

## Evaluation of Fatigue Crack Initiation for Volumetric Flaw in Pressure Tube

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### 1. Introduction

CAN/CSA-N285.4-94 requires the periodic in-service inspection and surveillance of pressure tubes in operating CANDU nuclear power reactors [1]. If the inspection results reveal a flaw exceeding the acceptance criteria of the Code, the flaw must be evaluated to determine if the pressure is acceptable for continued service.

Currently, the flaw evaluation methodology and acceptance criteria specified in CSA-N285.05-2005 [2], "Technical requirements for in-service evaluation of zirconium alloy pressure tubes in CANDU reactors". The Code is applicable to zirconium alloy pressure tubes.

The evaluation methodology for a crack-like flaw is similar to that of ASME B&PV Sec. XI, "Inservice Inspection of Nuclear Power Plant Components". However, the evaluation methodology for a blunt volumetric flaw is described in CSA-N285.05-2005 code.

The object of this paper is to address the fatigue crack initiation evaluation for the blunt volumetric flaw as it applies to the pressure tube at Wolsong NPP.

### 2. Methods and Results

#### 2.1 Technical Requirements for the volumetric flaw

If the inspection results reveal a volumetric flaw, the licensee shall demonstrate that fatigue crack initiation will not occur during the evaluation period. General fatigue crack initiation evaluation is followed:

- determining the time of flaw formation
- determining the operating transient history
- characterizing fatigue crack initiation for blunt flaw
- calculating the peak alternating von Mises effective stress
- evaluating the cumulative usage factor

#### 2.2 Postulated volumetric flaw of pressure tube

Normally, the shape and the size of a blunt flaw are determined on the replication results. To evaluate fatigue crack initiation, a postulated volumetric flaw is used. The geometry of a blunt flaw is followed:

- blunt flaw length : 2.8 mm
- with : 1.0 mm
- depth: 0.3 mm
- flaw root radius: 0.6 mm

The finite element of a postulated blunt flaw is modeled by IronCAD, which is showed in figure 1.

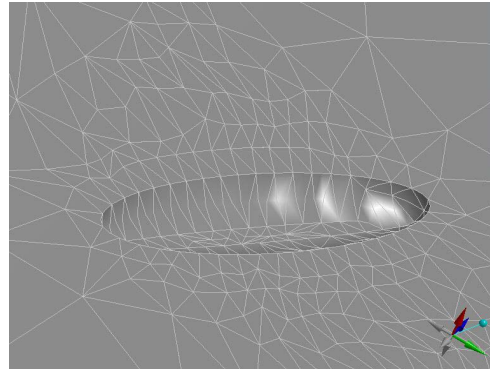


Figure 1. Finite element model of a volumetric flaw

#### 2.3 Pressure Tube Dimension and Material

The predicted pressure tube dimensions at the end of the pressure tube design life of a total of 210,000 EFPH were used in the evaluation. Pressure tube wall thinning is occurred due to creep and corrosion. The finite element model of a pressure tube is followed:

- inner diameter: 108.9 mm
- wall thickness: 3.65 mm
- pressure tube length: 200.0 mm
- material: Zr 2.5% Nb

The finite elements of the postulated volumetric flaw are modeled on the inside surface of the pressure tube.

#### 2.4 Alternating Peak Stress Analysis

To evaluate the fatigue crack initiation, the applied alternating von Mises effective peak flaw-tip stress shall be calculated. There are two ways to calculate the alternating peak stress. The first way is based on stress intensity factor. The other is based on elastic stress concentration factor in this paper. To use the elastic stress concentration factor, the finite element analysis is obtained from the results of DesignSpace program. 10MPa pressure is loaded on the surface of the inner pressure tube and the volumetric flaw. Maximum and Minimum von Mises stress results are showed in figure 2.

The elastic stress concentration factor,  $k_t$ , is calculate by eq. 1.

$$k_t = \frac{\text{von Mises Stress on the flaw - tip}}{\text{Nominal von Mises Stress}} \quad (1)$$
$$= \frac{257.808}{142.759} \text{MPa} = 1.81$$

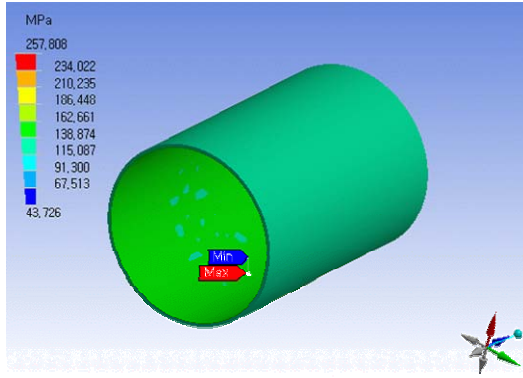


Figure 2. Von Mises peak stress on a blunt flaw

The maximum range ( $\Delta\sigma_n$ ) of the nominal stress is calculated for all service level A and B load transients. The alternating von Mises effective peak stress is calculated using the following equation (2) proposed by the Code.

$$S = 0.435k_t\Delta\sigma_n \quad (2)$$

### 2.5 Cumulative Usage Factor Evaluation

All service level A and B load transients are considered from the pressure tube stress analysis design report of Wolsong NPP. For each type of stress cycle, the value of alternating von Mises effective peak flaw-tip stress is calculated

Usage factors are calculated by

$$U_i = \frac{n_i}{N_i} \quad (3)$$

where

$n_i$  = total number of load cycles for cycle type i  
 $N_i$  = allowable number of load cycle from the fatigue crack initiation evaluation curve for blunt flaws in the Code

$U_i$  = total number of load cycle types i

The cumulative usage factor, U, is calculated using

$$U = U_1 + U_2 + \dots + U_m \quad (4)$$

where

$m$  = total number of load cycle types

Preventing the fatigue crack initiation for all service level A and B transient loads is demonstrated when the cumulative usage factor is less than 1.0.

The cumulative usage factor concerned with all the design service level A and B load transients at Wolsong NPP is 0.07. The calculated cumulative usage factor is less than 1.0.

### 3. Conclusion

The evaluation of fatigue crack initiation is demonstrated that the pressure tube with a postulated volumetric flaw meets the criteria of the CSA code. All pressure tube design transients at Wolsong NPP are

used in the evaluation and a very small volumetric flow is modeled and analyzed. The cumulative usage factor for the postulated blunt flaw is less than 1.0.

Fatigue crack for the postulated volumetric flaw is therefore predicted not to initiate up to the end of pressure tube design life.

### REFERENCES

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