SMiRT-12 / K. Kussmaul (Editor)

C05/2

CASI: PREDICTION OF FUEL ASSEMBLY AXIAL BEHAVIOUR UNDER IRRADIATION

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1. INTRODUCTION

During its in-core residence time, a PWR fuel assembly is subjected to various loadings, including irradiation. This produces different physical phenomena affecting the materials, such as free growth and creep of Zircaloy (fuel rod cladding and guide thimble) and relaxation of Inconel (holddown system and grid spring). Its main effects, observable over assembly lifetime, are fuel rod growth, to a lesser extent assembly growth and reduction in fuel rod restraint inside the grid cells. In-reactor experience feedback shows that there is a close interaction between these phenomena, arising from the type of fuel assembly design, and that they are liable to constitute a peak burnup limit, particularly for geometrical compatibility aspects. A method for evaluating the axial behaviour of a fuel assembly in the reactor has been developed, in order to validate new structural concepts with regard to these phenomena and to establish the corresponding design justification.

2. METHODOLOGY

The method implemented in the CASI software relies upon a simplified axial representation of the fuel assembly, of the mass-spring type. For each event in the fuel assembly lifetime producing a change in any one of its characteristics, the method is to modify the corresponding parameter(s) and to calculate the new static equilibrium state with the aid of the CASAC software program /1/. The assembly lifetime is thus simulated by a succession of computation steps, with at each step :

- modification of model parameters,
- calculation of the new equilibrium state,
- interpretation of the results,
- preparation of the parameters of the next step, from :
  - the results of the on-going step,
  - the variation in external conditions.

3. MODEL

Figure 1 shows an in-reactor assembly axial model, where :

- the set of guide thimbles is represented at each span by a pre-loadable linear spring,
- the set of rods is represented by pre-loadable linear springs between the grids and springs with a gap at the ends (rod - nozzle gaps),

- the restraint by friction of the rods in the grids is modelled by sliding elements at each grid,
- the nozzles are modelled by pre-loadable linear springs,
- the holddown system is represented by a linear spring and non-linear springs to represent its non-linear characteristic,
- the boundary conditions introduced by the reactor internals are modelled by a linear spring and the top nozzle - core plate by a gap spring,
- the masses of the different assembly components are distributed among the nodes (lumped masses).

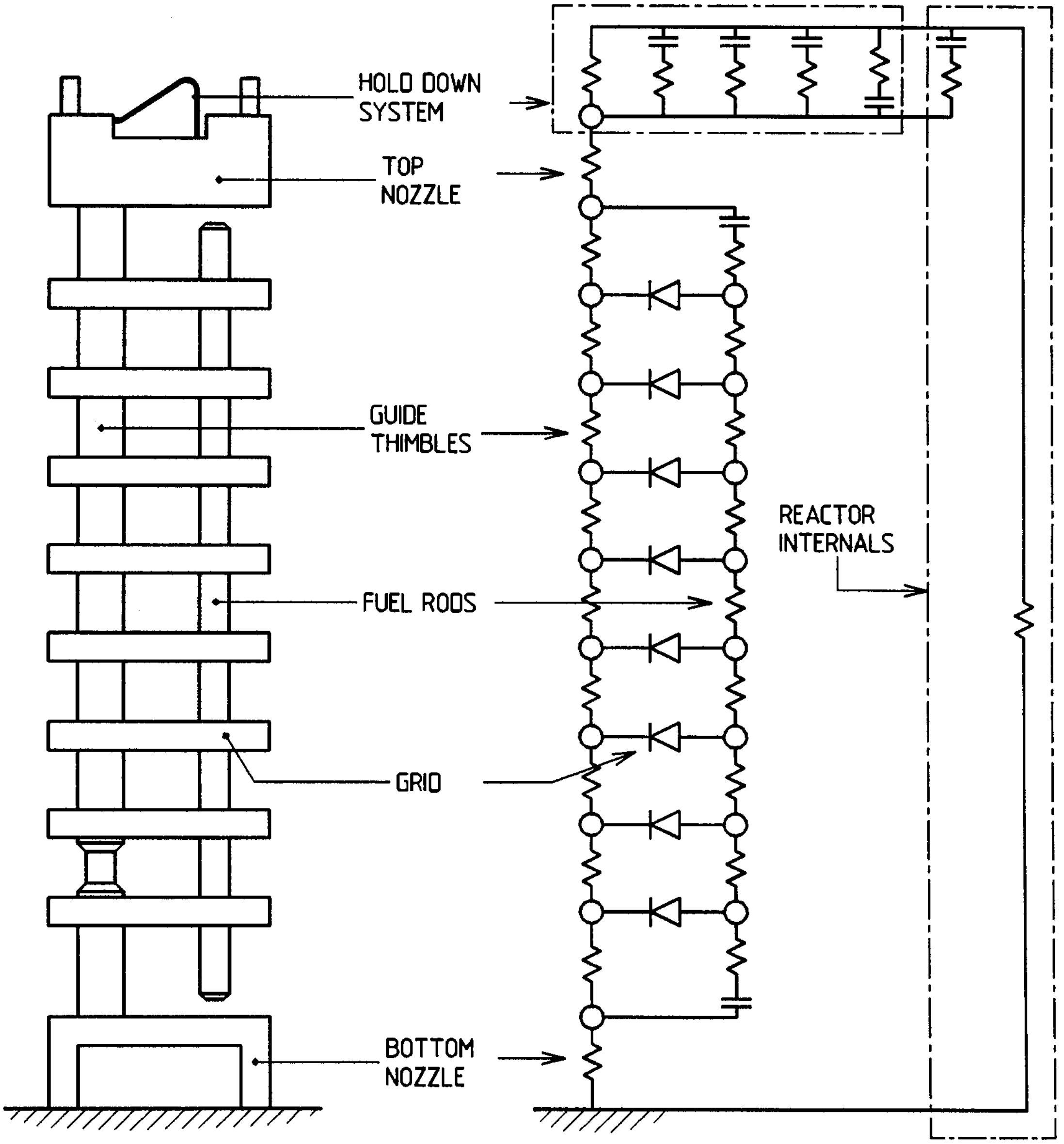

Fig. 1. IN-REACTOR ASSEMBLY AXIAL MODEL

The external forces liable to be exerted on the assembly are the gravity forces, buoyancy force and the hydrodynamic forces ; they are applied to the different nodes of the model.

The transition to hot conditions and return to cold conditions produce :

- variations in the material mechanical properties (Young's modulus), which translate into a change in the stiffness of the spring elements and the sliding element thresholds,
- thermal expansions or contractions, which are input in the form of spring preloads.

Irradiation causes :

- growth of Zircaloy tubes (guide thimbles and rod cladding) modelled in the form :
  $\epsilon = \epsilon\ (\phi_t)$
  where ϵ represents relative tube elongation (in %)
  and ϕ_t represents fluence (in $n.cm^{-2} > 1$ MeV)
- creep of guide thimbles subjected to tensile or compressive stresses modelled by :
  $\epsilon = \epsilon\ (\phi, \sigma, t, T)$
  where ϵ represents relative tube elongation (in %)
  ϕ neutron flux at the guide thimble (in $n.cm^{-2}.s^{-1} > 1$ MeV)
  σ stress (in MPa)
  t time (in hours)
  T temperature (in °C)
- the relaxation of the forces developed by the assembly holddown system and by the grid cell springs, expressed by $R = R\ (\phi_t)$
  where R denotes holddown force relaxation rate
  and ϕ_t denotes fluence at the spring (in $n.cm^{-2} > 1$ MeV)

Like thermal expansion, irradiation-induced elongation is input by means of preloads in the model springs. Relaxation is reflected in a decrease in the holddown system spring gaps and in a drop in the thresholds of the sliding elements representing the grids.

4. RUNNING OF CALCULATIONS

Each of the fuel assembly irradiation cycles consists of the following phases :

- water filling (cycle 1 only),
- vessel closure,
- startup of pumps,
- transition to hot conditions,
- irradiation,
- return to cold conditions,
- stopping of pumps,
- vessel opening.

Table 2 summarizes the loadings or physical phenomena allowed for at each phase.

The irradiation phase is discretized into several steps in order to take into account the interaction of the different non-linear phenomena. At each step, model static analysis is in two stages :

- allowance for guide thimble free growth, fuel rod (and possibly grid cell) irradiation growth, holddown spring and grid spring relaxation and evaluation of guide thimble stresses,
- input of guide thimble creep,

Each phase or calculation step supplies :

- displacements at the nodes, allowing growth in particular to be determined (for example : assembly growth),

- spring gaps (for example : rod - bottom and top nozzle gaps and the nozzle - core plate gap),
- spring forces (for example : guide thimbles and rods).

TABLE 2 : LOADINGS OR PHYSICAL PHENOMENA ALLOWED FOR AT EACH PHASE

	ELEMENTS PHASES	REACTOR INTERNALS	NOZZLES	GUIDE THIMBLES	FUEL RODS	GRIDS	HOLDDOWN SYSTEM
	WATER FILLING		BUOYANCY FORCE				
	VESSEL CLOSURE	ADDITION OF SPRINGS					
	STARTUP OF PUMPS		ADDITION OF HYDRODYNAMIC FORCES				
	TRANSITION TO HOT CONDITIONS	THERMAL EXPANSION VARIATION IN THE MECHANICAL PROPERTIES					
N CYCLES P STEPS	IRRADIATION			FREE GROWTH CREEP	GROWTH	RELAXATION GROWTH	RELAXATION
	RETURN TO COLD CONDITIONS	THERMAL CONTRACTION VARIATION IN THE MECHANICAL PROPERTIES					
	STOPPING OF PUMPS		ELIMINATION OF HYDRODYNAMIC FORCES				
	VESSEL OPENING	ELIMINATION OF SPRINGS					

5. RESULTS

The curve in figure 3 plots the growth of a typical fuel assembly (assembly A) for a residence time of five cycles. Figure 4 shows fuel rod - nozzles gap trends. The assembly measurements at the end of each cycle are indicated on these figures and show good calculation - measurement agreement.

Figure 5 shows the impact on assembly growth of an increase in holddown system forces. The two assemblies A and B are identical, with the exception of holddown system stiffness ; the increase in this stiffness in assembly B limits its growth relative to assembly A.

Lastly, figure 6 shows the growth of an assembly C, identical to assembly B, except for a reduction in the fuel rod restraining force in the grids. The growth kinetics is further reduced.

In both the above cases, the difference lies basically in the change in the creep contribution to guide thimble growth.

6. CONCLUSION

The method used in the CASI software enables the highly non-linear behaviour of a fuel assembly during its in-reactor residence time to be evaluated. It allows the effect of each of the involved physical phenomena to be analyzed.

This method can also be applied to the evaluation of the assembly lateral behaviour, by making use of beam-based lateral structural models. This extension should ultimately provide closer insight into fuel assembly distortion mechanisms.

REFERENCE

/1/ LEROUX, J.C., 1983 - CASAC : A Code Computing the LOCA and Seismic Loading on PWR Fuel Assemblies. SMIRT 7 CHICAGO.

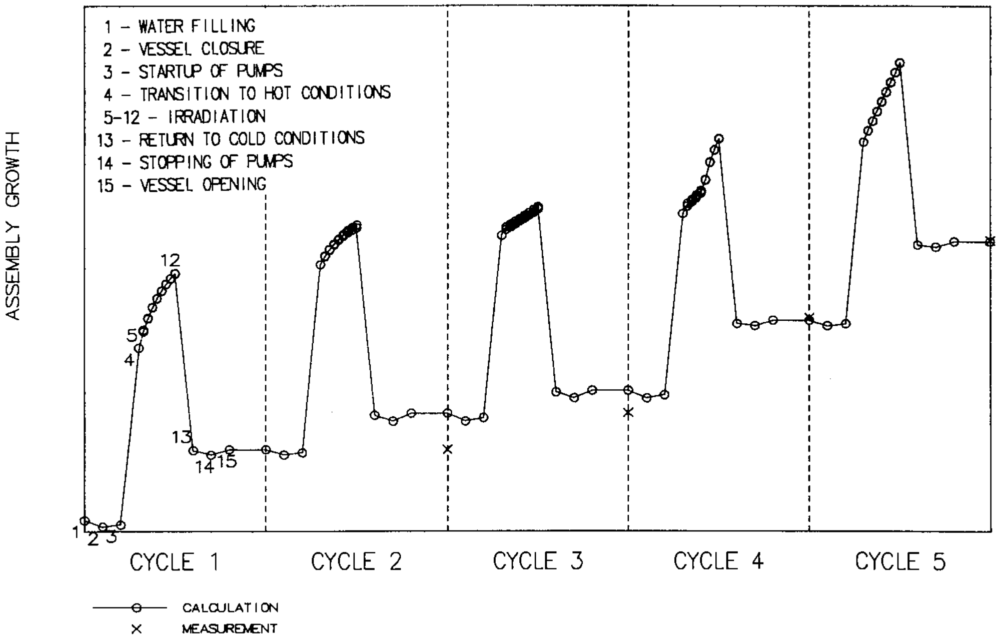

Fig. 3 : GROWTH OF A TYPICAL FUEL ASSEMBLY

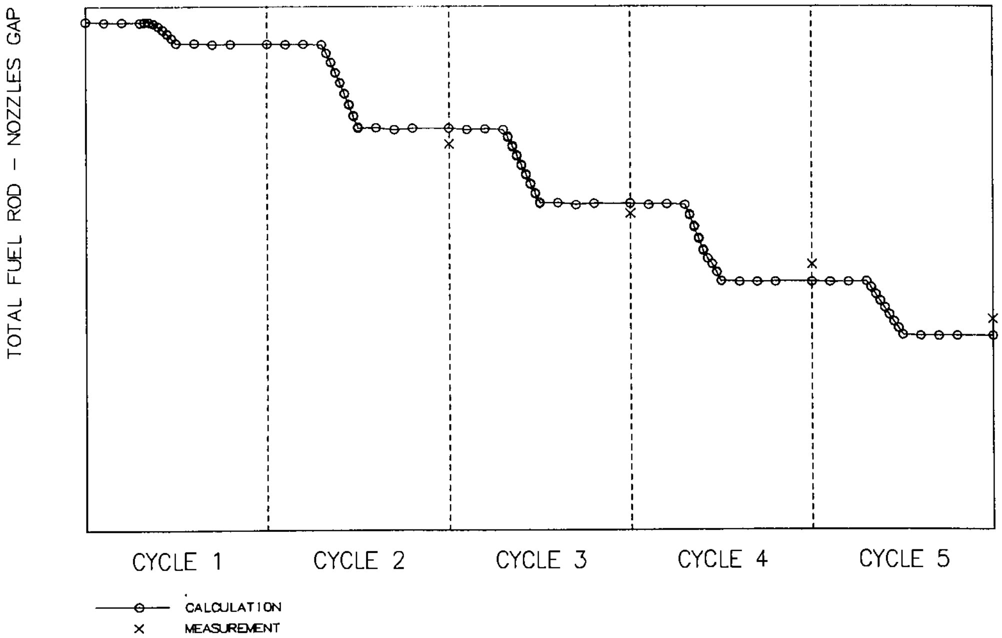

Fig. 4 : FUEL ROD - NOZZLES GAP TREND

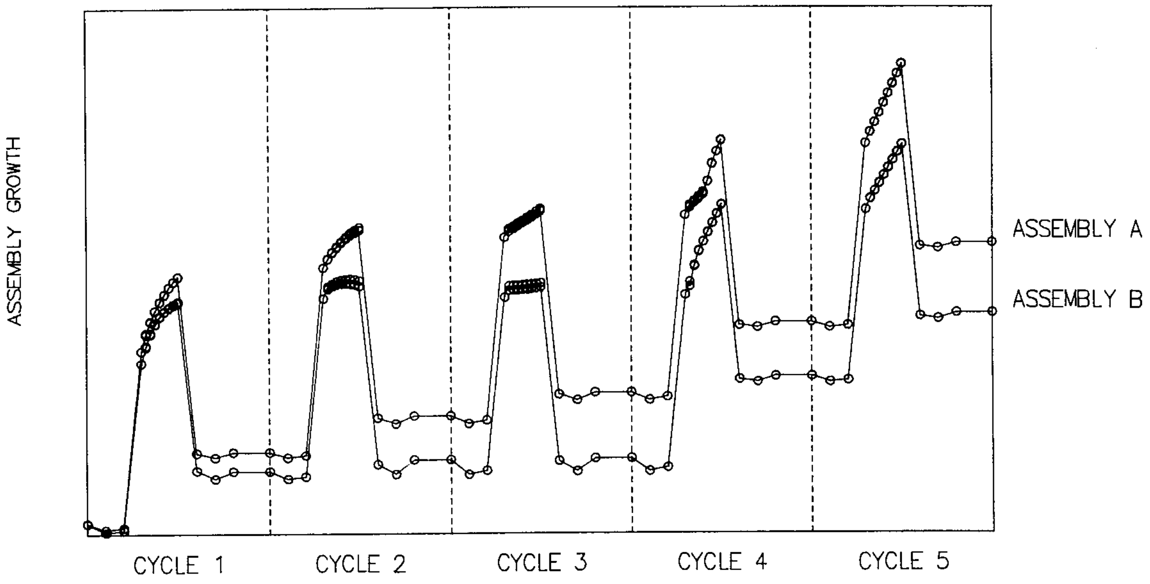

Fig. 5 : IMPACT OF AN INCREASE IN HOLDDOWN SYSTEM FORCES

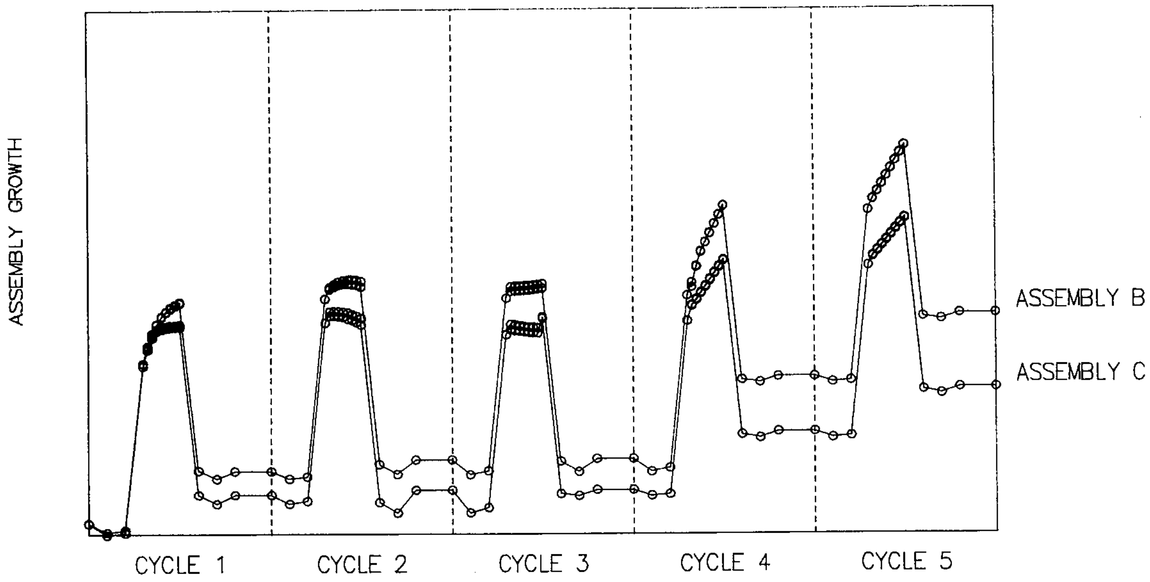

Fig. 6 : IMPACT OF A REDUCTION IN THE FUEL ROD RESTRAINING FORCE