Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

Sensitivity Study on Ageing Elements Using Degradation Model

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1. Introduction

To evaluate the safety margin effects for performance degradation of system and components due to ageing for CANDU reactors, it is required to identify the ageing elements for systems and components and to develop the degradation model for each element aimed to predict the ageing value during operating year adequately. However, it is recognized that the degradation model is not an independent parameter to assess the evaluation of safety margin change due to ageing. For example, the moderator temperature coefficient (MTC) is an important factor of power distribution and is affected by coolant flow rate. Hence all the ageing elements relevant with the flow rate at different system or components could be influenced the MCT. Therefore, it is necessary to identify the major elements affecting the safety margin. In this regard, this study investigate the coupled effect to concern the safety margin using a sensitivity analysis is conducted.

2. Degradation Model

In this section, some of the techniques used to degradation model are described. Also results of sensitivity study for ageing factor is explained

After identifying the ageing parameters, it is required to predict the variation of these parameters properly. Unfortunately, it is not easy to make an explicit relation between the RELAP-CANDU parameters and ageing mechanism because of insufficient data and lack of applicable models. In this study, all the parameters are assumed to be in accord with the Bath-tub Curve and Weibull distribution [1][2]. Bath-tub Curve is an extensively used model for the machinery life cycle prediction and Weibull distribution is most commonly used in life data analysis, which is a continuous probability distribution with the probability density function. Using Bath-tub Curve and Weibull distribution is based on the assumption that the ageing effects can be defined as a kind of general machinery defects. In this study, these two models are adopted with some adjustments to deal with the ageing effects in suitable manner. In detail, the first period (A) of Bath-tub Curve (Fig. 1) is nullified because the early failure period is out of interest with respect to the ageing. As a result, the new curve has only two periods, intrinsic failure period and wear-out (ageing) failure period. The ageing progress is stagnant during the intrinsic failure period and accelerated during the wear-out failure period. The final formula of the curve is built as shown in Eq.1. In this formula, C is the ageing factor constant and each ageing factor has different constant values according to the type of components and the degree of ageing. And the threshold time, r, is the time point of distinction between intrinsic failure period and wear-out failure period. The shape parameter, m, is a measure of the steepness of the curve. The values of the parameters are decided temporarily for an exemplary calculation. The values of C are fitted to make the degree of long-term ageing to be physically feasible. The value of shape parameter is assigned as 3 to make the curve to be a quadratic function. The threshold time is assigned as 10 year. The final values of the parameters can be determined more accurately if reliable ageing data are available enough to make a statistical process possible.

$$\lambda(t) = \frac{m}{\eta}\left(\frac{t-r}{\eta}\right)^{m-1} \Rightarrow \lambda(t) = C(t-r)^{m-1} \quad \text{Eq.1}$$

$m = shape\ parameter$, $\eta = scale\ parameter$, $r = position\ parameter$

$m = shape\ parameter$, $r = threshold\ time$, $C = ageing\ factor\ const$

TABLE I

Identified ageing components and elements

Ageing Component	Ageing element	Assumptions	Degradation Model
Fuel Channel	Roughness(+)	$C = 0.00111$, $r = 10$	$\lambda(t) = 0.00111(t-10)^2$
	Loss coefficient(+)	$C = 0.00055$, $r = 10$	$\lambda(t) = 0.00055(t-10)^2$
	Hydraulic diameter(-)	$C = 0.00014$, $r = 10$	$\lambda(t) = 0.00014(t-10)^2$
	Flow area(-)	$C = 0.00014$, $r = 10$	$\lambda(t) = 0.00014(t-10)^2$
Pump	Pump head(-)	$C = 0.00004$, $r = 10$	$\lambda(t) = 0.00004(t-10)^2$
	Pump flow(-)	$C = 0.00008$, $r = 10$	$\lambda(t) = 0.00008(t-10)^2$
Steam Generator	Roughness(+)	$C = 0.00138$, $r = 10$	$\lambda(t) = 0.00138(t-10)^2$
	Hydraulic diameter(-)	$C = 0.00014$, $r = 10$	$\lambda(t) = 0.00014(t-10)^2$

* (+) increase -> $initial\ value \times (1+\lambda(t))$
(-) decrease -> $initial\ value \times 1/(1+\lambda(t))$

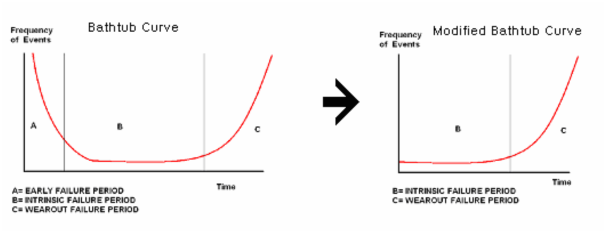


Fig. 1. Bathtub Curve

3. Sensitivity Study

A sensitivity analysis is conducted to examine the effect of ageing factors on MCT (Maximum Cladding Temperature) behaviors in transient states. MCTs are calculated applying the ageing factors given by the degradation model of Eq.(1). The values of the ageing factors are given as to every other year for 58 years.

The variation of each factor affects thermal hydraulic variables on steady and transient states in complex manner.[7] In Fig 2, it represent the MCTs calculated every other year as to two instance. But it is hardly able to find any regularities of dependency.

The variation of each ageing factor described in Figure 3 IV affects friction factor (fuel roughness, SG roughness), loss coefficient (fuel loss coefficient), hydraulic diameter (fuel HD, SG HD, Flow Area) and flow (pump flow, head, flow area). Then these variations cause decrease of channel flow, decrease of pressure drop and change of heat transfer coefficient on steady states due to increase of channel hydraulic friction. Also, in transient states, these variations bring decrease of break-flow owing to decrease of pressure difference between the primary side and the break side and decrease of mass flow rate in primary system. Finally, MCT is affected by these factors synthetically. There are positive factors to MCT such as increase of initial cladding temperature and decrease of primary flow. There are negative factors to MCT such as delay of core uncovering. Whether the result is positive or negative to MCT can be determined according to what dominant factor is. So it is not easy to define the contribution of some ageing factors as positive or negative to MCT, which make it difficult to correlate the ageing mechanism with the thermal-hydraulic effects explicitly. Also there are uncertainties of ageing model and inherent code uncertainties. These aspects make a statistical method to be thought more appropriate than a decisive method.

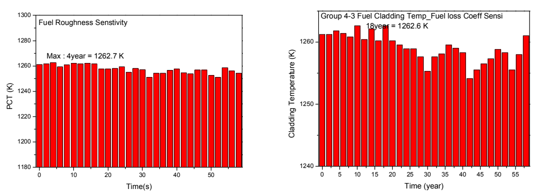
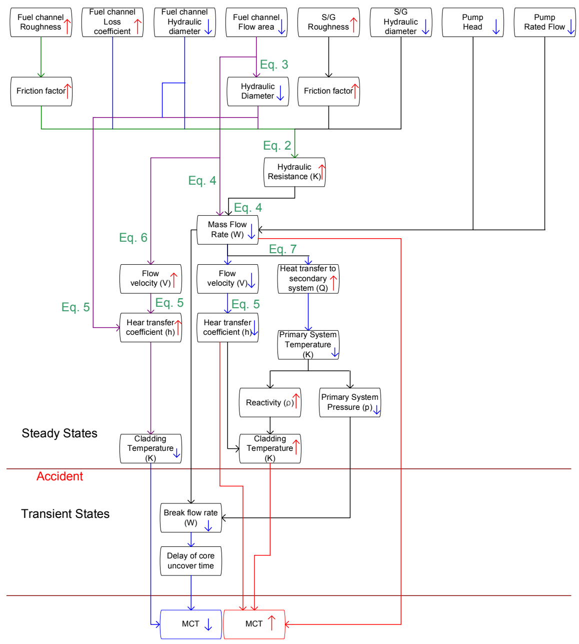


Fig. 2. Sensitivity Study of fuel channel roughness and loss coefficient (transient states)

Fig. 3. Diagram for effect of ageing factors



$$K = f\cdot\frac{L}{D_h} + 2\frac{(T_0 - T_i)}{T_0 - T_i} + \ln\frac{P_0}{P_i} + \tilde{e}_l + (\frac{\bar{m}\cdot\bar{A}}{m_0\cdot A_0})^2 - (\frac{\bar{m}\cdot\bar{A}}{m_i\cdot A_i})^2$$

where, K = Hydraulic resistance

f = Friction factor

$\tilde{e}_l$ = loss coefficient Eq. (2)

$$D_h = \frac{4A}{P}$$

where, D_h = Hydraulic diameter
A = Flow area
P = Wetted perimeter Eq. (3)

$$W = A\sqrt{\frac{2m\cdot\Delta p}{K}}$$

where, W = Mass flow rate
A = Flow area
K = Wetted perimeter Eq. (4)

$$h = 0.023\frac{k}{D_h}(\frac{D_h V\rho}{\mu})^{0.8}(\frac{c_p\mu}{k})^{0.4}$$

where, h = heat transfer coefficient
k = Thermal conductivity
μ = viscosity

$$\frac{V^2}{2} + \frac{P}{\rho} = const$$ Eq. (5)

$$\frac{Q}{Q_{\max}} = 1 - \exp(-\frac{t}{\tau})$$ Eq. (6)

where, Q_{max} = maximum transfer heat
t = time
τ = time constant $(\frac{\rho c V}{hA})$

Eq. (7)

* In Fig 2, the equations (Eq. 2~7)[3] show how some physical factors enclosed by a rectangle are related to the other ones.

3. Conclusions

In this study, it is developed that the degradation model represents the distribution of each ageing factor's value during operating year. And a sensitivity analysis is conducted as to ageing factors. It is also the major motive for development of this ageing analysis method named as *'determination of most suitable conservative ageing effect factor and statistical analysis method'*.

REFERENCES

[1] K. Das , "A comparative study of exponential distribution vs Weibull distribution in machine reliability analysis in a CMS design", Computers & Industrial Engineering, September 2006

[2] Weibull, W. (1951) "A statistical distribution function of wide applicability" J. Appl. Mech.-Trans. ASME 18(3), 293-297

[3] IAEA, "Assessment and management of ageing of major nuclear power plant components important to safety: CANDU Reactors assemblies" IAEA-TECDOC-1197, April 2001.