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极值I型分布恒加应力试验的非参数统计分析

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摘要 在极值I型分布场合排除所有的限制，在恒加应力寿命试验下，提出非参数统计分析法．给出正常应力水平寿命分布的参数估计，从而可获得所有的可靠性指标．

关键词 极值I型分布，恒加应力，非参数统计分析

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以前见到的书刊文献，都是介绍图分析法、线性无偏估计法和最佳线性无偏估计法．它们约束条件多、计算麻烦[~3]，要查许多数值表，且算出的结论误差大．应用最大似然估计法，虽有改进，但未能利用试验中的未失效信息，也有缺陷．本文应用非参数方法，可克服上述缺陷．

1 定理与公式

记产品的寿命的T，任取n个样品作寿命试验，结果在t_i处有r_i个失效，S_i个未失效．记$P_i = P_r(T \le t_i)$，$R_i = 1 - P_i = \boldsymbol{P}(T > t_i)$，$r(i) = (r_i, r_{i+1}, \cdots, r_m)$，$(i = \overline{1, m})$，$t_1 < t_2 < \cdots < t_m$．那么，在$(t_1, t_2, \cdots, t_m)$处试验结果的概率为

$$P_r(r(1) \mid P_1, P_2, \cdots, P_m) = \prod_{i=1}^{m} P_i^{r_i}(1 - P_i)^{S_i}, \tag{1}$$

其中$S_i = n - \sum_{k=1}^{i} r_k$，$P_i^{r_i}(1 - P_i)^{S_i}$，它表示在$t_i$处有$r_i$个失效、$S_i$个未失效的事件概率．这可称之为核函数．

由贝叶斯假设，有P_i为$r.v.$且$P_i \sim U(0, 1)$，密度函数$\pi(P_i) = \begin{cases} 1 & 0 < P_i < 1 \\ 0 & 其它 \end{cases}$且$P_i(i = \overline{1, m})$互相独立．记$\boldsymbol{P} = (P_1, P_2, \cdots, P_m)$为随机向量，其联合密度函数为

$$\pi(P) = \pi(P_1, P_2, \cdots, P_m) = \begin{cases} 1 & 当\boldsymbol{P} \in D, \\ 0 & 当\boldsymbol{P} \overline{\in} D, \end{cases}$$

$$D = \{\boldsymbol{P}: 0 < P_1 < P_2 < \cdots < P_m\}. \tag{2}$$

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证明 因 $V(D)=m!\int_0^{P_2}\mathrm{d}P_1\int_0^{P_3}\mathrm{d}P_2\cdots\int_0^{1}\mathrm{d}P_m = m!\frac{1}{m!}=1$，而 $\pi(\boldsymbol{P})=\begin{cases}\frac{1}{V(D)} & 当\ \boldsymbol{P}\in D\\ 0 & 当\ \boldsymbol{P}\ \overline{\in} D\end{cases}$，
故式(2)成立.

$r(1)=(r_1,r_2,\cdots,r_m)$ 与 $\boldsymbol{P}$ 的联合先验密度为

$$f(\boldsymbol{P},r(1))=\begin{cases}k\prod_{i=1}^{m}P_i^{r_i}(1-P_i)^{S_i} & \boldsymbol{P}\in D\\ 0 & 当\ \boldsymbol{P}\ \overline{\in} D\end{cases}\qquad (k\text{是比例常数}).\tag{3}$$

因此，$\boldsymbol{P}$ 的后验度函数为

$$f(\boldsymbol{P}|r(1))=\begin{cases}\prod_{i=1}^{m}P_i^{r_i}(1-P_i)^{S_i}\Big/\int_D\prod_{i=1}^{m}P_i^{r_i}(1-P_i)^{S_i} & 当\ \boldsymbol{P}\in D,\\ 0 & 当\ \boldsymbol{P}\ \overline{\in} D.\end{cases}\tag{4}$$

定理 P_1的后验密度函数为

$$f(P_1|r(1))=W_m^{-1}\sum_{j_m=\beta_m}^{g_m}\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\cdots\sum_{j_2=\beta_2}^{g_2}W(j_m,j_{m-1},\cdots,j_2)B(P_1|\alpha_1,\beta_1),$$

其中

$$\left.\begin{aligned}&\alpha_m=r_m+1,\beta_m=S_m+1,g_m=\alpha_m+\beta_m-1,S_m=n-\sum_{k=1}^{m}r_k,\\&\alpha_i=r_i+g_{i+1}+1-j_{i+1},\beta_i=S_i+1+j_{i+1},g_i=\alpha_i+\beta_i-1,\\&S_i=n-\sum_{k=1}^{i}r_k(i=\overline{1,m}),C_{j_i}=\binom{g_i}{j_i}B(\alpha_{i-1},\beta_{i-1}),\\&g_i=S_{i-1}+g_{i+1}-1(i=\overline{2,m-1}),W(j_m,j_{m-1},\cdots,j_2)=\prod_{i=2}^{m}C_i.\end{aligned}\right\}\tag{5}$$

证明 由式(4)可知

$$f(P_1|r(1))=W^{*-1}\{P_1^{r_1}(1-P_1)\int_{P_1}^{1}P_2^{r_2}(1-P_2^{S_2})\mathrm{d}P_2\cdots\int_{P_{m-1}}^{1}P_m^{r_m}(1-P_m)^{S_m}\mathrm{d}P_m\},$$

$$W_m^*=\int_D\prod_{i=1}^{m}P_i^{r_i}(1-P_i)^{S_i}\mathrm{d}P_i,D=\{\boldsymbol{P}:0<P_1<P_2<\cdots<P_m<1\}.$$

重复应用恒等式，有

$$\int_y^1 x^{\alpha-1}(1-x)^{\beta-1}\mathrm{d}x=B(\alpha,\beta)\sum_{j=\beta}^{\alpha+\beta-1}\binom{\alpha+\beta-1}{j}y^{\alpha+\beta-1-j}(1-y)^j,$$

$$I_m=\int_{P_{m-1}}^{1}P_m^{r_m}(1-P_m)^{S_m}\mathrm{d}P_m=\int_{P_{m-1}}^{1}P_m^{r_m+1-1}(1-P_m)^{S_m+1-1}\mathrm{d}P_m=$$

$$\int_{P_{m-1}}^{1}P_m^{\alpha_m-1}(1-P_m)^{\beta_m-1}\mathrm{d}P_m=$$

$$B(\alpha_m,\beta_m)\sum_{j_m=\beta_m}^{\alpha_m+\beta_m-1}\binom{\alpha_m+\beta_m-1}{j_m}P_{m-1}^{g_m-j_m}(1-P_{m-1})^{j_m},$$

$$I_{m-1}=\int_{P_{m-2}}^{1}P_{m-1}^{r_{m-1}}(1-P_{m-1})^{S_{m-1}}I_m\mathrm{d}P_{m-1}=B(\alpha_m,\beta_m)\sum_{j_m=\beta_m}^{g_m}\binom{g_m}{j_m}\cdot$$

$$\int_{P_{m-2}}^{1}P_{m-1}^{r_{m-1}+g_m+1-j_m-1}(1-P_{m-1})^{S_{m-1}+1+j_m-1}\mathrm{d}P_{m-1}=$$

$$B(\alpha_m,\beta_m)\sum_{j_m=\beta_m}^{g_m}\binom{g_m}{j_m}B(\alpha_{m-1},\beta_{m-1})\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\binom{g_{m-1}}{j_{m-1}}P_{m-2}^{g_{m-1}-j_{m-1}}(1-P_{m-2})^{j_{m-1}},$$

$$I_{m-2}=\int_{P_{m-3}}^{1}P_{m-2}^{r_{m-2}}(1-P_{m-2})^{S_{m-2}}I_{m-1}\mathrm{d}P_{m-2}=B(\alpha_m,\beta_m)\sum_{j_m=\beta_m}^{g_m}\binom{g_m}{j_m}B(\alpha_{m-1},\beta_{m-1})\cdot$$

$$\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\binom{g_{m-1}}{j_{m-1}}P_{m-2}^{g_{m-1}-j_{m-1}}(1-P_{m-2})^{j_{m-1}}\cdots$$

$$I_2=\int_{P_1}^{1}P_2^{r_2}(1-P_2)^{S_2}I_3\mathrm{d}P_2=B(\alpha_m,\beta_m)\sum_{j_m=\beta_m}^{g_m}\binom{g_m}{j_m}B(\alpha_{m-1},\beta_{m-1})\cdot$$

$$\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\binom{g_{m-1}}{j_{m-1}}B(\alpha_{m-2},\beta_{m-2})\cdots B(\alpha_2,\beta_2)\sum_{j_2=\beta_2}^{g_2}\binom{g_2}{j_2}P_1^{g_2-j_2}(1-P_1)^{j_2},$$

$$I_1=P_1^{r_1}(1-P_1)^{S_1}I_2=B(\alpha_m,\beta_m)\sum_{j_m=\beta_m}^{g_m}\binom{g_m}{j_m}B(\alpha_{m-1},\beta_{m-1})\cdot$$

$$\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\binom{g_{m-1}}{j_{m-1}}B(\alpha_{m-2},\beta_{m-2})\cdots\sum_{j_2=\beta_2}^{g_2}\binom{g_2}{j_2}B(\alpha_1,\beta_1)B(P_1|\alpha_1,\beta_1),$$

$$f(P_1|r(1))=I_1/W_m^*.$$

因 $\int_0^1 f(P_1|r(1))\mathrm{d}P_1=1$，得 $W_m^*=B(\alpha_m,\beta_m)W_m$，故

$$f(P_1|r(1))=W_m^{-1}\sum_{j_m=\beta_m}^{g_m}\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\cdots\sum_{j_2=\beta_2}^{g_2}W(j_m,j_{m-1},\cdots,j_2)B(P_1|\alpha_1,\beta_1).$$

推论1　在二次损失下，P_1 的贝叶斯估计为

$$\hat{P}_1=W_m^{-1}\sum_{j_m=\beta_m}^{g_m}\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\cdots\sum_{j_2=\beta_2}^{g_2}W(j_m,j_{m-1},\cdots,j_2)\left(\frac{\alpha_1}{\alpha_1+\beta_1}\right).\tag{6}$$

证明　$B(P|u,v)=\begin{cases}\dfrac{1}{B(u,v)}P^{u-1}(1-P)^{v-1} & 0<P<1\\ 0 & \text{其它}\end{cases}$，故 $\hat{P}=E(P|u,v)=\dfrac{u}{u+v}$，立即得式(6)．

推论2　考虑 $0<P_2<P_3<\cdots<P_m<1$，记 $r(2)=(r_2,r_3,\cdots,r_m)$，即得

$$f(P_2|r(2))=W_{m-1}^{-1}\sum_{j_m=\beta_m}^{g_m}\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\cdots\sum_{j_3=\beta_3}^{g_3}W(j_m,j_{m-1},\cdots,j_3)B(P_2|\alpha_2,\beta_2).$$

在二次损失下，P_2 的贝叶斯估计为

$$\hat{P}_2=W_{m-1}^{-1}\sum_{j_m=\beta_m}^{g_m}\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\cdots\sum_{j_3=\beta_3}^{g_3}W(j_m,j_{m-1},\cdots,j_3)\left(\frac{\alpha_2}{\alpha_2+\beta_2}\right).\tag{7}$$

一般地，因 $(r_{i-1},S_{i-1})(i=\overline{2,k})$ 不能提供 P_k 的信息，故有 $f(P_k|r(k))=W_{m-k+1}^{-1}\sum_{j_m=\beta_m}^{g_m}\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\cdots\sum_{j_{k+1}=\beta_{k+1}}^{g_{k+1}}W(j_m,j_{m-1},\cdots,j_{k+1})B(P_k|\alpha_k,\beta_k)$，其中 $W_{m-k+1}=\sum_{j_m=\beta_m}^{g_m}\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\cdots\sum_{j_{k+1}=\beta_{k+1}}^{g_{k+1}}W(j_m,j_{m-1},\cdots,j_{k+1})$，$r(k)=(r_k,r_{k+1},\cdots,j_m)\ (k=\overline{1,m-1})$．在二次损失下，有

$$\hat{P}_k=W_{m-k+1}^{-1}\sum_{j_m=\beta_m}^{g_m}\sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}}\cdots\sum_{j_{k+1}=\beta_{k+1}}^{g_{k+1}}W(j_m,j_{m-1},\cdots,j_{k+1})\left(\frac{\alpha_k}{\alpha_k+\beta_k}\right).\tag{8}$$

因 $f(P_m|r_m)=P_m^{r_m+1-1}(1-P_m)^{S_m+1-1}/B(\alpha_m,\beta_m)$，故有

$$\hat{P}_m = E(P_m | \alpha_m, \beta_m) = \frac{r_m + 1}{r_m + S_m + 2}. \tag{9}$$

为便于计算机计算，可将式(8)改写为如下形式

$$W_{m-k+1} = \sum_{j_m=\beta_m}^{g_m} \sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}} \cdots \sum_{j_{k+1}=\beta_{k+1}}^{g_{k+1}} \prod_{i=k+1}^{m} \frac{g_i!}{g_{i-1}!} \frac{(S_{i-1}+j_i)!}{j_i!} \frac{(r_{i-1}+g_i-j_i)!}{(g_i-j_i)!}, \tag{10}$$

$$I_k = \sum_{j_m=\beta_m}^{g_m} \sum_{j_{m-1}=\beta_{m-1}}^{g_{m-1}} \cdots \sum_{j_{k+1}=\beta_{k+1}}^{g_{k+1}} \prod_{i=k+1}^{m} \left(\frac{g_i!}{g_{i-1}!}\right) \cdot$$

$$\frac{(S_{i-1}+j_i)!}{j_i!} \cdot \frac{(r_{i-1}+g_i-j_i)!}{(g_i-j_i)!} \cdot \frac{(r_k+g_{k+1}+1-j_{k+1})!}{(g_i-j_i)!}, \tag{11}$$

$$\hat{P}_k = I_k / W_{m-k+1} \quad (k = \overline{1, m-1}), \qquad \hat{P}_m = \frac{r_m+1}{S_m+r_m+2}. \tag{12}$$

由公式(10)～(12)，可以算得下面的可靠性指标。(1) 在 t_k 处的可靠度 $\hat{R}_k = 1 - \hat{P}_k$, $k = \overline{1, m}$. (2) 在 t_k 处的失效率 $\hat{\lambda}_k = \hat{P}_k / t_k$, t_k 为试验时间。(3) 总体的平均失效率估计 $\hat{\lambda} = \frac{1}{m}\sum_{k=1}^{m} \hat{\lambda}_k$.

2　试例

某型号的电子器件，其寿命服从极值I型分布，对其进行温度恒加应力寿命试验，结果列于表1. 试求在正常温度 $S_0 = 323$ K 下，产品寿命的分布函数及其可靠性特征值. 取 $\varphi(S) = \frac{1}{k_0 S}$, ($k_0 = 0.861\ 7 \times 10^{-4}$), $\varphi(S_0) = 35.929$.

表1　恒加应力试验的结果(h)

应力水平/K	样品数	失效时间：失效个数	失效时间：未失效个数	截止时间
358	20	59, 79, 402, 490 (1, 19), (1, 18), (1, 17), (1, 16)		500 (0, 16)
398	16	18, 22, 47, 186 (1, 15), (1, 14), (1, 13), (1, 12)		200 (0, 12)
423	12	11, 13, 87, 90 (1, 11), (1, 10), (1, 9), (1, 8)		100 (0, 8)
448	8	6, 9, 30, 52 (1, 7), (1, 6), (1, 5), (1, 4)		60 (0, 4)

应用公式(9)～(11)，可以算得表2. 在表2的应力水平(1)中，出现 $\hat{P}_{15} < \hat{P}_{14}$ 是没有错的，而照理写为 $\hat{P}_{15} > \hat{P}_{14}$ 反而是错的. 这是因为表1中490(1, 16)和500(0, 16)，表示在时间490处有1

表2　不同应力水平下的计算结果

	应力水平(1)				
$\hat{P}_{1i}$	0.040 74	0.049 91	0.065 97	0.105 26	0.058 82
$\hat{R}_{1i}$	0.959 26	0.950 09	0.934 03	0.894 74	0.941 18
	应力水平(2)				
$\hat{P}_{2i}$	0.051 09	0.062 97	0.083 64	0.133 33	0.079 23
$\hat{R}_{2i}$	0.948 91	0.937 03	0.916 36	0.866 77	0.920 28

续表

			应力水平(3)		
$\hat{P}_{3i}$	0.068 49	0.085 29	0.114 21	0.181 78	0.111 11
$\hat{R}_{3i}$	0.931 51	0.914 71	0.885 79	0.818 22	0.888 89
			应力水平(4)		
$\hat{P}_{4i}$	0.103 52	0.131 56	0.178 91	0.281 80	0.209 00
$\hat{R}_{4i}$	0.899 65	0.868 44	0.821 09	0.718 20	0.791 00

个失效16个未失效, 而在500处没有失效却有16个未失效. 表1中的其它3个水平, 同样有类似的情况.

3　参数计算

设 $T\sim F(t)=\exp\{-\exp(-\frac{t-\mu}{\sigma})\}$, $P_{ji}=F(t_{ji})$. 即 $\hat{P}_{ji}=\exp\{-\exp(-\frac{t_{ji}-\hat{\mu}_j}{\hat{\sigma}_j})\}$, $\ln\hat{P}_{ji}=\exp(-\frac{t_{ji}-\hat{\mu}_j}{\hat{\sigma}_j})\}$, $\ln(-\ln\hat{P}_{ji})=-\frac{t_{ji}}{\sigma_j}+\frac{\mu_j}{\sigma_j}$. 记 $y_{ji}=\ln(-\ln\hat{P}_{ji})$, $x_{ji}=-t_{ji}$, $\hat{b}_j=1/\hat{\sigma}_j$, $\hat{a}_j=\hat{\mu}_j/\hat{\sigma}_j$. 得 $y_{ji}=\hat{b}_j x_{ji}+\hat{a}_j(j=\overline{1,4}, i=\overline{1,4})$. 为求得 $F_0(t)=\exp\{-\exp(-\frac{t-\mu_0}{\sigma_0})\}$, 就必须求得正常应力水平上的 μ_0, σ_0. 为此进行分步讨论, 首先求 $\hat{\mu}_j$, $\hat{\sigma}_j(j=\overline{1,4})$, 尔后求 $\hat{\mu}_0$, $\hat{\sigma}_0$. 有

$x_{1i}=-59,\ -79,\ -402,\ -490,\ -500$, $\bar{x}_1=-306$, $S_{x_1x_1}=193\ 246$, $S_{x_1}=439.6$,

$y_{1i}=1.163\ 3, 1.097\ 8, 1.000\ 1, 0.811\ 5, 1.041\ 4$, $\bar{y}_1=1.022\ 8$,

$S_{y_1y_1}=0.070\ 9$, $S_{y_1}=0.266\ 2$, $S_{x_1y_1}=89.147\ 9$, $r_{x_1y_1}=0.761\ 8>r_{0.05}=0.754\ 5$,

$\hat{a}_1=\bar{y}_1-\hat{b}_1\bar{x}_1=1.022\ 8+4.6\times10^{-4}\times306=1.163\ 6$

$\hat{b}_1=\frac{S_{x_1y_1}}{S_{x_1x_1}}=4.6\times10^{-4}$, $\hat{\sigma}_1=1/\hat{b}_1=2\ 173.9$, $\hat{\mu}_1=\hat{\sigma}_1\hat{a}_1=2\ 529.6$;

$x_{2i}=-18,\ -22,\ -47,\ -186,\ -200$, $\bar{x}_2=-94.6$, $S_{x_2x_2}=3\ 286\ 7$, $S_{x_2}=181.3$,

$y_{2i}=1.090\ 0, 1.017\ 1, 0.908\ 8, 0.700\ 9, 0.932\ 4$, $\bar{y}_2=0.929\ 4$,

$S_{y_2y_2}=0.086\ 2$, $S_{y_2}=0.293\ 6$, $S_{x_2y_2}=38.482$,

$r_{x_2y_2}=0.723\ 0$, $r_{0.1}(5)=0.669\ 4$, $\hat{a}_2=\bar{y}_2-\hat{b}_2\bar{x}_2=1.040\ 1$,

$\hat{b}_2=S_{x_2y_2}/S_{x_2x_2}=1.17\times10^{-3}$, $\hat{\sigma}_2=1/\hat{b}_2=254.7$, $\hat{\mu}_2=\hat{a}_2\hat{\sigma}_2=888.79$;

$x_{3i}=-11,\ -13,\ -87,\ -96,\ -100$, $\bar{x}_3=-61.4$, $S_{x_3x_3}=8\ 225.2$, $S_{x_3}=90.69$,

$y_{3i}=0.986\ 2, 0.900\ 9, 0.774\ 6, 0.533\ 5, 0.787\ 2$, $\bar{y}_3=0.796\ 5$,

$S_{y_3y_3}=0.116\ 2$, $S_{y_3}=0.341\ 5$, $S_{x_3y_3}=24.639\ 8$,

$r_{x_3y_3}=0.795\ 6$, $r_{0.05}=0.754\ 5$, $\hat{a}_3=\bar{y}_3-\hat{b}_3\bar{x}_3=0.612\ 5$,

$\hat{b}_3=S_{x_3y_3}/S_{x_3x_3}=2.996\times10^{-3}$, $\hat{\sigma}_3=1/\hat{b}_3=333.78$, $\hat{\mu}_3=\hat{a}_3\hat{b}_3=204.44$;

$x_{4i}=-6,\ -9,\ -30,\ -52,\ -60$, $\bar{x}_4=-31.4$, $S^2_{x_4x_4}=2\ 391.2$, $S_x=48.9$,

$y_{4i}=0.818\ 9, 0.707\ 2, 0.542\ 3, 0.236\ 3, 0.448\ 2$, $\bar{y}_4=0.506$,

$S^2_{y_4y_4}=0.205\ 8$, $S_y=0.451\ 7$, $S_{x_4y_4}=19.717\ 4$,

$r_{x_4y_4}=\dfrac{S_{x_4y_4}}{S_{x_4}S_{y_4}}=0.8927,\ r_{0.05}=0.7545,\ r_{x_4y_4}>r_{0.05}$,

$\hat{b}_4=\dfrac{S_{x_4y_4}}{S_{x_4x_4}}=\dfrac{19.7174}{2391.2}=8.25\times10^{-3},\ \hat{\sigma}_4=1/\hat{b}_4=121.2,\ \hat{a}_4=\bar{y}_4-\hat{b}_4\bar{x}_4=0.2916$,

$\hat{\mu}_4=\hat{a}_4\hat{\sigma}_4=35.34,\ \hat{\sigma}_1=2173.9,\ \hat{\sigma}_2=854.7,\ \hat{\sigma}_3=333.8,\ \hat{\sigma}_4=121.2$,

$\hat{\mu}_1=2529.6,\ \hat{\mu}_2=888.97,\ \hat{\mu}_3=204.44,\ \hat{\mu}_4=35.34$,

$\ln\hat{\sigma}_i=7.6843, 6.7508, 5.8105, 4.7974,\ \overline{\ln\sigma}=6.2608,\ S^2_{\sigma\sigma}=4.6108,\ S_\sigma=2.1472$,

$\varphi(S_i)=32.4161,\ 29.1582,\ 27.4348,\ 25.9039,\ \varphi(S_0)=35.929,\ \bar{\varphi}=28.7282$,

$S^2_{\varphi\varphi}=23.4348,\ S_\varphi=4.8410,\ S_{\sigma\varphi}=10.1695$,

$r_{\sigma\varphi}=0.9783>r_{0.01}(4)=0.9172,\ \hat{b}=\dfrac{S_{\sigma\varphi}}{S_{\varphi\varphi}}=0.4339$,

$\hat{a}=\overline{\ln\sigma}-\hat{b}\hat{\bar{\varphi}}=-6.2044,\ \ln\hat{\sigma}=-6.2044+0.4339\varphi(S),\ \ln\hat{\sigma}_0=9.3852,\ \hat{\sigma}_0=11910.7$,

$\ln\hat{\mu}_i=7.8358, 6.7901, 5.3201, 3.5650,\ \overline{\ln\mu}=5.8778$,

$S^2_{\mu\mu}=10.3261,\ S_\mu=3.2134,\ S_{\mu\varphi}=14.860$,

$r_{\mu\varphi}=\dfrac{S_{\mu\varphi}}{S_\mu S_\varphi}=0.9553>r_{0.01}=0.9172,\ \hat{b}=\dfrac{S_{\mu\varphi}}{S_{\varphi\varphi}}=0.6341.\ \hat{a}=\overline{\ln\mu}-\hat{b}\hat{\bar{\varphi}}=-12.3388$

$\ln\hat{\mu}=-12.3388+0.6341\varphi(S),\ \ln\hat{\mu}_0=10.4438,\ \hat{\mu}_0=34330.14$,

$\hat{F}_0(t)=\exp\{-\exp(-\dfrac{t-34330.4}{11910.7})\},\ \hat{R}_0(t)=1-\exp\{-\exp(-\dfrac{t-34330.14}{11910.7})\}$.

由此,可获得所有的可靠性指标.

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Nonparametric Statistical Analysis of Life Test under Constantly Accelerating Stress for the Distribution of Extreme Value Ⅰ Type

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Abstract For the distribution of extreme value Ⅰ type where all the restricution are rejected, a nonparametric statistical analysis is made on life test under constantly accelerating stress. A parametric estimation is given to life distribution under normal stress level, and all the indices of reliability ean thus be obtained.

Keywords distribution of extreme value Ⅰ type, constantly accelerating stress, nonparametric statistical analysis