Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2009

The design Life calculation of non-metallic parts in mechanical components using Canadian analysis practice

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1. Introduction

Canadian EQ(Environmental Qualification) standard is CSA N290.13-05 mentioned about qualification by analysis is possible only there exists mathematical modelling and comparison with established engineering information and manufacturers' data. So in Canada, EQ qualification by analysis alone are used very often whereas American's. American EQ qualification by analysis are usually used with another qualification method like type testing or operation experience.

The typical Canadian qualification method by analysis is using System 1000 program. Most of Cadadian nuclear power utilities like NB Power(owns PointLepreau NPP), Hydro Quebec(owns Gentilly-2 NPP) and OPG(owns Pickering & Darlington NPPs) use the System 1000 program to evaluate the design life for their EQ components. This is the difference with American EQ. Type testing method is preferred than qualification by analysis in America.

System 1000 program made by RCM Technologies, Inc. is Material Aging and Radiation Effects Library (they call MAREL). This program provides thermal information calculations, and radiation effects data for organic materials used in various environments.

The EQ component selection method is also different American with Canadian. Americans select only electrical components as EQ component, Canadians select both electrical and mechanical component as EQ components. So I use the System 1000 program only for the mechanical components. In this paper, I'd like to practice the Canadian analysis method, using System 1000 program for the design life calculation only for the non-metallic parts in mechanical components.

2. Methods and Results

2.1 The theory of design Life calculation for thermal aging using System 1000 program

Desing life means expected life(including temperature aging) for the case with steady normal service temperature for the entire service period. Equation 1 shows the relation between desing life and expected life.

$$\text{Design Life} = (\text{Expected Life} - \text{ADE})/3 \qquad (1)$$

※ ADE : Accident Degradation Equivalency

Equation 2 shows the expected life calculation equation.

$$\text{Expected Life} = e^{\left[\left(\frac{\text{Slope}}{(\text{Temp}(\text{Kelvin}))}+\text{int}\right)\right]} \qquad (2)$$

where;

$\text{Slope} - \frac{F_a}{k_B}$, (Found on System 1000) –

$\text{Int} =$ intercept found on system 1000) =

E_a = Activation Energy (Found on System 1000)

k_R = Stephan Boltzmans Constant = 8.617 E – 5 eV/°K

Temperature (°K) = T(℃) + 273

To calculate ADE(Accident Degradation Equivalency) for temperature aging, use the accelerated ageing form of the Arrhenius equation shown below. With reference to the accident profile, we can see that temperature varies with time. Therefore we must integrate the above equation over the span of the accident. We can do this in a simpler manner by enveloping the profile with a series of step changes in temperature. Thus the profile is broken down into a series of intervals of constant temperature. The total accident degradation equivalency is simply the sum of the To's for all intervals. This must also include any requirement for post-accident mission time. Equation 3 shows the ADE calculation equation.

$$T_o = T_s \cdot e^{\left[\text{slope} * \left(\frac{1}{T_o} - \frac{1}{T_s}\right)\right]} \qquad (3)$$

where;

T_o = Accident Degradation Equivalency (hours) at reference temperature (normal service temperature) T_o (Kelvin)

T_s = time(hours)at temperature T_s (accident temperature) in Kelvin

Slope = same as above

$\text{Accident Degradation Equivalency} = T_o = \sum T_{ox}$

2.2 The theory of design Life calculation for radiation aging using System 1000 program

The desing life for radiation aging can be calculated as follows, Eqation 3 shows design life calculation equation.

$$\text{DesignLife(Radiation)} = \frac{\text{25\%DegradationLevel} - \text{AccidentDose}}{\text{NormalDose/year}} = \text{x ... years} \tag{3}$$

2.3 The theory of design life decision

The design life can be decided as the minimum value of the thermal design life and the radiation design life. Eqation 4 shows final design life calculation equation regarding both thermal and radiation aging.

Component Design Life
= Min[Design Life (Thermal)&Design Life (Radiation)] (4)

2.4 Application of the design life calculation - Fisher 64R25 model Viton O-ring

To applicate the System 1000 program, I selected a PRV(Pressure Regulating Valve) made by Fisher Inc. The nomal temperature and radiation level is 56℃ and 87.7rad/year. Figure 1 shows the accident temperature and the accident radiation level is 2.3E+07.

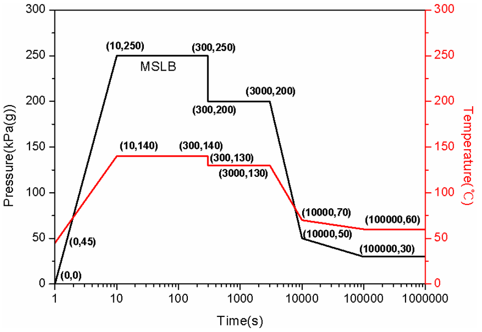

Figure 1. accident temperature and pressure profile

One of the non-metallic part of the valve is valve plug, viton material. The activation enery(Ea), intercept and 25% degradation level was found as 1.0975, -17.142 and 2.23E+08 in the System 1000 database. Design life and ADE for thermal design life was calculated as follows; Equaion 5, 6, 7 and 8 shows the calculation of expected life, ade, thermal design life and radiation design life.

$$\text{ExpectedLife} = e^{\left(\frac{\text{Slope}}{T+273} - \text{Int}\right)} \tag{5}$$

$$\text{ExpectedLife} = 2333459186\ \text{hr} = 266377\ \text{year}$$

$$\text{Hr1} = \left(\frac{\text{Int\_s1}}{3600}\right) \cdot e^{\left[\text{Slope}\cdot\left(\frac{1}{(T+273)} - \frac{1}{(\text{Int\_t1}+273)}\right)\right]} = 0.025 \tag{6}$$

$$\text{Hr2} = \left(\frac{\text{Int\_s2}}{3600}\right) \cdot e^{\left[\text{Slope}\cdot\left(\frac{1}{(T+273)} - \frac{1}{(\text{Int\_t2}+273)}\right)\right]} = 0.376$$

$$\text{Hr3} = \left(\frac{\text{Int\_s3}}{3600}\right) \cdot e^{\left[\text{Slope}\cdot\left(\frac{1}{(T+273)} - \frac{1}{(\text{Int\_t3}+273)}\right)\right]} = 0.014$$

$$\text{Hr4} = \left(\frac{\text{Int\_s4}}{3600}\right) \cdot e^{\left[\text{Slope}\cdot\left(\frac{1}{(T+273)} - \frac{1}{(\text{Int\_t4}+273)}\right)\right]} = 0.388$$

ADE = Hr1+Hr2+Hr3+Hr4=0.803

$$\text{Design Life (thermal)} = \frac{(\text{ExpectedLife} - \text{ADE})}{3} = 88792\ \text{year} \tag{7}$$

$$\text{Design Life (radiation)} = \frac{\text{25\% degradation level} - \text{Accident Dose}}{\text{NormalDose (year)}} = 2283105\ \text{year} \tag{8}$$

The component's EQ design life is the minimum value for both thermal and radiation design life. It is decided the this component's EQ design life is 88792 year. Equation 9 shows design life decision equation.

Component Design Life = Min[88792, 2283105]=88792 (9)

3. Conclusions

Only if I know the material of a non-metallic part, the activation enery(Ea), intercept and 25% degradation level can be found in the System 1000 program. Using normal environmental conditions(temperature and radiation) and accident environmental conditions(temperature and radiation), thermal design Life and radiation design life is calculated for normal operation period and DBE period using System 1000 program. The EQ design life is decided as the minimum value of the thermal design life and radiation design life.

If there is several non-metallic part in the mechanical EQ components, the EQ design life for each non-matallic part should be assessed and the minimum value of can be the component's EQ design life.

For the mechanical EQ components like pumps, air-operated valves and pressure regulating valves, not for the electrical EQ components, the System 1000 program can be used as qualification method as a kind of "qualification by analysis".

To calculate the EQ design life reasonably, the mission time should be considered for ADE calculation. Excessive ADE calculation over the mission will reduce thermal design life of the component. Also if the non-metallic part is surrounded in the metals, the beta-ray radiation shoud be ignored to prevent reducing radiation design life.

REFERENCES

[1] CSA standard N290.13-05 "Environmental qualification of equipment for CANDU nuclear power plants"
[2] RCM Technology "System 1000 revision 17 user's manual"
[3] Hydro-Quebec G2-P-03 "Development of environmental qualification assessment(EQA)"