

Analysis of the Loading of the PWR Reactor Control Rod Elements in Operating Conditions

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ABSTRACT

The control of the reactivity of a PWR reactor is obtained by adjusting the concentration of boron contained in the primary coolant and the insertion of the control rods elements.

In the PWR reactor manufactured by FRAMATOME, each control rod element consists of a cluster of 24 control rods. It is driven by an electro-mechanical system located at the reactor vessel head. A set of electromagnets contained in this drive mechanism and sequentially energized enables to insert or withdraw the control rod element in successive discrete steps of 15.9 MM (.625 IN).

With this drive mechanism design, the displacement of control rods element is characterized by high velocities and impact phenomena at end of each displacement step.

A structural model of the control rod element has been developed by FRAGEMA in order to evaluate the efforts resulting from this step by steps motion.

The purpose of the paper is a general presentation of this analysis.

The code CASAC (which is presented in an other paper) is used. This code is optimized for such a dynamic non linear problem.

Tests on drive mechanisms and control rods elements, where displacement and forces have been recorded, enable to adjust some parameters of the model.

Complementary sensitivity studies are performed in order to identify the model parameters which have to be accurately determined.

1 INTRODUCTION

In the PWR reactors the reactivity control is obtained both by modification of the boron concentration in the primary coolant and by adjustment of the insertion of neutron absorber elements (control rods).

The main features of the control rod system are illustrated by the figure 1.

The control rods insertion is kept at a specified level or is modified through the combined actions of two types of latch (stationnary and movable latches) with sequentially grip the control rods grooved shaft (figure 2).

The actions of these latches are obtained by energizing three types of electrical magnets.

The control rods withdrawal is obtained by performing the step 2 through 6 of the sequence defined in table 1.

TABLE 1

Sequence step	Associated functions	Electrical magnets		
		A	B	C
1	Stationnary latch engaged (stationnary state)	YES	NO	NO
2	Movable latch engagement	YES	YES	NO
3	Stationnary latch disengagement	NO	YES	NO
4	Upwards motion of the movable latch and of the coupled control rods	NO	YES	YES
5	Stationnary latch reengagement	YES	YES	YES
6	Movable latch disengagement	YES	NO	YES
7	Return of the movable latch to zero-power state (down position) (end of the upwards elementary sequence and return to the stationnary state)	YES	NO	NO

A : Stationnary latch gripping when energized

B : Movable latch gripping when energized

C : Movable latch in upper position when energized.

To insert the control rods, the order of sequence step is this indicated by table 2.

TABLE 2

Sequence step	Associated functions	Electrical magnets energized		
		A	B	C
1	Stationary latch engaged (stationary state)	YES	NO	NO
2	Upwards motion of the movable latch	YES	NO	YES
3	Movable latch gripping	YES	YES	YES
4	Stationary latch disengaged	NO	YES	YES
5	Downwards motion of the movable latch and of the coupled control rods	NO	YES	NO
6	Stationary latch reengagement	YES	YES	NO
7	Movable latch desengagement (return to the stationary state)	YES	NO	NO

The main advantage of such a driving system is its reliability in the upset operating conditions, where a rapid and safe shutdown of the reactor is required by insertion of the control rods.

In this case, the electrical power on the magnets is automatically shutdown and the control rods drop in the core by gravity.

But in normal operating conditions, this step-by-step system results in significant efforts on the control rods.

These loads are due to the high accelerations produced when gap closures occur at the end of the very rapid motions of the movable latch (its travel over a length of about 15mm is performed in less than one tenth of second).

The more important effects are obtained when the control rods are moved in up direction. In this case an important impulsive force is communicated by the electrical magnet displacing the movable latch.

For the down motion, the impact velocities are only due to the gravity and hence are less. These impact effects result in equivalent static accelerations exceeding 10 g (g = gravity acceleration) on the control rods structure.

And since the control rods are subjected to a large amount of motions steps over their life (more than 10^6), the fatigue is of concern. To verify the control rods design, endurance and fatigue tests are usually performed on full scale prototypes. In these tests, the efforts induced by the step-by-step motions have been also measured.

On the basis of these tests, an analytical model was developed. It enables to perform complementary evaluations of the control rod dynamic behaviour. The paper gives a detailed description of the model and the results of some typical analyses.

II CONTROL ROD ANALYTICAL MODEL

The model shown in figure 3 enables to analyze the control rod motions induced by the movable latch upwards displacements (step 2 through 4 in table 1).

In this model, the following non-linear phenomena are considered :

- closure or opening of gaps at the movable latch travel end,
- closure or opening of the gaps existing between control rod and movable latch,
- motion of the absorber material inside its cladding tube (under step-by-step motion, lift-off of the absorber occurs since the force applied by the spring at the absorber top can not fully balance the high acceleration effects).

A dynamic non-linear analysis is performed on this model by using the CASAC code (this code is presented in another paper).

III ANALYSIS RESULTS

The typical motion of the control rods during an upwards step is given in figure 4.

Two major impacts occur, first when the upwards motion is restrained by interference between the movable latch and the control rod grooved shaft and then when the control rod is again resting on the movable latch.

The damping in the model is adjusted until a good agreement between analytical results and tests measurements are obtained. The parameters then checked are the control rod motion versus time and the maximal forces induced on the control rod elements.

Sensitivity analyses enable to identify the model parameters whose deviations significantly modify the model dynamic response.

The results of these analyses are used :

- to fix the model characteristics which have to be accurately defined,
- to make a prediction of the further behaviour, by taking into account the cumulative operation effects (irradiation effect),
- to investigate control rod design modifications.

The so far available main results are the followings :

a) Absorber spring force influence :

The absorber motion is restrained by a spring located at the control rod top. In operation, a modification of the spring preloaded is expected mainly due to the irradiation effects.

Figure 5 gives the results obtained by modifying this force preload.

b) Effect of a friction phenomenon between absorber and cladding tube :

Initially a diametral clearance is provided between absorber and the cladding tube. So, the absorber motion inside the tube is not restrained. The creep and growth phenomena induced by irradiation can significantly increase the friction effect between the absorber and the cladding.

Figure 6 gives the results obtained when the absorber motion is progressively restrained.

c) Control rod design modification effects :

Various absorbers can be used in the PWR reactors (silver absorber, Hafnium, Boron Carbide). These materials having very different weight densities, absorber substitution would result in a modification of the control rod dynamic characteristics. If absorber change is considered, its incidence on control rods loading have to be evaluated.

On the other hand, improvement of the control rod cladding strength can be obtained by increasing the cladding thickness. But in this case, the control rod stiffness features would be modified and the consequences on the loads in step-by-step motions must be calculated

IV CONCLUSIONS

With the model here presented, the designer can precisely analyse the dynamic behaviour of the control rods.

By using the CASAC code, the computer time and the analysis total duration are minimized, since this code is suitable for the non-linear dynamic analysis.

The model will be improved, as soon as further tests results will be available (tests in progress).

Sensitivity analyses so far performed show that the dynamic loads are only slightly modified during the life of the control rods.

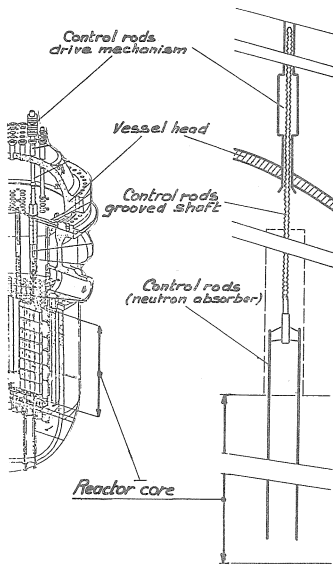
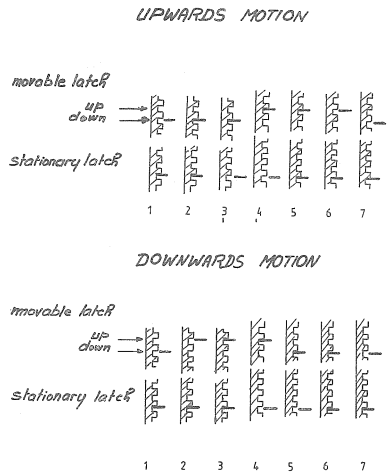


FIGURE 1 : PWR CONTROL ROD SYSTEM



Notes.

- latch engaged
- latch disengaged

FIGURE 2 : MOVABLE AND STATIONARY LATCHES ACTION SEQUENCE

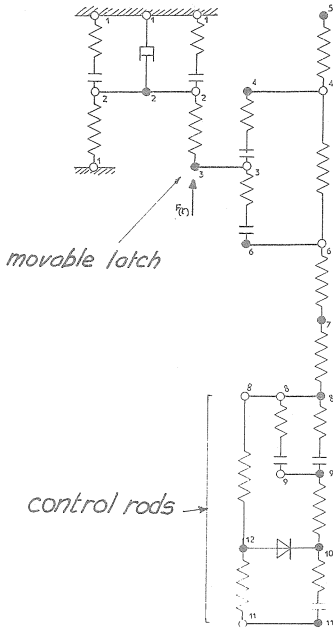


FIGURE 3 : CONTROL ROD MODEL

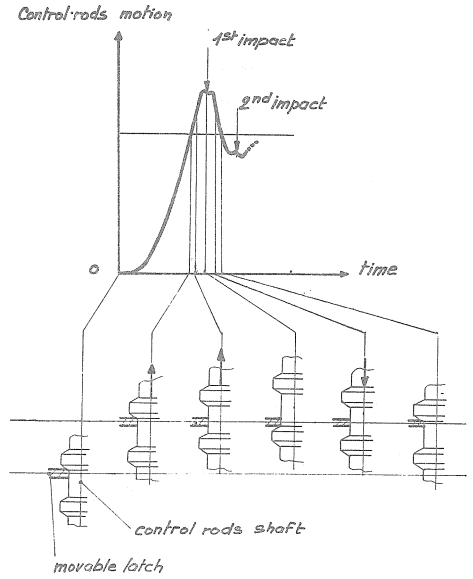


FIGURE 4 : CONTROL ROD ANALYSIS/UPWARDS MOTION/TYPICAL RESULTS

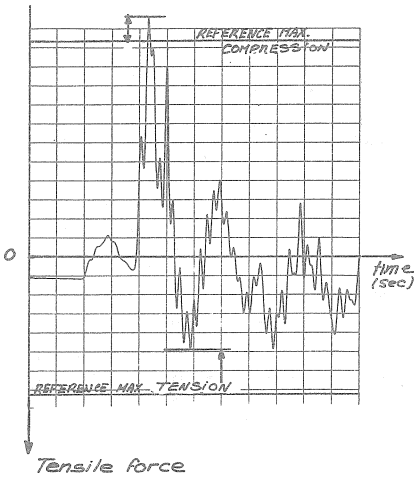


FIGURE 5 : SENSITIVITY ANALYSIS/UPWARDS MOTION/STIFFER ABSORBER SPRING

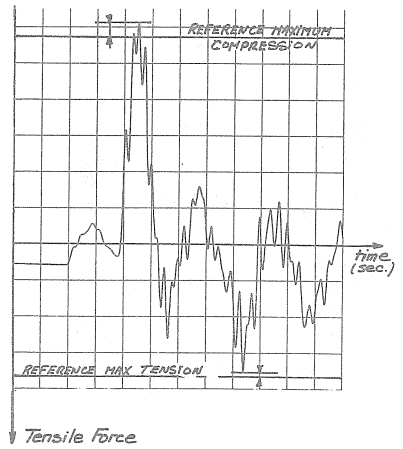


FIGURE 6 : SENSITIVITY ANALYSIS/UPWARDS MOTIONS/ABSORBER FULLY RESTRAINED