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THERMAL FATIGUE IN NUCLEAR VALVES: THREE DIMENSIONAL CALCULATION OF A CHECK VALVE SUBMITTED TO A THERMAL SHOCK

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1. INTRODUCTION

This study takes place in a validation programme of a new rule for the analysis of thermal fatigue damage in nuclear valves [1]. More exactly the aim of this work is to have a better knowledge of the stress level which is reached in a check valve during a thermal transient.

In the primary cooling system of nuclear plants, in normal and upset conditions, valves are submitted to many thermal transients. The valves' bodies include different wall thicknesses which are connected with fillets (Figure 1). The thermal expansion of the inner side leads to an important strain level in the fillet.

The fatigue resistance analysis of this equipment is normally performed using the French RCC-M code rules [2]. The B 3500 rule is a simplified method used for valves. In this rule, the stresses are given by analytic formulas. The B 3200 rule is more general but requires generally finite elements calculations for the evaluation of the stresses. Those calculations are usually based on axisymmetrical models. In each case, the maximum range of stress intensity is used for the determination of the allowable number of cycles through the fatigue curves.

During qualification tests of a check valve in Les Renardières EDF Research Centre, the initiation and the growth of a fatigue crack in the fillet occurred after a low number of thermal cycles in disagreement with the B 3500 rule predictions. In this particular case of severe thermal shocks, the conception rule seems to be invalidated!

In fact, this simplified rule is not conceived for severe shocks; transients are taken in account with the only temperature range, if temperature increases faster than 55°C per hour. This is too conservative for slow transients but not sufficient for fast transients as thermal shocks.

Then a modification of this simplified rule has been proposed by EDF-SEPTEN [3] and a new validation tests programme has been performed in Les Renardières. The three dimensional calculation of the valve was realised concurrently with the interpretation of this tests.

2. THREE DIMENSIONAL CALCULATIONS

The check valve geometry is not really axisymmetrical. In particular, the presence of the orifices (inlet and outlet) in the body of the valve could modify the stress field in the fillet region. In order to evaluate this geometrical effect, several three dimensional calculations have been made by EDF. At first in the case of a pressure loading and lately in the case of a thermal loading.

2.1. PRESSURE LOADING CASE

In 1986, EDF-MMN realised a 3D calculation of a similar valve loaded with pressure [4]. At this moment, the conclusion was that the stress increased (up to 20%) in the fillet in the vicinity of the outlet orifice. Nevertheless, the pressure loading is not the most important part during operating of these components and, because it is not a cyclic loading, pressure has not to been taken in account in the fatigue analyses.

2.2. THERMAL LOADING CASE

The 3D calculation of the check valve submitted to a thermal loading has been made with the new developments of calculation facilities as the ASTER EDF code on CRAY computer and modelling tools on workstations. The particular geometry effects on the stress field have been evaluated through the comparison of 3D and 2D calculations.

2.2.1. MODELLING

The modelling of the valve has been restricted to the cylindrical middle part of the body. The cap and the ribs have not been represented but, on the other hand, the real geometry of the orifices has been respected. In fact, ribs are designed to increase stiffness in case of in plane bending moment and, as the cap, they don't affect the behaviour in case of severe thermal shock.

2.2.2. MESH VALIDATION

The conception of the 3D mesh has been done in order to obtain a sufficient precision while limiting the number of elements (Figure 2). The precision degree that we obtained with this mesh in regard to the 2D mesh results is evaluated by the comparison of two axisymmetrical calculations. The first one is based on a high refined mesh, as those which are generally used for application of the B3200 RCC-M rule. The mesh used in the second calculation is the image of the median section of the 3D mesh, so it has the same refinement.

Nevertheless a great difference between meshes refinements, the maximum stress value we obtain with the second model is only 5% lower than the value obtained with the refined one. So, we consider that the 3D mesh refinement is sufficient for having a good representation of the thermal shock effect. This mesh is composed with 1256 quadratic quadrilateral elements (6435 nodes).

2.2.3. LOADING

The thermal loading is representative of the hot shock which is applied to the valve on the test loop. In the first part of the transient, the water temperature increase from 60 to 280°C during few seconds. The calculation is not prolonged all along the thermal cycle which ends by a slow cooling and does not produce high stresses. The thermal exchange between the water and the wall is considered as uniform and constant. The value of the thermal exchange coefficient is evaluated with the Colburn formula at the average test temperature. Mechanical characteristics, modulus of elasticity and coefficient of thermal expansion, are taken in the RCC-M code. Their values are depending of the temperature.

2.2.4. RESULTS

First, thermal and thermoelastic calculations are performed on the axisymmetrical model . The maximum stress intensity value (1384 MPa) is reached in the middle part of the fillet 13 seconds after the beginning of the shock. Then, the 3D thermoelastic calculations were performed only for different times around 13 seconds. The stress intensity is not constant along the fillet. The maximum value (1300 MPa) is reached in the median part of it. Far from the orifices, this value is practically constant. Near the outlet, due to the decreasing of stiffness, stress intensity decreases to 600 MPa (Figure 3).

3. DISCUSSION

The maximum stress intensity value resulting from the 3D calculation is 6% lower than the value given by a 2D calculation. This difference is not very important according to the precision generally accepted concerning finite elements calculations. However, the important decrease of the stress near the outlet proves that the effect of this orifices is a relaxation of the stresses. So, taking into account the outlet has two opposite effects depending of the loading case : pressure or temperature.

4. CORRELATION BETWEEN TEST AND CALCULATION

During and after the cycling test, the inside wall of the valve has been inspected in order to detect the apparition of fatigue cracks. A good correlation between the localisation of the crack indications and the regions where the stress intensity level is maximum in the 3D calculation has been noticed. In particular, the absence of crack under the outlet is verified.

5. CONCLUSION

The maximal stress obtained by three dimensional calculations is slightly lower than by a similar axisymmetrical calculation. This is true only for thermal shock loading and not for pressure loading. The operating conditions for this kind of check valves consists essentially in thermal shocks for the fatigue analysis. So this demonstration of the conservatism of the axisymmetrical approach for thermal loading cases validates the use of these models in current studies.

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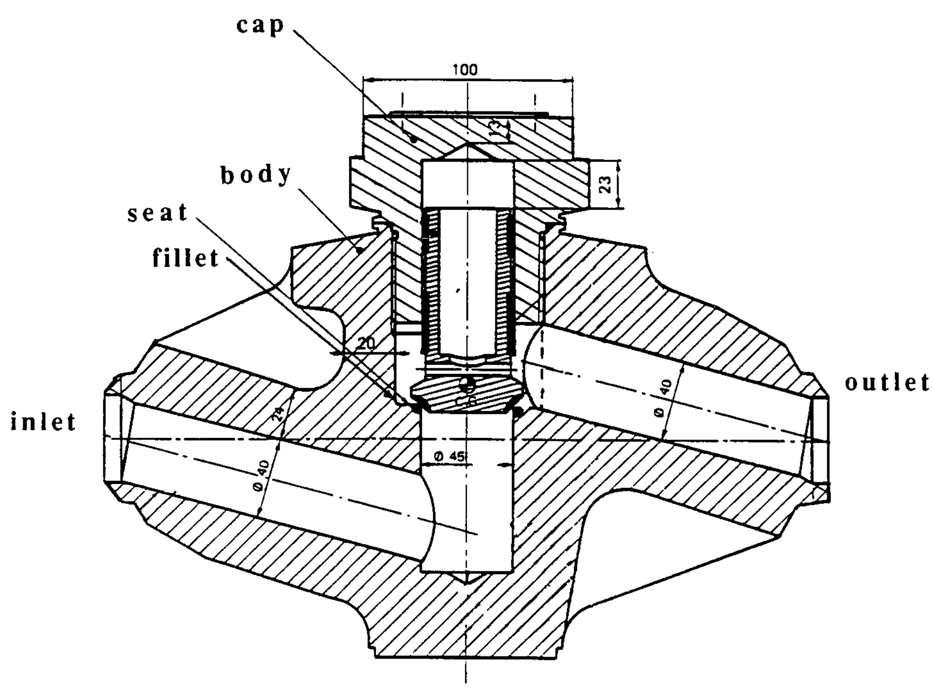

FIGURE 1 : CHECK VALVE CROSS SECTION

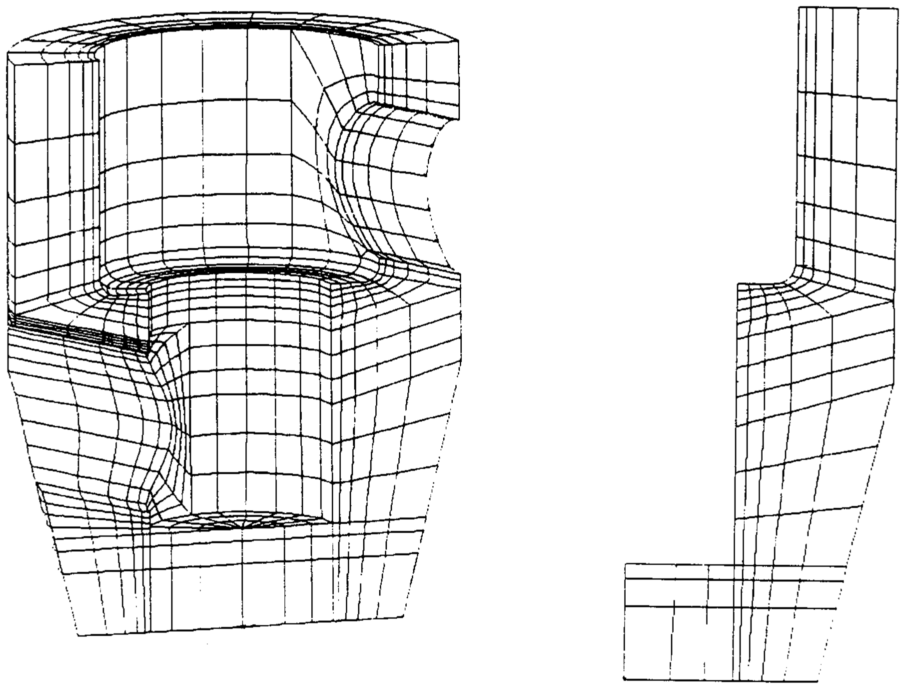

FIGURE 2 : THREE DIMENSIONAL MESH COMPARED TO AXISYMETRICAL MESH

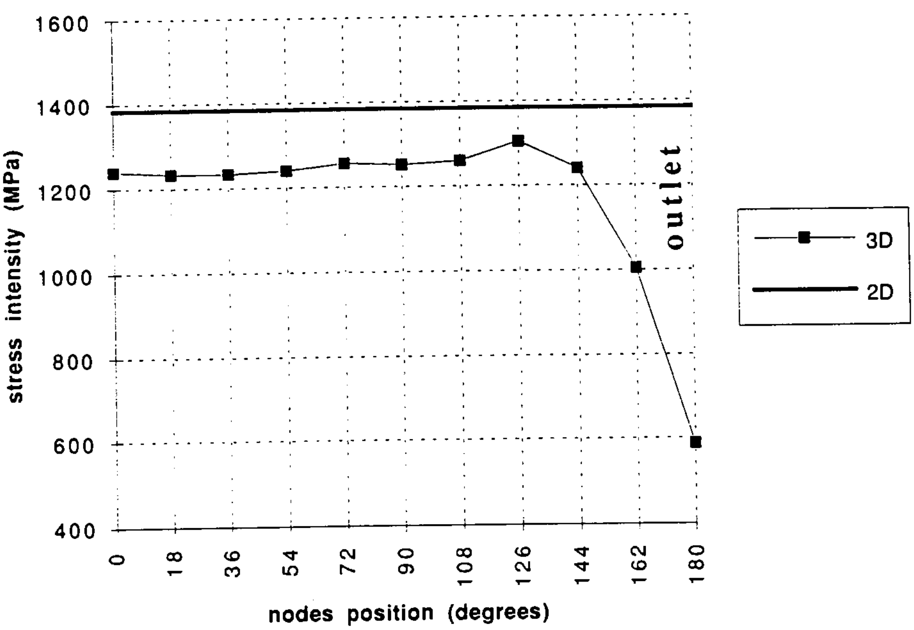

FIGURE 3 : STRESS INTENSITY ALONG THE FILLET