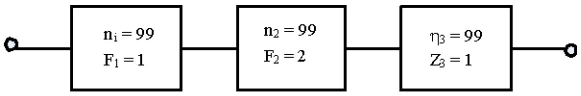

Fig. 3: Reliability diagram of the series system

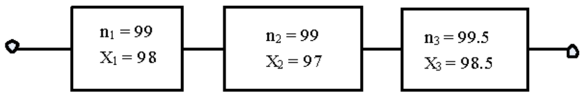

Fig. 4: Equivalent reliability diagram of chip system

Table 2: Reliability confidence limits of the other subsystems

Subsystems	Reliability confidence limits
Spindle assembly	0.9228
Clamping attachments	0.9226
Main drive system	0.9223
Turret system	0.9219
Electrical systems	0.9225
Protective equipment	0.9229
Cooling system	0.9227
Lubrication system	0.9225
X-axis feed system	0.9222
Chip system	0.9220
Hydraulic system	0.9226
others	0.9246

Z_i refers to the values related to failure rate Υ_i of the converted exponential life type unit; For censored life test, $Z_i = \Upsilon_i$; for the other life tests, $Z_i = \Upsilon_i+1$.

The success or failure and exponential life type reliability data of the chip system is given in Fig. 3 and the given confidence limit ã is 0.9.

- Convert the third unit into success or failure unit, we can get from Eq. 7 and 8, we can get:

$$\hat{n}_3 = \frac{(1-e^{-Z_3/\eta_B})\cdot\eta_3^2}{e^{-Z_3/\eta_B}\cdot Z_3} = 99.5$$

$$\hat{x}_3 = \frac{(1-e^{-Z_3/\eta_B})\cdot\eta_3^2}{Z_3} = 98.5$$

The equivalent system of Fig. 3 is shown as Fig. 4.

- $\hat{n}, \hat{x}, \hat{F}$

There's no failure unit in the success or failure series system and we select MML method.

From Eq. 1-3, we can get: $\hat{n} = 100.4,\ \hat{x} = 96.4,\ \hat{F} = 4$.

- R_L

According to $\gamma = 0.9$, $\hat{n} = 100.4$, $\hat{F} = 4$, we look up R_L in the table:

When $\hat{n} = 100, \hat{F} = 4$, we get: R_L = 0.9217; When $\hat{n} = 101, \hat{F} = 4$, we get: R_L = 0.9224. As $\hat{n} = 100.4, \hat{F} = 4$, we use interpolation method to get R_L = 0.9217+(0.9224-0.9217)×0.4 = 0.9220.

That is, the reliability confidence limit of the chip subsystem R_L.0.9220.

From the above algorithm, we get the reliability confidence limits of the other subsystems of the CNC machine tools as given in Table 2.

CONCLUSION

We calculate the reliability confidence limits of the subsystems with CMSR method when we regard the subsystems of the CNC machine tools as success or failure and exponential life types and the results are shown in Table 1 and 2.

We can see the numerical in Table 2 is lower than the numerical in Table 1. When we regard the units of the subsystems as the exponential life type the, the results can not evaluate the reliability of the subsystems well. The MTBF of the CNC machine tools doesn't pass the exponential test which illustrates the validity of the conclusions.

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