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ONE SYSTEM RELIABILITY ASSESSMENT METHOD FOR CNC GRINDER

METODA OCENY NIEZAWODNOŚCI SYSTEMUSZLIFIERKI CNC

The reliability level of CNC (Computer Numerical Control) grinder is usually assessed by fault data counted in laboratory or in field, which needs the grinder to be assembled and it is one afterwards estimation method. To evaluate the reliability level of CNC grinder in design phrase, one system reliability assessment method and algorithm was put forward by subsystem's reliability in this article, which needs subsystem classification, reliability test, distribution function fitting, parameters estimation and reliability assessment. The calculation result showed that the method was feasible and accurate compared with the traditional way. The method is one contribution to reliability design for CNC grinder and is one reference to other mechatronic products.

Keywords: *system reliability, assessment method, MTBF, CNC grinder.*

Poziom niezawodności szlifierki CNC (sterowanej numerycznie) zazwyczaj ocenia się na podstawie danych o uszkodzeniach liczonych w laboratorium lub w terenie, co wymaga zmontowania szlifierki i jest metodą oceny post-factum. Aby umożliwić ocenę poziomu niezawodności szlifierki CNC na etapie projektowania, w niniejszym artykule zaproponowano metodę oceny niezawodności systemu oraz odpowiedni algorytm wykorzystujące dane dotyczące niezawodności podsystemów. Model ten wymaga klasyfikacji podsystemów, badań niezawodności, dopasowania funkcji rozkładu, oceny parametrów oraz oceny niezawodności. Wyniki obliczeń wykazały, że omawiana metoda sprawdza się i jest dokładna w porównaniu z metodą tradycyjną. Przedstawiona metoda stanowi wkład do procesu projektowania niezawodności szlifierki CNC i znajduje odniesienie do innych produktów mechatronicznych.

Słowa kluczowe: *niezawodność systemu, metoda oceny, MTBF, szlifierka CNC.*

1. Introduction

CNC grinder is one machine tool which uses the grinding tools to grind or polish the parts' surface and it is widely applied in the fields of mechanical manufacturing industry, such as aviation and spaceflight, vehicles, ship, etc. Because CNC grinder is the last equipment in manufacturing process usually, its stability and reliability is very important. The critical of reliability enhancement of CNC grinder is design and manufacturing, which needs to evaluate current reliability level and find the weak link to redesign. The reliability assessment, estimation or prediction is the important reference to reliability design and the article aims at the reliability assessment method and algorithm for CNC grinder.

Some approaches for reliability assessment have been proposed and a few achievements have been gained. Young KS proposed one method of reliability prediction of engineering system which the system functionality and system performance are considered [19]. Mohammed TL presented one simple reliability-oriented method to calculate complex distribution system reliability, which is one simplified method [10]. Nathan G developed one method to predict the reliability of electronic packages by expert system [13]. Wei-jenn K proposed one reliability evaluation algorithm countering for imperfect nodes in distributed computing networks [8].

Copal C proposed one system reliability calculation algorithm illustrated through some well-known structures, such as series, parallel, k-out-of-n:G and a fire detector system. The algorithm has been programmed [3]. The difficulty of the algorithm is to solve the structure function. Donald SJ proposed one method to estimate the field-reliability for field-replaceable unit [5]. The estimation model of the method has the merit that the effects of special causes are considered, in addition to the wear of components.

Zunino JL developed the reliability assessment program for MEMS which includes the reliability assessing models and test methodologies [20]. Reliability assessment program is described of aerospace electronic equipment by Condra L [4]. Although the program is standardized, the method is not uniform, instead, it is flexible.

Lu H proposed the reliability sensitivity analysis of mechanical parts with failure modes and Guo J proposed one reliability sensitivity analysis method to identify which variable has the highest contribution to system reliability [11, 7].

The traditional estimation or prediction methods have some shortcomings as follows. 1) The fault distribution function principle of subsystems can not be explored and the distribution function of system is random. 2) Reliability estimation for new product needs to be assembled, which needs high cost and long period. 3) The fact that one product is composed of some universal subsystems whose distributions are known by accumulated reliability data was ignored. For the above, one subsystem distribution function fitting and system MTBF solution method was proposed and the reliability of CNC grinder was assessed by the method.

2. Subsystem distribution function

2.1. Fault data statistic

To find the subsystem's fault time distribution regularity and then evaluate the subsystem's reliability level, the reliability experiments and fault data acquisition are necessary, which are the basis of fault time distribution function fitting of subsystems. Enough fault data must be collected for confidence level and the usual method is time curtailed test. The test time is chosen as the maximal of subsystem's

MTBF (Mean Time Between Failures). Fault data acquisition should meet the conditions as follows [1].

1) Only the relevant fault should be counted and the fault caused by experiment condition or human factor should be ignored.
2) The faults caused by one relevant fault should be combined into one fault with the relevant fault.
3) The fault happened at intermitted period and end of experiment should be counted.

The fault data should be divided into groups by time and the number of groups should be not too big that the probability density will be anamorphic or too small that the calculation load will be heavy and the fitting will be difficult. The number of groups can be calculated by Equation (1) [18].

$$\hat{k} = 1 + 3.3\ln(\sum n_i) \quad (1)$$

The number of group k can be gained by rounding of $\hat{k}$ and the fault data statistics table should be drawn as table 1. In table 1, Δt_{i-} is the left terminal, Δt_{i+} is the right terminal and $\overline{\Delta} t_i$ is the middle of the time group. n_i is the fault number of the ith group and t_{test} is the test time.

Table 1. Fault data grouping

No.	Δt_{i-}	Δt_{i+}	$\overline{\Delta} t_i$	n_i
1	0	t_{test}/k	$t_{\text{test}}/2k$	n_1
2	t_{test}/k	$2t_{\text{test}}/k$	$3t_{\text{test}}/2k$	n_2
…	…	…	…	…
k	$(k\text{-}1)t_{\text{test}}/k$	t_{test}	$(2k\text{-}1)t_{\text{test}}/2k$	n_k

2.2. Distribution type identification

After the fault numbers of every interval were counted, the observed value of fault probability density can be calculated by Equation (2). In Equation (2), Δt is the time of each group.

$$\hat{f}(t_i) = \frac{n_i}{\Delta t \sum n_i} \quad (2)$$

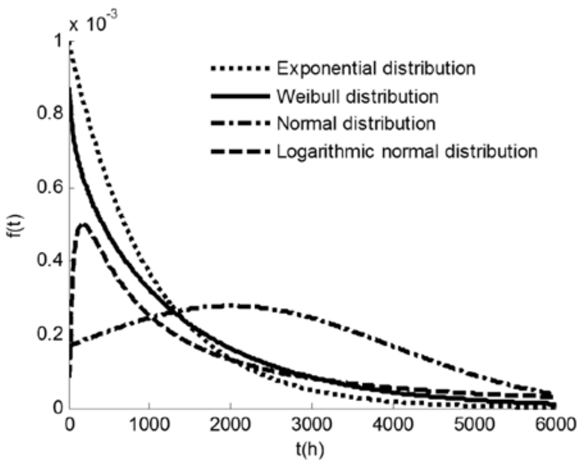

Fig. 1. Common probability distribution

The common probability distributions of mechatronic product are exponential, weibull, normal and logarithmic normal distribution as shown in Fig.1[15]. CNC grinder is one typical mechatronic product and the probability of its subsystem can be confirmed by plotting the scatter points and identifying which distribution curve is the most similar.

2.3. Parameters estimation

2.3.1. Least square method [6, 14]

Least square method is the most common method for parameters estimation as its convenience and practicality. Supposing that there are n values $\{x_i, y_i\}$(i=1, 2, … , n), if the relation of x and y is linear and their relation can be fitted by one equation as shown in Equation (3). The parameters a and b can be estimated by Equation (4) using least square method:

$$\hat{y} = a\hat{x} + b \quad (3)$$

So, when using the least square method for parameters estimation, the linear equation should be created firstly and the parameters in probability density function can be solved by inverse-solving after a and b being calculated by Equation (3). The linear equation creation methods of common distributions are introduced as follows:

$$\begin{cases} a = \frac{1}{n}\sum_{i=1}^{n} y_i - \frac{b}{n}\sum_{i=1}^{n} x_i \\ b = \frac{\sum_{i=1}^{n}\left(x_i - \frac{1}{n}\sum_{i=1}^{n} x_i\right)\left(y_i - \frac{1}{n}\sum_{i=1}^{n} y_i\right)}{\sum_{i=1}^{n}\left(x_i - \frac{1}{n}\sum_{i=1}^{n} x_i\right)^2} \end{cases} \quad (4)$$

2.3.2. Normal distribution

Probability density function of normal distribution is shown in Equation (5) and it has two parameters μ and σ [12]:

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(t-\mu)^2}{2\sigma^2}\right) \quad (5)$$

The accumulative distribution function meets the relation as shown in Equation (6) if the function is converted to standard normal distribution. The value of $F(t_i)$ can be calculated by Equation (7):

$$F(t_i) = \Phi\left(\frac{t_i - \mu}{\sigma}\right) = \Phi(z_i) \quad (6)$$

$$F(t_i) = \sum_{k=0}^{i} f(t_k) \quad (7)$$

The linear equation can be constructed for normal distribution as shown in Equation (8):

$$t_i = \sigma z_i + \mu \quad (8)$$

In Equation (8), z_i is the lower fractile of standard normal distribution and can be calculated by inverse function of standard normal distribution. If the sample data meet normal distribution, z_i and t_i are linear and the observed value of parameters μ and σ can be calculated by Equation (9).

$$\begin{cases}\hat{\mu}=b\\ \hat{\sigma}=a\end{cases} \tag{9}$$

2.3.3. Logarithmic normal distribution

Probability density function of logarithmic normal distribution is shown in Equation (10) [2] and it has two parameters μ and σ. The accumulative distribution function meets the relation as shown in Equation (11) if the function is converted to standard normal distribution:

$$f(t)=\frac{1}{\sigma t\sqrt{2\pi}}\exp\left(-\frac{(\ln t-\mu)^2}{2\sigma^2}\right) \tag{10}$$

$$F(\ln t_i)=\Phi\left(\frac{\ln t_i-\mu}{\sigma}\right)=\Phi(z_i) \tag{11}$$

The linear equation can be constructed for logarithmic normal distribution as shown in Equation (12):

$$\ln t_i=\sigma z_i+\mu \tag{12}$$

If the sample data meet logarithmic normal distribution, z_i and $\ln t_i$ are linear and the observed value of parameters μ and σ can be calculated by Equation (13):

$$\begin{cases}\hat{\mu}=b\\ \hat{\sigma}=a\end{cases} \tag{13}$$

2.3.4. Exponential distribution

Probability density function of exponential distribution is shown in Equation (14) and it has one parameter λ. The accumulative distribution function of exponential distribution is shown in Equation (15):

$$f(t)=\lambda e^{-\lambda t} \tag{14}$$

$$F(t_i)=1-e^{-\lambda t_i} \tag{15}$$

Taking the logarithm on both sides of the Equation (15) and Equation (16) can be gained. Supposing $y=\ln[1-F(t_i)]$ and $x=t_i$, the linear equation can be created as Equation (17):

$$\ln[1-F(t_i)]=-\lambda t_i \tag{16}$$

$$y=-\lambda x \tag{17}$$

So, if the sample data meet exponential distribution, t_i and $\ln[1-F(t_i)]$ are linear and the observed value of parameters λ can be calculated by Equation (18).

$$\hat{\lambda}=-a \tag{18}$$

2.3.5. Weibull distribution

Probability density function of weibull distribution is shown in Equation (19) [9] and it has three parameters m, η and γ. Normally, it is considered that the product has the probability of fault when the product starts to run. So, parameter γ equals to zero. The accumulative distribution function of two-parameter weibull distribution is shown in Equation (20):

$$f(t)=\frac{m}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{m-1}\exp\left(-\left(\frac{t-\gamma}{\eta}\right)^m\right) \tag{19}$$

$$F(t_i)=1-\exp[-(t_i/\eta)^m] \tag{20}$$

Taking the logarithm twice on both sides of the Equation (20) and Equation (21) can be gained. Supposing $y=\ln\ln\frac{1}{1-F(t_i)}$ and $x=\ln t_i$, the linear equation can be created as Equation (22):

$$\ln\left(\ln\frac{1}{1-F(t_i)}\right)=m\ln t_i-m\ln\eta \tag{21}$$

$$y=mx-m\ln\eta \tag{22}$$

If the sample data meet weibull distribution, $\ln\ln\frac{1}{1-F(t_i)}$ and $\ln t_i$ are linear and the observed value of parameters m and η can be calculated by Equation (23):

$$\begin{cases}\hat{\mu}=b\\ \hat{\eta}=\exp\left(-\frac{a}{b}\right)\end{cases} \tag{23}$$

2.4. Goodness of fit test

To find the difference of the fitted values and the real values, the fitting effect should be test after the parameters were estimated, and it is called goodness-of-fit test. The aim of goodness of fit test is to test the quality of fitting and it can be marked by R called goodness of fit coefficient which can be solved by Equation (24) [16]:

$$R^2=\frac{\sum_{i=1}^{n}(y_i-\bar{y})^2}{\sum_{i=1}^{n}(\hat{y}_i-\bar{y})^2} \tag{24}$$

In Equation (24), y_i is the fitted value, $\hat{y}_i$ is the observed value and $\bar{y}$ is the average of y_i. The bigger R is, the better the goodness of fit is. Goodness of fit not only can evaluate the quality of fitting, but also can find the best distribution type when some distributions are meet one sample at the same time.

3. Algorithms

Reliability grade, failure rate and MTBF are the common index for reliability level and MTBF is the most universal. The system MTBF assessment method of CNC grinder was proposed as follow after the subsystem's distribution functions were fitted.

3.1. Subsystem reliability assessment method

Supposing that the *MTBF* of exponential distribution, weibull distribution, normal distribution, logarithmic normal distribution are $MTBF_{ex}$, $MTBF_{wb}$, $MTBF_{nm}$, $MTBF_{ln}$. *MTBF* of different distribution can be calculated by its definition (Equation (25)) as shown in Equation (26), Equation (27), Equation (28) and Equation (29). So, the subsystem's *MTBF* of CNC grinder can be gained after its probability density function being fitted:

$$MTBF=\int_0^{\infty} tf(t)dt \tag{25}$$

$$MTBF_{ex}=\frac{1}{\lambda} \tag{26}$$

$$MTBF_{wb}=\gamma+\eta\Gamma(1+\frac{1}{m}) \tag{27}$$

$$MTBF_{nm}=\mu \tag{28}$$

$$MTBF_{ln}=e^{(\mu+\sigma^2)/2} \tag{29}$$

3.2. System MTBF solution algorithm

Supposing that there are n subsystems of the CNC grinder and their reliability are signed as MT_1, MT_2, … , MT_n. The system *MTBF* solution algorithm is proposed as follows.

1) Sort the subsystem's *MTBF*. Vector T is the sorted *MTBF* of subsystem as shown in Equation (30):

$$\mathrm{T}=\mathrm{sort}(MT_1,MT_2,\cdots,MT_n) \tag{30}$$

2) Calculate the fault number during truncated time. The truncated time is the maximum *MTBF* of subsystem and k_i is the rounding value of T_n/T_i as shown in Equation (31):

$$k_i=\left[\frac{T_n}{T_i}\right]\ (1\le i\le n) \tag{31}$$

3) Calculate summary of fault number. θ is the summary of all subsystems' fault number during truncated time as shown in Equation (32):

$$\theta=\sum_{i=1}^{n}k_i \tag{32}$$

4) Calculate the fault time points. ***tb*** is the faults time points matrix ($n\times k_1$) and tb_{ij} is the jth fault time point of the ith subsystem as shown in Equation (33).

$$\boldsymbol{tb}=\begin{bmatrix} T_1 & 2T_1 & \cdots & k_1T_1\\ T_2 & 2T_2 & \cdots & 0\\ \vdots & \vdots & \ddots & \vdots\\ T_n & 0 & \cdots & 0\end{bmatrix}_{n\times k_1} \tag{33}$$

5) Calculate system fault time points. System fault time points are the combination of all subsystems' fault time points. So, if $\boldsymbol{tb}=[\boldsymbol{tb}_1\ \boldsymbol{tb}_2\cdots\boldsymbol{tb}_n]^T$ (tb_i is one row vector), the system fault time points vector (t_s) can be gained by Equation (34):

$$\boldsymbol{t}_s=[\boldsymbol{tb}_1\ \boldsymbol{tb}_2\cdots\boldsymbol{tb}_n] \tag{34}$$

6) Combine all zeros to one. Many zeros exist in $\boldsymbol{t}_s$. Combine all zeros to one and the pure fault time points vector can be got as shown in Equation (35):

$$\boldsymbol{t}_{sp}=[t_\lambda]\ (0\le\lambda\le\theta) \tag{35}$$

7) Sort $\boldsymbol{t}_{sp}$. Sort the vector $\boldsymbol{t}_{sp}$ and the vector $\boldsymbol{t}$ is got as shown in Equation (36) and some critical point can be gained as shown in Equation (37):

$$\boldsymbol{t}=[t_m]\ (0\le m\le\theta, t_m<t_{m+1}) \tag{36}$$

$$\begin{cases} t_0=0\\ t_1=T_1\\ t_\theta=T_n\end{cases} \tag{37}$$

8) Solve system *MTBF*. System *MTBF* signed as *MTBFs* can be solved by Equation (38) based on its definition:

$$MTBF_s=\frac{\sum_{i=0}^{\theta}(t_{i+1}-t_i)}{\theta} \tag{38}$$

The flow chart of system *MTBF* solution is shown in Fig. 2 and the total solution can be programmed easily.

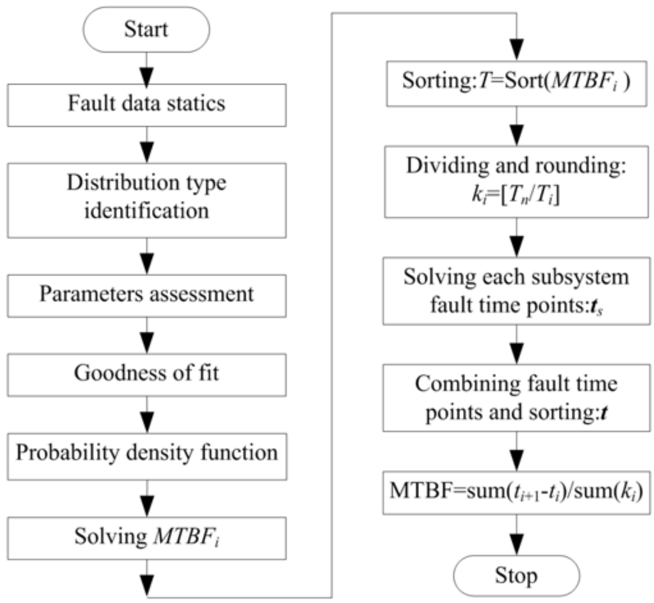

Fig. 2. Flow chart of system MTBF solution

3.3. Considering maintenance time

The maintenance time is ignored of system *MTBF* solution algorithm proposed in section 3.2. If the maintenance time is very small compared to subsystem's *MTBF*, the ignoring is feasible. Otherwise, the maintenance time must be considered [17]. Supposing that the average maintenance time of subsystem i is t_{ri}. Step 1) of section 3.2 should be modified by Equation (39) and the other steps are same:

$$\boldsymbol{T}=\mathrm{sort}(MT_1+t_{r1},MT_2+t_{r2},\cdots,MT_n+t_{rn}) \tag{39}$$

3.4. Considering variety of subsystem's MTBF

The subsystem's *MTBF* variety is not considered in section 3.2. Actually, the subsystem's *MTBF* will be decreased along with the increasing of fault number because of wear, deformation, aging and other factors. If the distribution of subsystem is exponential distribution, its *MTBF* is constant and the subsystem's *MTBF* of other distribution type will be varied after maintenance. In earlier time, the difference of *MTBF* between two maintenances is small and it will become bigger by the increasing of maintenance number. The subsystem's *MTBF* is exponential to the number of maintenance. Supposing that the coefficient is α, the relation between MT_{ij} and MT_{i1} meets Equation (40):

$$MT_{ij} = MT_{i1}(1 - e^{-\alpha(j-1)}) \tag{40}$$

In Equation (40), MT_{ij} is the *MTBF* after j times maintenance of subsystem i. If the subsystem's distribution is exponential, α is zero. The system *MTBF* solution method is as follows.

1) Calculate the fault number. The value of MT_{ij} is one geometric progression when i is one fixed value and the fault number j can be solved by Equation (41). k_i is the rounded of j:

$$MTBF_{i1}(2j - 1 - e^{-\alpha(j-1)}) + jt_{ri} \le T_n \tag{41}$$

2) Calculate the faults time points. Considering the subsystem's *MTBF* variety and maintenance time, the faults time points matrix can be solved as shown in Equation (42).

$$\boldsymbol{tb} = \begin{bmatrix} MT_{11} + t_{r1} & MT_{12} + t_{r1} & \cdots & MT_{1k_1} + t_{r1} \\ MT_{21} + t_{r2} & MT_{22} + t_{r2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ MT_{n1} & 0 & \cdots & 0 \end{bmatrix}_{n \times k_1} \tag{42}$$

After ***tb*** is solved, other calculation steps are same as the above.

4. Reliability assessment

4.1. Subsystems Partition

The first step of reliability assessment is subsystem partition. The schematic diagram of one type CNC grinder is illustrated in Fig. 3. The part is clamped between headstock and tail bracket. The part can be rotated around axis of headstock and the grinding wheel can be rotated around axis of spindle. The part's surface can be grinded as required by the rectilinear motion and rotatory motion of the headstock and the reciprocating motion of the grinding wheel.

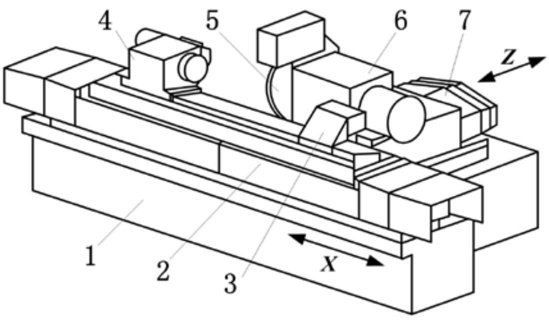

Fig. 3. Schematic diagram of CNC grinder. 1-base, 2- slide carriage of axis Z, 3-tail bracket, 4-headstock, 5-grinding wheel, 6- spindle box, 7-slide carriage of axis X

CNC grinder can be divided into 15 subsystems based its structure feature (in Fig. 3) as shown in table 2.

Table 2. Subsystems partition of CNC grinder

NO.	Subsystem	Abbreviation
1	Base	BS
2	CNC	CNC
3	Spindle	SD
4	Feeder	FD
5	CBN grinding wheel	GW
6	Servo	SV
7	Electrical	EC
8	Hydraulic	HY
9	Cooling	CL
10	Lubrication	LB
11	Safe guard	SG
12	Headstock	HS
13	Measure Instruments	MI
14	Wheel dresser	WD
15	Chip removal	CR

4.2. Subsystem's MTBF solution

The probability density function curves fitted by the fault data are shown in Fig. 4 and there is no fault data of BS in test time and its curve is not illustrated. The subsystems' *MTBF* of CNC grinder are shown in Table 3 solved by the method proposed above.

4.3. MTBF calculation and comparison

System MTBF of CNC grinder can be solved by the algorithm proposed in this paper and the result is 769 h.

If the CNC grinder is seen as one whole and all fault data belong to the whole machine, the probability density function of CNC grinder can be solved as shown in Equation (43) and the fitted curve is shown in Fig. 5, which meets weibull distribution. The system *MTBF* can be calculated by Equation (22) and its value is 785 h.

The design of CNC grinder starts at subsystems and reliability test also starts at subsystems. At this point, the system *MTBF* solution method by subsystems' *MTBF* proposed in this paper has more significance than the traditional method which the product is viewed as one whole:

$$f(t) = \frac{0.915}{753}\left(\frac{t}{753}\right)^{-0.085} \exp\left(\frac{t}{753}\right)^{0.915} \tag{43}$$

4.4. Sensitiveness analysis

Sensitiveness is defined as the increasing ratio of system *MTBF* by one subsystem's *MTBF* being increased a certain extent and other subsystems' *MTBF* maintaining no variety. The aim of sensitiveness analysis is to find that which subsystem has the most contribution to the increasing of system *MTBF*. The analysis result is shown in Fig. 6 by 10% increased of each subsystem.

The system *MTBF* will be enhanced by reliability increasing of SV, EC, HY, LB and CR whose *MTBF* is low relatively. The system *MTBF* will fall conversely when the reliability of BS increases because the fault number will increase during truncated time. Other subsystems' *MTBF* increasing has no influence to system *MTBF*. So, enhancing the *MTBF* of subsystems whose *MTBF* are lower is effective to the increasing of system *MTBF*.

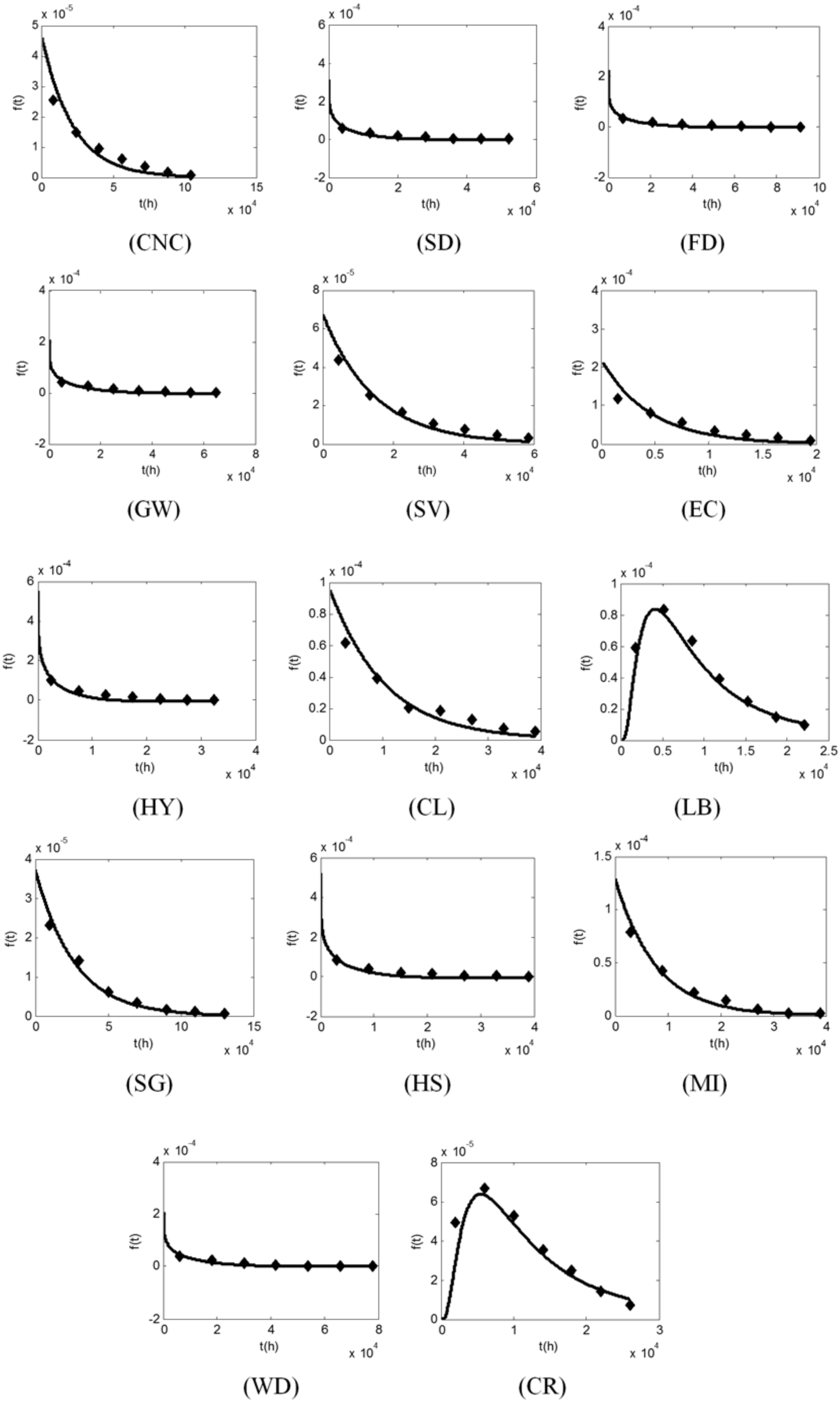

Fig. 4. Probability density function fitting

Table 3. Probability density function and MTBF solution of subsystem

NO.	Subsystem	Probability density function	$MTBF_i$(h)
1	CNC	$f(t)=\lambda e^{-\lambda t}$ ($\lambda=4.5968\times10^{-5}$)	21754
2	SD	$f(t)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}\exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right)$ ($\beta=0.8166$, $\eta=7.7875\times10^{3}$)	8698
3	GW	$f(t)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}\exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right)$ ($\beta=0.8373$, $\eta=1.1239\times10^{4}$)	12346
4	FD	$f(t)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}\exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right)$ ($\beta=0.7938$, $\eta=1.3174\times10^{4}$)	15010
5	SV	$f(t)=\lambda e^{-\lambda t}$ ($\lambda=6.7513\times10^{-5}$)	14812
6	EC	$f(t)=\lambda e^{-\lambda t}$ ($\lambda=2.1604\times10^{-4}$)	4628
7	HD	$f(t)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}\exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right)$ ($\beta=0.7849$, $\eta=4.4913\times10^{3}$)	5160
8	CL	$f(t)=\lambda e^{-\lambda t}$ ($\lambda=9.5243\times10^{-4}$)	10499
9	LB	$f(t)=\frac{1}{\sigma t\sqrt{2\pi}}\exp\left(-\frac{(\ln t-\mu)^2}{2\sigma^2}\right)$ ($\mu=9.0009$, $\sigma=0.8282$)	11429
10	SG	$\lambda=3.7371\times1$($\lambda=3.7371\times10^{-5}$)	26759
11	HS	$f(t)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}\exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right)$ ($\beta=0.7557$, $\eta=5.6728\times10^{3}$)	6712
12	MI	$f(t)=\lambda e^{-\lambda t}$ ($\lambda=1.2916\times10^{-4}$)	7742
13	WD	$f(t)=\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}\exp\left(-\left(\frac{t}{\eta}\right)^{\beta}\right)$ ($\beta=0.8292$, $\eta=1.1830\times10^{4}$)	13077
14	CR	$f(t)=\frac{1}{\sigma t\sqrt{2\pi}}\exp\left(-\frac{(\ln t-\mu)^2}{2\sigma^2}\right)$ ($\mu=9.2772$, $\sigma=0.8165$)	14921

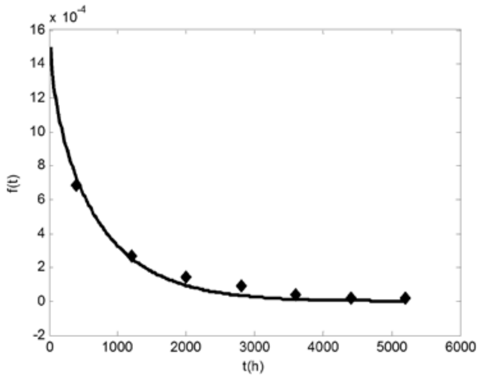

Fig. 5. Curve of probability density function

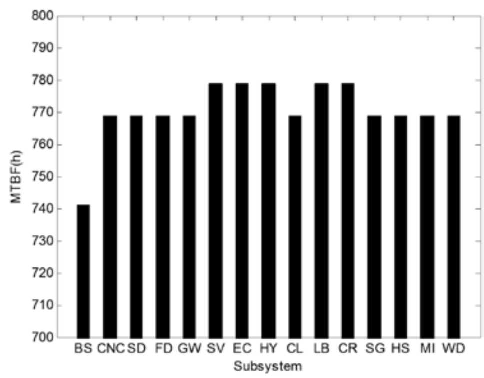

Fig. 6. Reliability sensitiveness analysis

5. Conclusion

Reliability assessment is one important link of product reliability design. The method of fault data processing and distribution type identifying were introduced and the linear equations were constructed for parameters estimation of common distribution. System *MTBF* solving method by subsystems' *MTBF* was proposed for CNC grinder. The reliability sensitiveness analysis method was introduced.

The probability density function of each subsystem was fitted and the *MTBF* of each subsystem was calculated of CNC grinder. The system *MTBF* of CNC grinder was solved by the subsystem's *MTBF*. The reliability sensitivity of subsystem of CNC grinder was analyzed. The result showed that the system *MTBF* calculated by the method proposed in the paper is close to the result calculated by the traditional way. The system *MTBF* solution method is easy and effective and it can be extended for other products.

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