RESULTS OF ULTRASONIC INSPECTIONS OF FATIGUE CRACK PROPAGATION IN A PWR VESSEL MOCK-UP

C.GONDARD * , A.LUCIA ** , J.ELBAZ **

In order to verify the validity of models for residual life predictions of structure, a mock-up at a 1/5th scale of a PWR vessel containing artificial defects was built. It was submitted to pressurization cycles at the JRC in ISPRA. The growth of the most important defects has been observed during 6 ultrasonic inspections on a 5 years period. After more than 600,000 cycles, some very large defects have occured and give an excellent opportunity to study advanced sizing methods.

INTRODUCTION

The JOINT RESEARCH CENTER (JRC) at ISPRA has undertaken for several years a study on the propagation of fatigue cracks in PWR vessels. The goal is to establish relation between parameters as size and location of the defects and the residual life of the structure (1).

The validity of this model was verified on a mock-up at a 1/5th scale of a PWR vessel, submitted to pressurization cycles. This paper makes a review of results obtained by CEA during 6 successive In-Service Inspections on a 5 years period, using an ultrasonic NDT method.

* CEA/CEREM, Saclay, France
** JRC/ISPRA, Italy

DESCRIPTION OF THE TEST FACILITY

The mock-up. It represents the reactor vessel and the closure head assembly of a 900MWe PWR at a 1/5th scale (figure 1). At the beginning, 9 intentional defects were introduced in the welds :

* slags,
* branching cracks due to cupper diffusion,
* incomplete fusion of the weld.

They were introduced at random, with a majority of defects near the internal surface.

The distribution of the stress field was studied at JRC ISPRA and verified with a series of stress measurements on the vessel. Results are closed to the one found at the scale 1 : (2) and (3).

The pressurization conditions were in the range 20/220 bars. Every 10.000 cycles, a marking of the growth of the defects was achieved with a special cycle of the type 120/220 bars. It will be used to reconstruct the growth of the defects during the fractographic analysis.

Ultrasonic control procedure. Complete inspections were performed from the inside of the vessel, this one filled with water, during stops of pressurization cycles (ISi, IS1, IS2, IS3 and IS5), using a inspection device developped at JRC ISPRA.

A need for a better expertise of the biggest defects appears, and we performed some controls from the outside during IS4 and IS5 with an special device which allows local survey on some defects which are evolving, without the necessity to open the vessel head and to remove the inside instrumentation.

The control is based on the use of focused ultrasonic transducers under immersion : (4) and (5). The data processing system, named STADUS digitalizes signals coming from the ultrasonic device.

The sizing procedure is applied automatically. The evolution of the image size of the defect is compared with those of the beam diameter, according to the level of re-reading (method of successive -6dB drops). It is possible to obtain rapidly the A, B, C or D views of each defect in order to better estimate their morphology, and eventually their orientation and tilting.

RESULTS FOR THE COMPLETE I.S.I's

Statistical analysis

The table 1 below presents the correlation rate for detection between the 5 complete ISI's. The reference inspections are plotted on abscissa; the inspections on which the comparison is made are on ordinate.

	ISi	IS1	IS2	IS3	IS5
Nb.of events	121	118	157	153	139
ISi	-	86%	87%	64%	65%
IS1	94%	-	86%	66%	68%
IS2	85%	87%	-	93%	78%
IS3	80%	84%	90%	-	86%
IS5	80%	84%	90%	83%	-

Table 1 : Correlation rate in detection.

The correlation rate in detection decreases as we compare 2 inspections more distant, whereas the total number of indications is rather stable.

Sizing of the defects

The 3 parameters which are important for the harmfulness of the defects are :
d : distance between the lower end of the defect and the internal surface of the vessel,
2a : height of the defect,
2b : the length of the defect along the weld.

We show at the Table 2 the evolution noted on the 3 more important defects in each weld.

Between ISi and IS5, all defects (except D and E) show a clear increase of their length ('2b'), when the height ('2a') notably changes only for A and H. The 'd' parameter is rather stable : the variations stay in the order of magnitude of the measurements accuracy (1mm).

The main increase in defect-height takes place towards the external wall; the case of the defects in the weld CA is slightly different since at this place the tensile stresses induced when securing the bolts of the vessel head are no more negligible with regard to the circumferential stresses induced by the pressure.

Weld			CA			CB			CL	
Def n°.		A	B	C	D	E	F	G	H	J
2b (mm)	IS5	91	43	33	45	47	140	76	83	31
	IS3	83	40	32	45	53	155	66	45	19
	IS2	74	27	26	48	52	135	62	48	20
	IS1	73	28	14	52	51	140	40	49	20
	ISi	34	N.S	16	50	50	60	40	49	20
2a (mm)	IS5	20	6	8	12	11	10	9	22	8
	IS3	21	6	8	13	12	11	9	13	6
	IS2	15	4	5	12	11	10	7	11	7
	IS1	16	4	6	10	8	11	7	7	7
	ISi	11	N.S	6	10	12	12	7	7	7
d (mm)	IS5	3	3	25	4	4	7	3	3	28
	IS3	3	3	24	4	3	7	2	2	28
	IS2	3	6	26	4	3	6	4	3	28
	IS1	3	6	26	6	6	6	5	5	29
	ISi	4	N.S	28	6	5	7	5	5	30

Nota : N.S= Non-sizeable

Table 2 : Evolution in the sizing of the 9 more important defects

Use of imaging softwares

The automatic processing must be joined with a sharp analysis, based on the handling of the projections on the 3 axes (B, C and DSCAN) of the ultrasonic images.

The figures 2 and 3 show the C and DSCAN of the defect F in CB. It is not rectilinear, with a smooth undulation along the X axis; this factor must be taken into account in order to avoid an over-sizing. The DSCAN indicates an elliptic shape, though the lower tip is rather irregular.

RESULTS FOR THE EXTERNAL ISI's

These inspections allow a local evaluation of the 3 most important defects located in the welds : A in CA, F in CB and H in CL.

The Table 3 below shows the final results.

Defect n°.		A(CA)	F(CB)	H(CL)
d(mm)	IS4	3	7	3
	IS5	3	7	3
2a(mm)	IS4	21	14	15
	IS5	31	25	25
2b(mm)	IS4	160	155	50
	IS5	170	150	90

Table 3 : Final results for the 3 defects of the IS4 and IS5.

They are in good agreement with those of the inspections performed from inside (Table 2), except for the parameter 2b for defect A, and parameter 2a for defect F. In the two cases, the new inspection discovered new diffraction zones which were not detectable during the IS3. The figure 4 shows the DSCAN on defect A : this is a complex image which mixes strong "corner effect" from the initial defect (between 38° and 50° on X axis) with many diffraction points, not necessarily lined out. The growth of the defect seems not regular on all the length, with branched cracks on the sides.

CONCLUSIONS

This work has given valuable informations about the growth of defects under pressure cycles. A through-wall defect appeared at the end of 1989. The vessel will be destroyed and a fractographic analysis will be carried out on the biggest defects and correlated with the results of NDT methods.

The large volume of data has allowed a statistical analysis which shows the reproducibility of the method on a long period.

The use of highly automatized data processing takes much of the hard work out. Nevertheless, an "image-analysis" procedure with all the knowledge of an "expert" is very useful when the standard sizing procedure is no more available (diffraction or corner echoes). With the help of up-to-date image processing technics, it will be soon possible to incorporate this point in the system (6).

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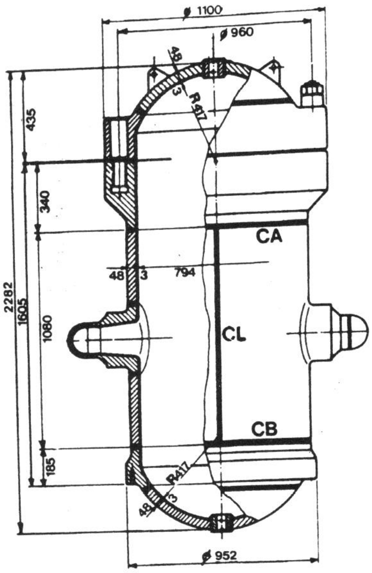


Figure 1 : Diagram of the 1/5th scale PWR vessel.

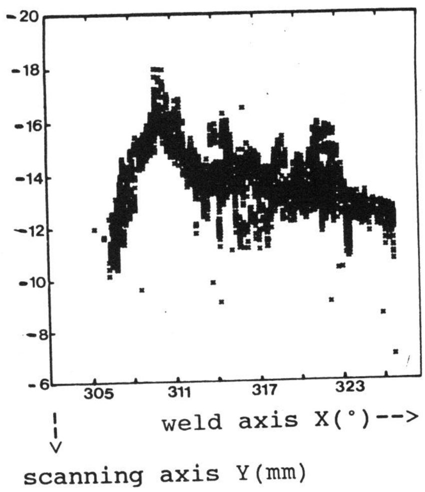
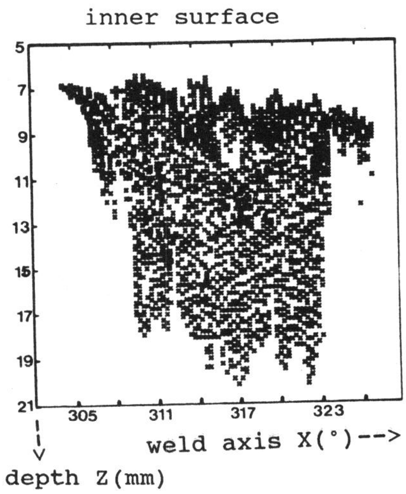


Figure 2 : CSCAN (top view) of defect F(CB) from inside



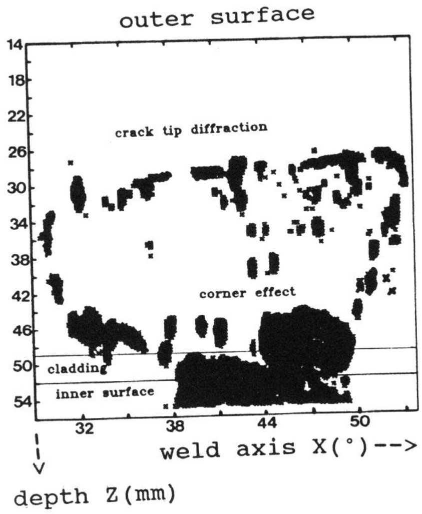


Figure 3 : DSCAN (side view) of defect F (CB) from inside

Figure 4 : DSCAN (side view) of defect F(CB) from outside