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Estimation of Transmitter Life in NPP's Environment

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1. Introduction

Both reliability and safety of I&C equipments are important for the safe operation of nuclear power plants [NPP]. Especially, breakdown of a transmitter that transmits various operational parameters of a nuclear power plant causes the power plant operation hazardous. Therefore, it is very important to estimate the life of transmitters and establish preventive maintenances (replacements) based on the estimated life. For these reasons we wish to estimate transmitter (Rosemount 1153) life by Arrhenius model and using the field life data.

2. Estimation of transmitter life by Arrhenius model

The tranmitters must have a qualified life, under typical nuclear plant conditions, of 10 years at a baseline service temperature of 120℉ , 20 years at 106 ℉ . Therefore, applying transmitter surrounding temperature to Arrhenius model, we calculate the life of the transmitter.

Arrhenius model represents the life-stress relation when the applied stress is temperature, so that it is widely used in accelerated life testing using temperature as a stress. The equation is that item's life is exponentially decreasing with the increase in temperature due to chemical reaction of materials (gas, liquid and solid).

Arrhenius model is (1):

$$\frac{1}{t} = A\exp\left(-\frac{E_a}{k_B T}\right), \qquad (1)$$

where

- t : life
- A : unknown nonthermal constant
- E_a : activation energy (eV)
- k_B : Boltzmann's Constant (8.617 x 10-5 eV/°K)
- T : absolute temperature

The lives of at normal temperature T_2 and accelerated temperature T_1 are related by (2):

$$\frac{t_2}{t_1} = \exp^{-\left(\frac{E_a}{k_B}\right)\left(\frac{1}{T_1}-\frac{1}{T_2}\right)}, \qquad (2)$$

where

- t_1 : accelerated aging life at temperature T_1
- t_2 : normal service life at temperature T_2
- E_a : activation energy (eV)
- k_B : Boltzmann's Constant(8.617x10^{-5} eV/°K)
- T_1 : accelerated aging temperature(°K)
- T_2 : normal service temperature(°K)

The materials sensitive to temperature among configured components of the transmitters are silicon, ceramic, nonwire-wound and metal film. Therefore, the activation energy has value of 0.78 to 1.14 as shown in the table 1. below, and we conservatively apply the value of 0.78. to the transmitters[1].

Table 1. Electronic Part Activation Energy

COMPONENTS	MATERIAL	Ea
Diode Rousemount P/N C11871	Silicon	1.14
Transister Rousemount P/N C11873	Silicon	1.02
IC(Amplifier) P/N LM308	Silicon	1.0
Capacitor, Fixed Rousemount P/N C12060	Ceramic	1.14
Thermistor Rousemount P/N C12066	Ceramic	0.87
Diode, Zener Rousemount P/N C12073	Silicon	1.13
PNP Transistor Rousemount P/N C12090	Silicon	1.02
Potentiometer Rousemount P/N C12237	Nonwire- Wound	0.78
Resitor Rousemount P/N C95150	Metal Film	0.78

Presently, the operating room temperature of transmitters is 100.4℉ (38℃).

Substituting t_1 = 20 years(qualified life at 106℉) and Ea = 0.78 into (2) yields a normal service life (life at temperature 100.4℉ (38℃)) of approximately:

$$t_2 = 20\exp^{-\left(\frac{0.78}{8.617\text{x}10\text{-}5}\right)\left(\frac{1}{314.27}-\frac{1}{311.16}\right)}$$
$$= 26.67 \text{ years.}$$

Transmitter life for temperature variations of 100.4℉ (38℃) ± 5℉ is calculated as follows.

Table 2. Life for surrounding temperature variations

TEMP(°F)	95.4	100.4	105.4
LIFE(years)	34.66	26.67	20.63

3. Estimation of transmitter life using field life data

The transmitters analyzed are mainly used in wolsung NPP. There have been many working transmitters more than 20 years since they were installed at the start of the operation of the plant. Failure data during about 18 years are investigated to analyze. Details are as follows.

- transmitter analyzed: Rousemount D/P CELL Type
- period analyzed: 1984.01.01 ~ 2001.12.30
- analysis method: Deficiency Report(DR) & Cal' Report analysis

Transmitters are inspected and calibrated every 18 months, and some defects such as the followings are considered as breakdowns.

√ The replacement of main parts of transmitter due to damage
√ Inoperation due to aging
√ Excessive drifts causing low accuracy and precision

The Weibull distribution is useful in many reliability works since it is a versatile distribution. By adjusting the distribution parameters, it can approximate a wide range of life distribution characteristics for numerous electronic items. [2]

The Weibull density function is (3):

$$f(t;\alpha,\beta) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right], \quad (3)$$

where

β : the shape parameter,
α : the scale parameter.

The likelihood function for given times $t_1, t_2, \cdots, t_n$ is (4):

$$L(\alpha,\beta) = \prod_{i=1}^{n}\left[\frac{\beta}{\alpha}\left(\frac{t_i}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{t_i}{\alpha}\right)^{\beta}\right]\right]^{\delta i}\left[\exp\left[-\left(\frac{t_i}{\alpha}\right)^{\beta}\right]\right]^{1-\delta_i}, \quad (4)$$

where $\delta_i = 1$ or 0 according to t_i is a failure time or a censored time.

Then, log-likelihood function is (5):

$$\log L(\alpha,\beta) = \sum_{i\in F}\log\beta - \sum_{i\in F}\beta\log\alpha + \sum_{i\in F}(\beta-1)\log t_i - \sum_{i=1}^{n}\left(\frac{t_i}{\alpha}\right)^{\beta} .(5)$$

where F means the set of failure times

If the number of time belonging to F is r, (5) becomes (6):

$$\log L(\alpha,\beta) = r\log\beta - r\beta\log\alpha + \sum_{i\in F}(\beta-1)\log t_i - \sum_{i=1}^{n}\left(\frac{t_i}{\alpha}\right)^{\beta} .(6)$$

Putting the partial derivatives of (6) with respect to α and β to 0, we get (7) to compute two MLE's of $\hat{\alpha}$ and $\hat{\beta}$:

$$\frac{\sum_{i=1}^{n} t_i^{\hat{\beta}} \log t_i}{\sum_{i=1}^{n} t_i^{\hat{\beta}}} - \frac{1}{\hat{\beta}} - \frac{1}{r}\sum_{i\in F}\log t = 0, \quad \hat{\alpha} = \left(\frac{1}{r}\sum_{i=1}^{n} t_i \hat{\beta}\right)^{\frac{1}{\hat{\beta}}}, (7)$$

MTBF is then computed as (8):

$$MTBF = \hat{\alpha}\Gamma(1+\frac{1}{\hat{\beta}}), \quad (8)$$

Newton-Raphson numerical method is used to find two MLE's of α and β and then MTBF. Computer program is as follows.

```
x_n_1 = int_VAL

Do

    k = k + 1 'do loop counter

    f_x = Maximum_LikeHood_F(int_VAL, t_CNT, f_SUM, f_CNT) 'function
    df_x = Dis_Maximum_LikeHood_F(int_VAL, t_CNT)  'differential

    x_n = x_n_1 - f_x / df_x 'newton method, beta cal

    If Abs(x_n - x_n_1) < err_lim Then Exit Do

    int_VAL = x_n
    x_n_1 = x_n

Loop

alpa_V = alpa_VAL(x_n, t_CNT, f_SUM) ^ (1 / x_n) 'alpa cal

MTBF = alpa_V * Exp(1 + GammaLn(1 / x_n))
```

Figure 1. MTBF estimation program source

Computational results are given as following table.

Table 3. Computational result

Initial	beta	alpa	MTBF(year)
1	1.41E+00	664.8027574	5.05E+01

4. Conclusion

In this paper, we estimate the life of transmitters that affects safe operation of NPP. The life is estimated by about 27 years in an ambient temperature of 38℃ by Arrhenius model, but the life estimated based on the field data is about 50 years. The life from field data is 23 years longer than that calculated by Arrhenius model. The large difference seems to stem from the fact that transmitters are operated in a milder environment and/or the current preventive maintenance for them is quite effective.

REFERENCES

[1] "Qualification Plan No. 45352-2", Wyle Laboratories, 1982.

[2] MIL-HDBK-338B, "Electronic Reliability Design Handbook", Department of Defense, 1988.