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Determination of stresses in 500MWe PHWR sealdisc during refuelling operation

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ABSTRACT

The sealdisc is a part of sealing plug assembly and its function is to create sealing action for heavy water inside the coolant channel. During onpower refuelling, the sealdisc removal and installation is carried out by use of fuelling machine which generates high stresses in the sealdisc body. Experiments have been carried out to determine the stresses in sealdisc during various loading stages using specially fabricated experimental setup. Measured stresses are compared with FEM computed stresses and it is found that they are in good agreement.

1 INTRODUCTION

The capability to carry-out on-power refuelling is one of the special features of the Indian pressurized heavy water reactors (PHWR). Both ends of each coolant channel of the reactor are designed such that remotely operated automatic fuelling machines can clamp on to the channel and carry out on-power refuelling operations. In order to contain high pressure fluid, a mechanism called the sealing plug assembly, is employed at each end of every coolant channel. Before refuelling, the fuelling machine removes the sealing plug assembly from the end-fitting of the coolant channel and after completing refuelling it is re-installed back into the end-fitting.

The sealdisc is a thin metallic disc and is circular in shape having typical variations in thickness from centre to outer periphery and it has a central stem for handling (Fig.1). The function of sealdisc is to create sealing action to prevent the leakage of heavy water from the coolant channel. To obtain the effective sealing force between nickel gasket (electro-deposited at outer periphery) and end-fitting sealing surface, a specific loading and locking arrangement is used. This causes high stresses in the sealdisc body. A failure of sealdisc may cause loss of coolant accident. The present paper deals with the experimental investigations of sealdisc (500MWe PHWR) stresses and comparison with FEM results.

2 LOADING STAGES

Fuelling machine is clamped with coolant channel just before the installation or removal of sealdisc. Thus fluid pressure on both the sides of sealdisc remains same till the fuelling machine is unclamped. During installation and operation sealdisc is supported at the end-fitting seating surface at its annular nickel gasket. The loads applied on sealdisc for installation/operation/removal can be categorised in to five stages[1,2] as described here.

(i)A load (p1) is applied on the central boss of the sealdisc to obtain a differential displacement of 0.81 mm between the centre and the rocker point of the sealdisc.

(ii)The load is applied at centre and at rocker point such that the differential displacement of 0.81 mm is maintained and sum of both the loads is equal to 1814 Kg. At the end of second stage of loading the rocker point is likely to deflect by 0.27 mm.

(iii)The deflection 0.27 mm (obtained in second stage of loading) is locked by extending the jaw into the corresponding groove in the end-fitting. After the locking, externally applied loads at centre and at rocker point are removed.

(iv)After third stage, the fuelling machine is unclamped from the channel. Thus, the fourth stage (operational stage) corresponds to a channel design pressure of 1.26 Kg/sqmm on the sealdisc, in addition to locked displacement of 0.27 mm at rocker point.

(v) Fifth stage is related with removal of sealdisc from installed condition. The loads are applied at centre and at rocker point such that differential displacement of 0.81 mm is maintained. The total load applied in this stage is 3091 Kg.

Above loading sequence (Fig. 2) makes it possible to install the sealdisc with the minimum load capacity available in fuelling machine and also to reduce the stresses induced in the sealdisc.

3 EXPERIMENTAL SET UP

To simulate the various loading stages, an experimental set up is designed and fabricated[1] as shown in Fig.3. The various components of the set up are outer vessel, its support, supporting legs, flange, closure cap, casing, top cover and deflecting pin. Sealdisc is made to rest on circumferential seating surface of outer vessel against downward ram load. This seating surface is designed in such a way that it should simulate the actual endfitting condition. Various components are fabricated separately. The components assembled during the experiment. The closure cap has circumferential projection which touches the sealdisc rocker point while loading. The surface of projected part of closure cap has convex shape. It has central hole of diameter marginally more than central boss of sealdisc. The casing fits on the top of closure cap. The casing also has central hole similar to the closure cap. The deflecting pin has diameter marginally less than hole present in the casing of closure cap. The length of deflecting pin is selected in such a way that once it is placed in the hole above the sealdisc central boss, its 0.81 mm length should project out of casing. This is for maintaining the differential displacement between centre and rocker point of sealdisc in second and fifth loading stage. The top cover can be fixed at top of outer vessel by tightening of bolts. This is used for locking of rocker point displacement. The flange is bolted to outer vessel at bottom. This is to create pressure at bottom side of sealdisc.

To measure the strains in sealdisc during various loading stages, two element 90 degree rosette strain gauges are employed. The strain gauges are placed at different radial locations of sealdisc at bottom surface. The radial locations (Fig. 1) are selected based on finite element analysis of sealdisc [2]. The strain gauges are installed at different circumferential locations to have sufficient space for installation. The placement of gauges at different circumferential location is not likley to affect the result due to axisymmetric geometry. The dial gauge is also used for measuring the displacement at centre of sealdisc.

4 ANALYSIS AND RESULTS

Experiment is carried out in two phases. In the phase 1 the experiment for first, second and fifth stage of loading is carried out. These loading stages involve the application of ram load only. Initially ram load equal to 1295 Kg (with flat face of ram) is applied at centre of sealdisc. This is first stage of loading. When the differential displacement between centre and rocker point becomes 0.81 mm, the deflecting pin top face reaches to the level of casing top face. After this, if ram load is increased further, the differential displacement of 0.81 mm is maintained and loads gets distributed at centre and at rocker point. This constitutes the second stage with the total load as 1814 kg. The fifth stage is similar to second stage of loading. The total load applied in fifth stage is 3091 kg.

Analysis for third and fourth loading stage of is carried out in phase 2. The third stage requires locking of 0.27 mm deflection at rocker radius. The dial gauge could not be mounted at rocker radius location due to space constraint on the sealdisc bottom surface. Therefore, the locking of rocker point displacement was carried out based on displacement at centre of sealdisc. Since the differential displacement of 0.81 mm is maintained during loading. Therefore, when the rocker point achieves the displacment of 0.27mm, the centre of sealdisc is displaced by 1.08 mm (0.27 + 0.81 mm = 1.08). Hence, when the sealdisc centre deflects by 1.08 mm, the bolts of top cover are tightened. By this process, the closure cap locks the displacement of rocker radius. Now the ram load is removed. This simulates the third stage of loading. The fourth stage loading requires application of pressure on flat surface (bottom surface in experiment) of sealdisc in addition to locked rocker radius displacement. The flange is attached with outer vessel at bottom. Pressure is applied using manually operated hydraulic pump.

The strains are measured for different stages of loading. The displacement of sealdisc centre is also measured for various stages. The measured radial and hoop strains are converted to radial and hoop stresses. Fig. 4 and 5 show the variation of measured radial and hoop stress with radius at bottom surface of seal disc for different stages of loading. For the first, second and fifth loading stages the variation of radial and hoop stress show nearly similar trend. In the third stage, the magnitude of stresses are less as compared to other stages. In the I, II, III and V stage, most of the sealdisc bottom surface has tensile stress except small compressive stress near the periphery. While in the fourth stage, the trend is reversed. Near the centre it shows compressive stress and away from centre there are tensile stress at bottom surface of sealdisc. This happens because pressure is acting in the direction opposit to the application of ram load. In the fourth stage the rocker point is also locked in the deflected position along with the pressure. The high tensile radial stresses are observed at rocker radius on bottom of sealdisc.

6 COMPARISON OF EXPERIMENTAL AND COMPUTED RESULTS

The sealdisc experiment is carried out at room temperature. To have comparison, the stresses and deflections in sealdisc are also computed at room temperature using finite element computer code NISA[3]. The finite element analysis is carried out using elastic as well as elasto-plastic theory. The finite element mesh used for the analysis is shown in figure 6.

The deflection, radial stresses and hoop stresses obtained from the experiment are compared with finite element results. Fig. 7 shows the computed and experimental load (ram load) Vs deflection at centre of sealdisc. The four different measured experimental readings are plotted. The agreement is satisfactory. Figs. 8 to 12 show the comparison between experimental and computed radial and hoop stresses for different stages of loading. The comparison seems to be satisfactory. The experimental and FEM stresses show similar trend of stress variation with radius. Various sets of experimental data are plotted in all the graphs.

7 DISCUSSION AND CONCLUSION

Experimental stress analysis of sealdisc of 500 MWe PHWR is carried out for all the five stages of loading. Measured stress distribution in sealdisc for various loading stages are compared with finite element computed stress. Both the results show similar trend of radial and hoop stresses. Measured stresses are dependent on the intial placement and setting of sealdisc. Slight eccentric placement of sealdisc causes change in readings due to change in boundary conditions. In the third stage of loading the rocker point displcement is locked using number of bolts. Various bolts are to be tightened such that the displacement of 0.27 mm should be maintained at rocker point all along the circumference. But in the experiment, it is difficult to achieve equal tightening of all the bolts. When the bolt is tightened, there is chance of relaxation in the other bolts. The error due to bolt tightening is seen in III and IV stage of loading. The other possible reasons for differences in two results are shift of seating point due to curvature of seating surface, shift of loading/locking point at rocker seat due to curvature of closure cap, yielding in metal near seating location and consequently change of seating point and seating area. Overall the agreement between measured and computed results, is satisfactory.

ACKNOWLEDGEMENT

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2. Chawla D.S. et al. 1989. The final report on Stress Analysis of Sealdisc of 500 MWe PHWR. BARC/1474, 1989.
3. NISA. A finite element computer package. EMRC. Troy Michigan. USA.

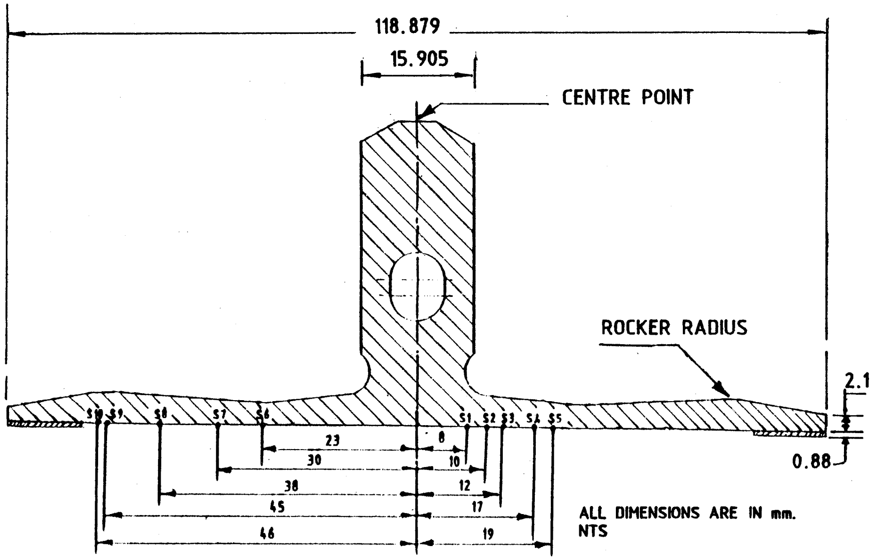

FIG. 1 RADIAL LOCATIONS OF VARIOUS STRAIN GAUGES

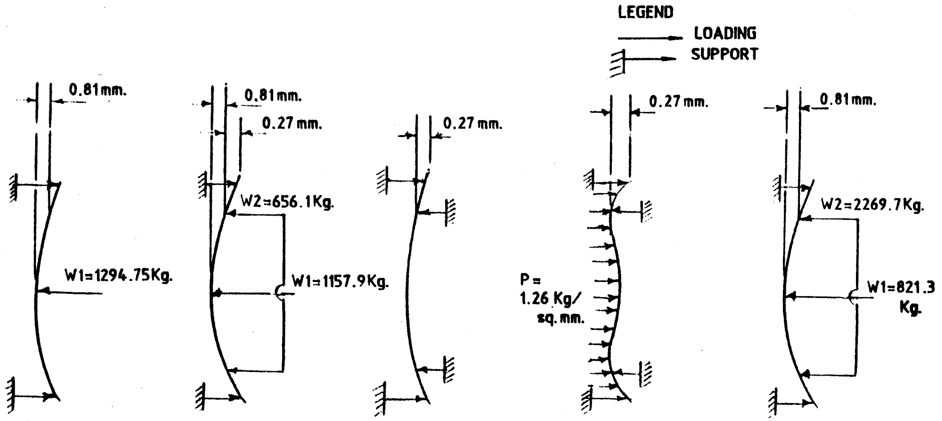

FIG. 2 VARIOUS STAGES OF LOADING

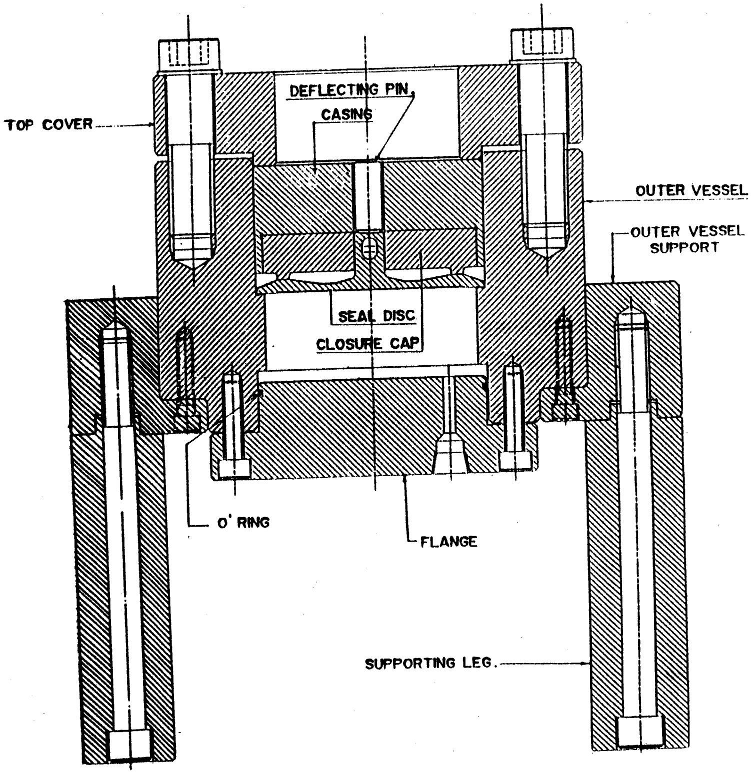

Fig. 3 EXPERIMENTAL SET UP

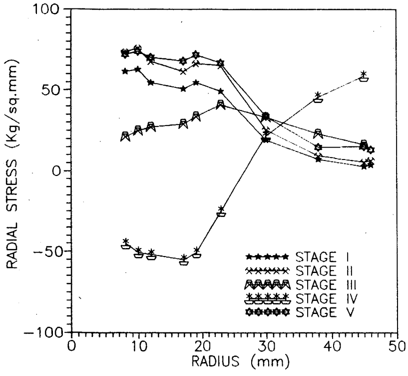

FIG. 4 MEASURED RADIAL STRESSES AT BOTTOM SURFACE OF SEALDISC.

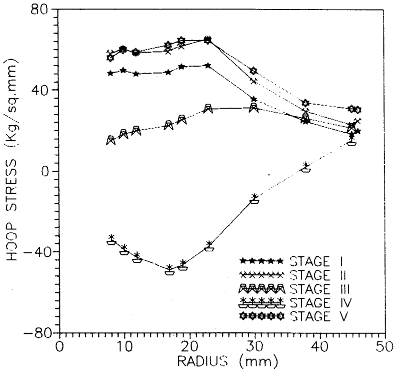

FIG. 5 MEASURED HOOP STRESSES AT BOTTOM SURFACE OF SEALDISC.

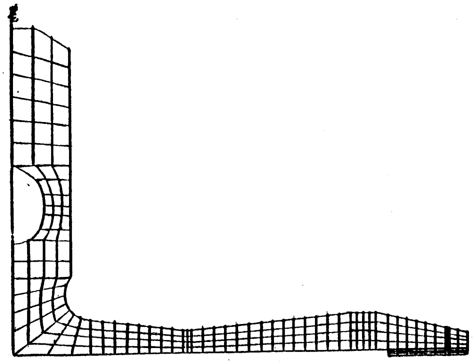

FIG. 6 FINITE ELEMENT MODEL OF SEALDISC

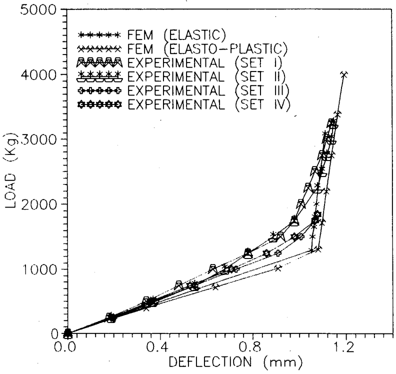

FIG. 7 COMPARISON OF COMPUTED AND MEASURED LOAD Vs DEFLECTION AT SEALDISC CENTRE.

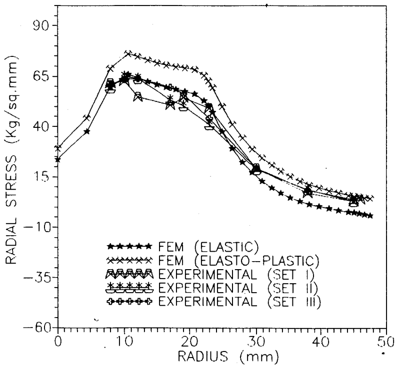

FIG. 8a COMPARISON OF COMPUTED & MEASURED RADIAL STRESS FOR STAGE I LOADING.

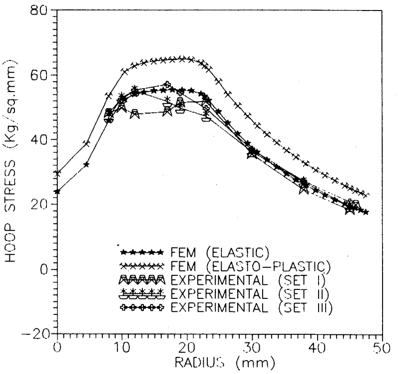

FIG. 8b COMPARISON OF COMPUTED & MEASURED HOOP STRESS FOR STAGE I LOADING.

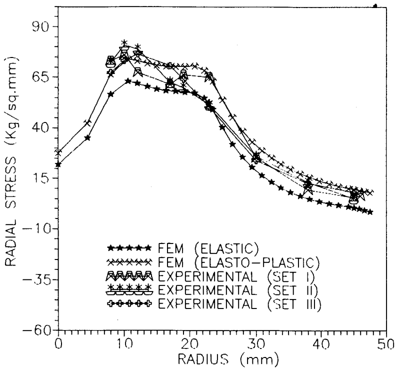

FIG. 9a COMPARISON OF COMPUTED & MEASURED RADIAL STRESS FOR STAGE II LOADING.

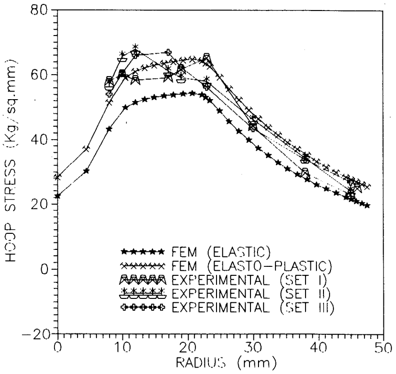

FIG. 9b COMPARISON OF COMPUTED & MEASURED HOOP STRESS FOR STAGE II LOADING.

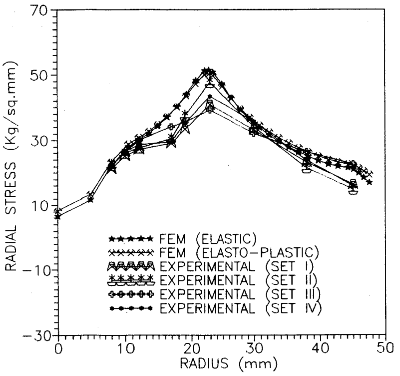

FIG. 10a COMPARISON OF COMPUTED & MEASURED RADIAL STRESS FOR STAGE III LOADING.

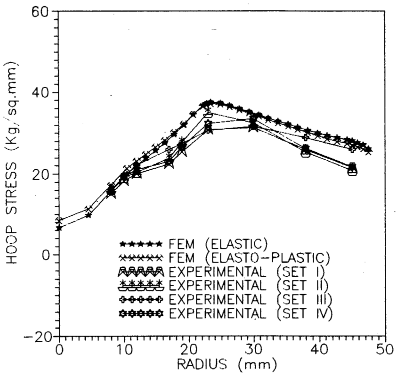

FIG. 10b COMPARISON OF COMPUTED & MEASURED HOOP STRESS FOR STAGE III LOADING.

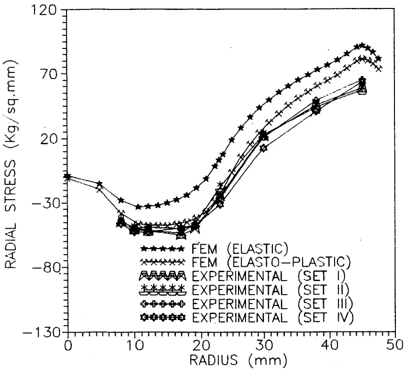

FIG. 11a COMPARISON OF COMPUTED & MEASURED RADIAL STRESS FOR STAGE IV LOADING.

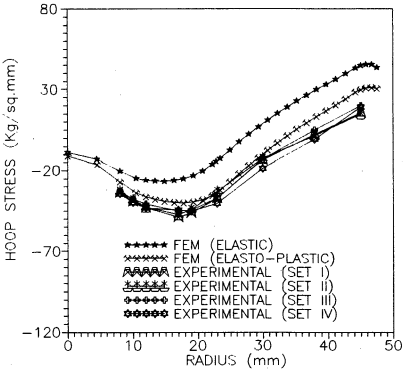

FIG. 11b COMPARISON OF COMPUTED & MEASURED HOOP STRESS FOR STAGE IV LOADING.

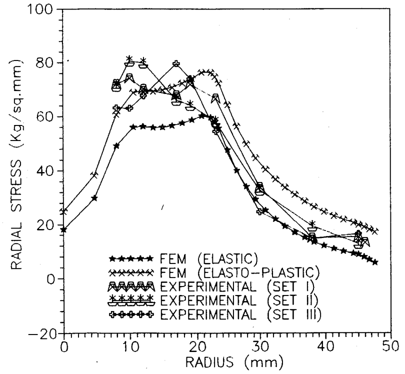

FIG. 12a COMPARISON OF COMPUTED & MEASURED RADIAL STRESS FOR STAGE V LOADING.

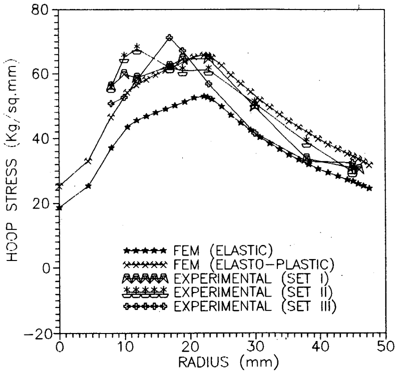

FIG. 12b COMPARISON OF COMPUTED & MEASURED HOOP STRESS FOR STAGE V LOADING.