Analysis of CR Scrammability Characteristics on the Condition of the Forced Vibration of Fuel Assemblies

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Abstract

In a boiling water reactor (BWR), the reactor shut down capability against earthquake is one of the most important safety criteria. It is required that control rod (CR) should insert rapidly whenever fuel assemblies in core vibrate with any amplitude during any predictive seismic. This capability is called Scrammability.

For the reqirement, we have a program to make sure the CR scrammability by the experiments on the high pressure and the high temperature condition simulate an actual plant, and on the condition which keeps the forced vibration amplitude of fuel assemblies steady state during the CR insertion. From these experiments, we have evaluated the influence of the vessel pressure, the vessel temperature, the amplitude, and frequency of fuel assemblies vibration etc. on the CR scrammability characteristics. These experiments have been carried out for each type of BWR plants.

Also we have another program to research on the CR scrammability characteristics under the condition which is the hole test apparatus vibrate vertical, holizontal, and simultaneous.

The other hand, the analysis code CRIN has been developed by the authors in order to evaluate the CR scrammability characteristics on the condition of the forced vibration of fuel assemblies for various types of BWR plants.

In the analysis code CRIN, the process of the CR insertion is divided into six by each contact cases between CR and fuel assemblies and the deformation of CR guide tube and the clearance between CR and CR guide tube are considered. The CR blade contact position with fuel assemblies is obtained by the insertion method calculation.
The friction force effects on CR is calculated with a function of the amplitude of fuel assemblies and the stroke of CR. And then, using this result , the CR position is calculated every second by solving the equation of CR insert motion.

1. Introduction

We have a program to make sure the CR scrammability by experiments on high pressure and high temperature condition sumulate on actual plant and condition which keeps the forced vibration amplitude of fuel assemblies steady state during the CR insertion. From these experiments, we have evaluated the influence on the CR scrammability characteristics. These experiments have been carried out for each type of BWR plants.

The other hand, the development of fast scram CRD(FSCRD) was taken place. FSCRD is able to insert CR with about double speed than the present CRD. FSCRD will be used in new plants. And also the new long life CR which is made with new material and the new type of CRD which has new driving mechanics are developed.

Then it is important to evaluate analytically the CR scrammability characteristics for the various configulations on the development program. For this need, we have developed the analysis code CRIN(CR INsertion analysis code) on the condition of forced vibration of fuel assemblies.

2. Description of the analysis code CRIN

2.1 Basic Equation

The CR-CRD scram system schematic model is shown in Fig.1.

When the scram valves of the supply line and the withdraw line is opened by the scram signal, the high pressure of accumulator is supplied the lower surface of drive piston and the pressure of the upper surface releases to the pressure of dump tank.

By this pressure difference, CR is inserted in core. When the stroke of CR becomes more than 99 % of full stroke, CR is operated the resistance of the buffer.

Equation of CR scram motion is shown as follows:

$$\frac{W}{g}\ddot{x} + W + F_{fr} + F_b + F_r = A_u P_u - A_0 P_0 - A_r P_r \qquad (1)$$

where
- x : Stroke of CR (vertical position)
- W : Weight of movable part (drive piston, CR, ...)
- g : Acceleration of gravity
- F_{fr} : Frction force
- F_b : Resistance of the buffer
- F_r : Resistance of fluids
- P_u, P_0 : Pressure at the lower surface and the upper serface of the drive piston
- A_u, A_0 : Area of lower surface and upper surface of the drive piston
- P_r : Reactor pressure

$$F_b = \frac{\gamma A_b^3 \dot{x}^2}{2g\, C_b^2 A_c^2(x)} \qquad (2)$$

where

A_b : Area of buffer piston

C_b : Flow coefficient

$A_c(x)$: Cross section of orifice

($A_c(x)$ is a function of CR stroke.)

$$F_r = C_d \frac{\gamma}{2g} S \dot{x}^2 \qquad (3)$$

where Cd: Resistance coefficent of CR velocity limiter

S: Projection area of CR velocity limiter

$$P_u = P_{A0} \left(\frac{V_N}{A_u x + V_N} \right)^{1.4} - C_u \frac{\gamma}{2g} \dot{x}^2 - \frac{\gamma A_u}{g A_{pu}} L_u \ddot{x} \qquad (4)$$

where

P_{A0} : Initial accumulator pressure

V_N : Initial N_2 volume

C_u : Hydraulic resistance coefficient

A_{pu} : Cross section of insert pressure supply line

L_u : Length of scram power supply line

$$P_0 = P_d + C_0 \frac{\gamma}{2g} \dot{x}^2 + \frac{\gamma A_0}{g A_{p0}} L_0 \ddot{x} \qquad (5)$$

where

P_d : Dump tank pressure

C_0 : Flow resistance coefficient

A_{p0} : Cross section of withdraw line

L_0 : Length of withdraw line

2.2 Friction Force

(1) Friction Force : F_{fr}

$$F_{fr} = F_0 + f(x,A) \qquad (6)$$

where

F_0 : Drive piston friction force

$f(x,A)$: CR friction force

A : Amplitude of fuel channels (horizontal amplitude)

The CR friction force is calculated by following assumption; The lateral inertia force of CR is negligible. The deformation of the part of velocity limiter is negligible. The CR guide tube and clearance between CR and CR guide tube is considered. The local deformation of fuel assemblies due to contact with CR is considered.

The process of the CR insertion is divided into six by each contact cases between CR and fuel assemblies (as shown in Fig.2).

[(1) EDGE]: is the condition that the roller of velocity limiter contacts with CR guide tube, CR blade contacts with fuel support casing and the edge of CR top contacts with fuel assemblies. In according with CR insertion from (1) EDGE condition, following conditions are set step by step.

[(2) NOSE BLADE]: is the condition that CR nose blade contacts with fuel assemblies . The upper part of CR blade is named as CR nose.

[(3) ROLLER]: is the condition that rollers of CR nose contact with fuel assemblies.

[(4) BLADE]: is the condition that CR blade contacts with fuel assemblies.

[(5) 4 POINTS]: is the condition that there are four contact points. (the roller of velocity limiter contacts with CR guide tube, CR blade contacts with fuel support casing, and CR blade and the edge of CR top contact with fuel assemblies.)

[(6) 3 POINTS]: is the condition that there are three contact points. (CR blade contacts with fuel support casing, and also CR blade and the edge of CR top contact with fuel assemblies.)

As the CR blade contact position with fuel assemblies is not calculated directly, it is obtained by the iteration method calculation. The friction force could be calculated by the method as shown in Fig.3 for example.

2.3 Flow-Chart of the analysis code "CRIN"

As the CR friction force is calculated with a function of the amplitude of fuel assemblies and the stroke of CR, the CR position is calculated every second by solving the equation of CR insert mortion. Flow - chart of the analysis code CRIN is show in Fig.4 .

3. Experiment

The CR scrammability test apparatus is shown in Fig.5. The special feature of it is capability to make the condition of high pressure and the temperature simulate the actual BWR plant condition during vibration test. In this report, the case of using FSCRD is described. The configulation of core is the newst type in Japan . Especially the special fuel channels are used for vibrating the core model easily on this test, the cross section shapes of which are half of regular channels and used without fuel pins and spacers. We simulate the vibration of fuel assemblies in core by the forced vibration of the modified fuel channels.

The fuel vibration system is shown in Fig.6. In order to prevent the influence of the high pressure, the pressure balance cylinder is adopted in it. The oil vibrater is controlled to steady state amplitude during the DR insertion. The push point is 400mm under the center of channels which length is about 4000mm due to the position of nozzle of pressure vessel.

The other hand, we experimentally investigated the coefficient of dynamic frction between fuel channel and surface of CR blade and between fuel support casing and the surface of CR blade. The average of coefficent on room temperature (20°C) was 0.16 and on high temperature (300°C) was 0.19.

4. Calculated and experimental results

The calculated results on condition that the amplitude of fuel channels is 30mm, the frequency of them is 3Hz, the oprating pressure is 70.7Kg/cm^2 and the operating temperature is 286.0°C are shown in followlng figures; Fig.7(the friction force) , Fig.8(the velocity of CR) , Fig.9 (the stroke of CR)

We calculated the scram time of the 75% stroke of CR about various parameters and compared with experimental results as shown in Fig.10～Fig.14.

Some experimental results could meet very well to the calculated results using the analysis code CRIN. The CR scram time on the condition of high temperture is shorter than the room temterture condition. From Fig.10 , we find that the decrase of Young's modulus influerce to scram time larger than the increase of coeffient of friction. There is no influence of the frequency of fuel assemblies from Fig.13. The influence of gap between fuel assemblies is a little from Fig.14 .

5. Conciution

The detail process of the CR insertion is obtained from this analysis.

Some results from experimental programs could meet very well to the calculated results using the analysis code CRIN. We had found out that there is no influence of the frequency of fuel assemblies and the CR scram time on the condition the high temperature is shorter than on the room temperature condition.

By the analysis code CRIN, it is able to conservatively evaluate the CR seismic scrammability characteristics. This analysis code could be possible to apply to evaluate one of the new type BWR plants.

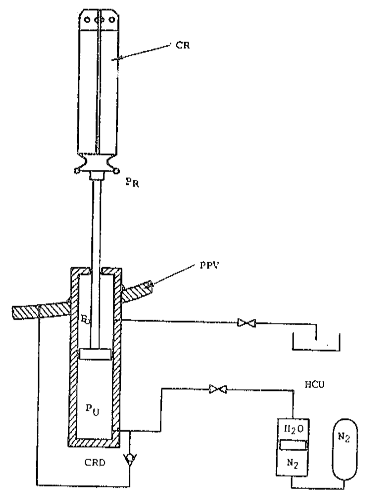

Fig.1 The CR-CRD scram system schematic model

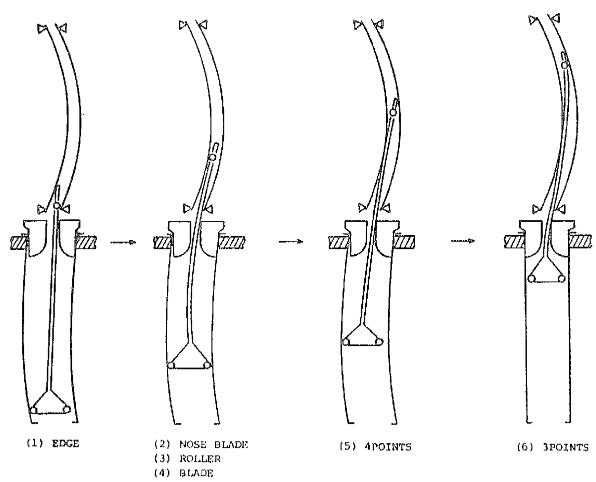

Fig.2 Process of insertion

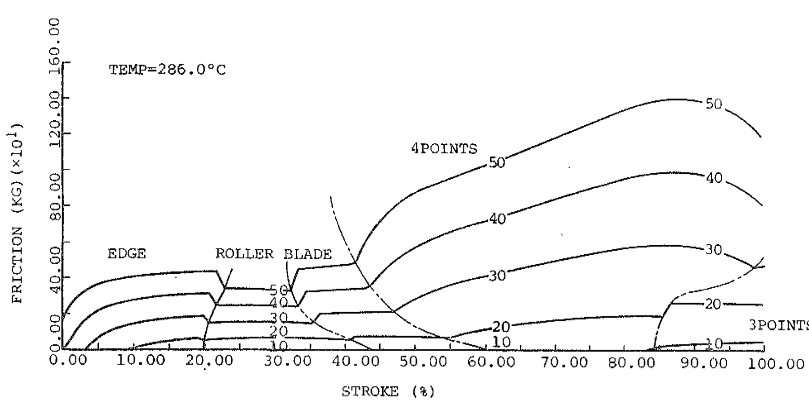

Fig.3 CR friction force

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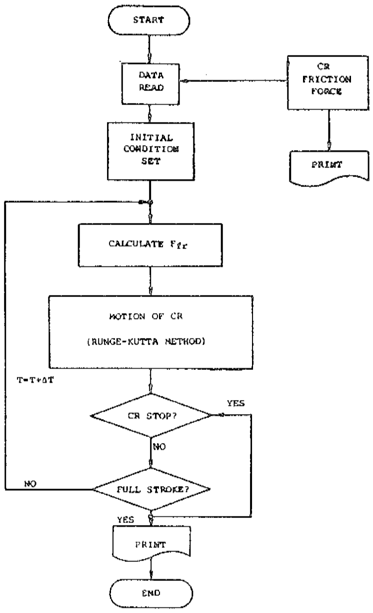

Fig.4 Flow chart

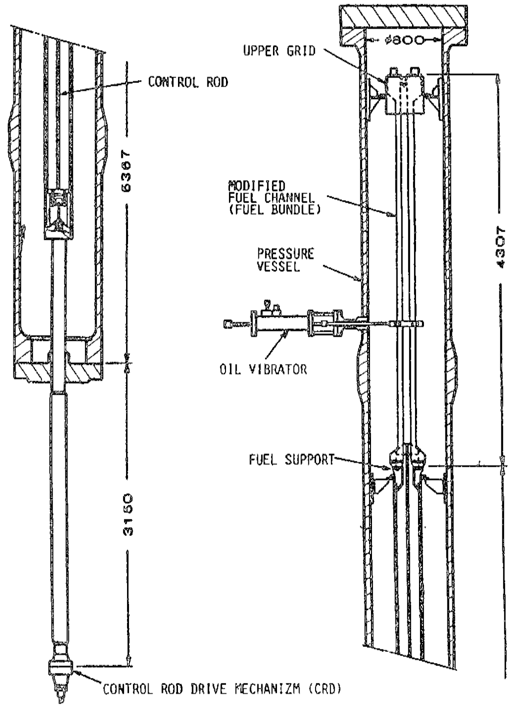

Fig.5 Scrammability test apparatus

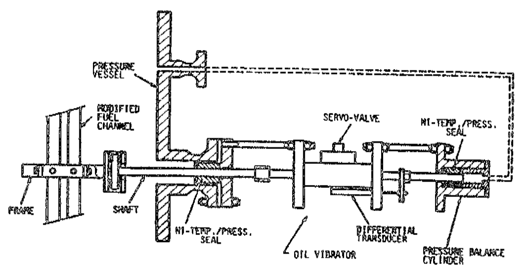

Fig.6 Fuel vibration system

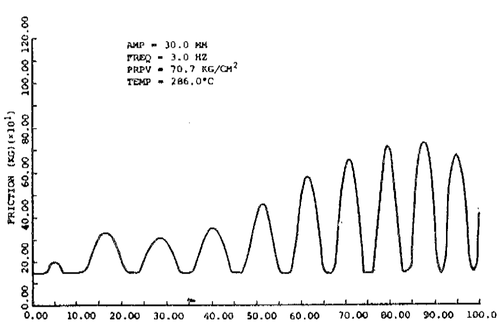

Fig.7 Friction force

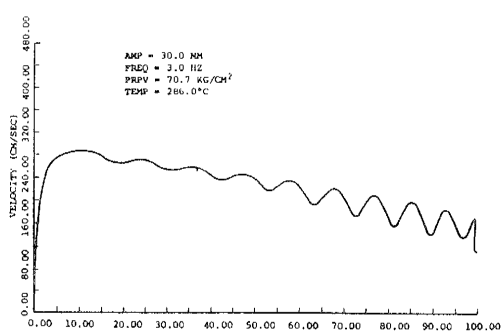

Fig.8 velocity

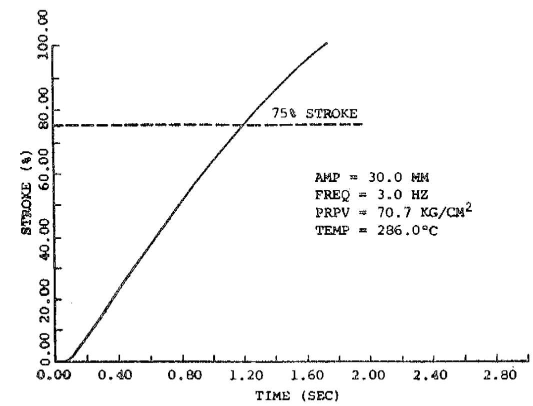

Fig.9 Stroke of CR

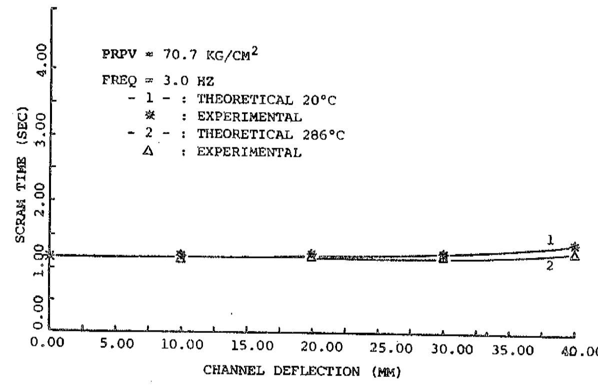

Fig.10 Reactor temperture

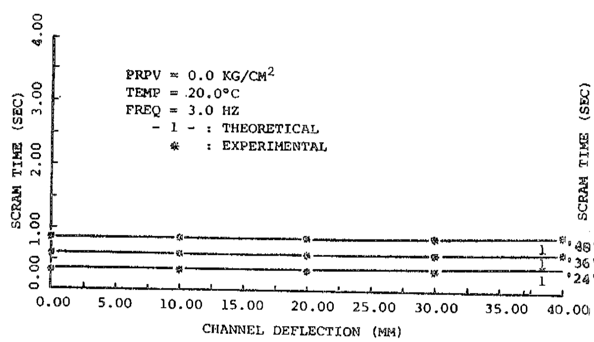

Fig.11 CR initial position

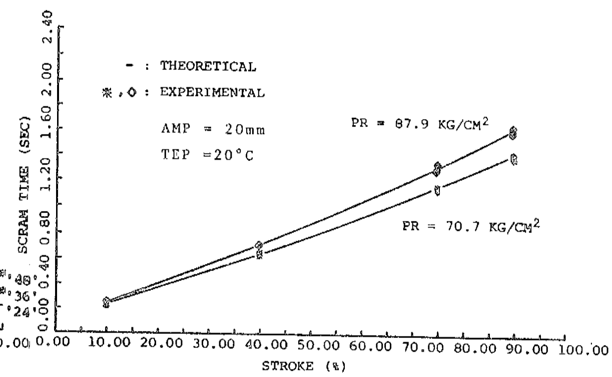

Fig.12 Reactor pressure

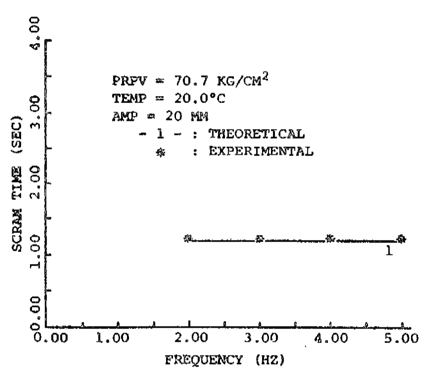

Fig.13 Frequency of fuel assembles

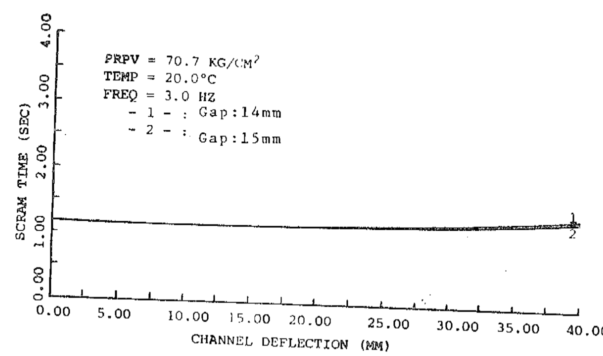

Fig. 14 Gap between fuel assembles