Nuclear Engineering and Design 314 (2017) 11–28

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Dynamic characteristics of immersed plate-type fuel assemblies under seismic excitation

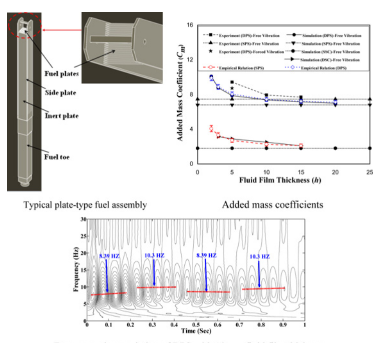
Gaurav Verma [a], M. Eswaran [b,*], Samiran Sengupta [a], G.R. Reddy [c], Shaji Mammen [a]

[a] Research Reactor Design and Project Division, Bhabha Atomic Research Centre, Mumbai, India
[b] Reactor Safety Division, Bhabha Atomic Research Centre & Faculty, Homi Bhabha National Institute, Mumbai, India
[c] Reactor Safety Division, Bhabha Atomic Research Centre & Senior Professor, Homi Bhabha National Institute, Mumbai, India

HIGHLIGHTS

- High flex reactor fuel assemblies' characteristics are studied under seismic load.
- The correlations are developed for plate immersed in water through experiments and verified with simulation.
- Wavelet analysis is performed to distinguish and identify the time variation of liquid and structure frequencies.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 July 2016
Received in revised form 2 January 2017
Accepted 2 January 2017

Keywords:
Plate-type fuel assembly
Fluid film thickness
Added mass coefficient
Damping coefficient

ABSTRACT

The present paper deals with the investigation of plate type fuel assemblies immersed in still water under simulated seismic load. In a typical high flux reactor, plate type fuel assemblies are closely arranged to achieve the high neutron flux. The coolant filled gaps between the fuel assemblies play a significant role in determining and altering its dynamic characteristics. To account the added mass and damping effects posed by the fluid film present in these gaps, a number of experimental and numerical case studies are conducted for a specific range of fluid film thickness for single and double plate systems (SPS and DPS) and square channels. A coupling beat phenomenon has been observed in DPS for a certain range of fluid film thickness. To investigate the beating phenomenon further, wavelet analysis is performed to identify the frequencies in the vibration of submerged plates. It is observed that added mass coefficient (c_m) follows a linear relation while the damping coefficient (c_v) follows a cubic relation with fluid film thickness. It is also found that maximum displacement of the fuel assembly is significantly small than the fluid film gap, as per the present correlations under the seismic load.

1. Introduction

The key characteristic parameters involved when solving coupled-fluid-structure vibration problems are added mass and added damping. These parameters play a major role in characterizing the dynamic behavior of a structure immersed in a fluid. Added mass is the property of the fluid in presence of an oscillating/moving solid. When a solid oscillates or moves in a fluidic medium, the quantity of the fluid directly affected by the motion of the solid imparts additional inertial load (impedance) to the solid (Newman, 1977; Han and Xu, 1996). Added damping, again, is the property of the fluid resulting in faster dissipation of the elastic energy of the vibrating solid. When a structure vibrates in fluid,

* Corresponding author.
E-mail addresses: eswaran@barc.gov.in, eswarm21@gmail.com (M. Eswaran).

http://dx.doi.org/10.1016/j.nucengdes.2017.01.005
0029-5493/

Nomenclature

m	modal mass (kg)
c	modal damping (Ns/m)
k	modal stiffness (N/m)
c_{ad}	added damping (Ns/m)
m_0	structural mass (kg)
m_{ad}	added mass (kg)
ζ	damping ratio
ω_n	circular natural frequency (rad/s)
ω_d	damped circular natural frequency (rad/s)
C_m	added mass coefficient
C_v	added damping coefficient
ρ_l	density of the liquid (kg/m^3)
V	volume of the structure (m^3)
M_s	structural mass matrix
C_s	structural damping matrix
K_s	structural stiffness matrix
F_s	applied load vector
x	nodal displacement vector
DSC	double square channel
$\dot{x}$	nodal velocity vector
$\ddot{x}$	nodal acceleration vector
M_{fs}	mass equivalent matrix at the fluid-structure interface
M_f	fluid mass matrix
C_f	fluid damping matrix
K_{fs}	stiffness equivalent matrix at the fluid-structure interface
K_f	fluid stiffness matrix
d	width of the plate (mm)
h	fluid film thickness (mm)
υ	kinematic viscosity (m^2/s)
DAF	dynamic amplification factor
f	body force (per unit volume)
P	pressure (Pa)
DPS	double plate system
t	time (s)
$\boldsymbol{v}$	flow velocity vector
SPS	single plate system
SSC	single square channel
OP	out-of-phase
IP	in-phase

fluid reaction force on structure increases substantially and can be interpreted as an added mass and a damping contribution to the dynamic response of the component (Wambsganss et al., 1974). Some of the nuclear reactor components are typically immersed in a liquid coolant environment and, also, are often closely spaced such as fuel assemblies in reactor core, spent fuel racks, etc. In these structures, the effect of the liquid coolant in terms of forces and damping must be considered.

A typical high flux reactor employs plate-type fuel assemblies and geometry of a typical plate-type fuel assembly is shown in Fig. 1. In general, the gap between two fuel assemblies is of the order of 3–5 mm approximately to obtain high neutron flux. A typical fuel assembly arrangement is shown in Fig. 2. Since these fuel assemblies are immersed in water, the gaps between these are filled by fluid films. These fluid films are quite significant as it alters dynamic behavior of the fuel assemblies such as frequency, mode shape and damping. The computation of added mass and damping for fuel assemblies is important for the safety of the reactor. Dynamic analyses must be performed on structure components to ensure safety of the reactor and unobstructed functioning during a severe earthquake or other dynamic phenomenon. As stated by Towhata (2008), Vosoughifar and Naderi (2014) and Eswaran et al. (2015) the heavy damages have been reported due to strong earthquakes as evident in Niigata in 1964, Alaska in 1964, Parkfield in 1966, Imperial County in 1979, Coalinga in 1983, Northridge in 1994, and Kocaeli in 1999.

Many researchers developed analytical and experimental methods to determine the dynamic vibration characteristics such as added mass and damping for coupled fluid-plate interaction problems. One of the most important works on estimation of coefficients c_m and c_v on FBR hexagonal fuel assembly undergoing harmonic oscillations was done by Wilson (1991). The author analytically obtained velocity and pressure coefficients for moderate frequencies for a thin gap approximation. Yang and Zhang (1997) deduced added mass and damping for a multi-span rectangular

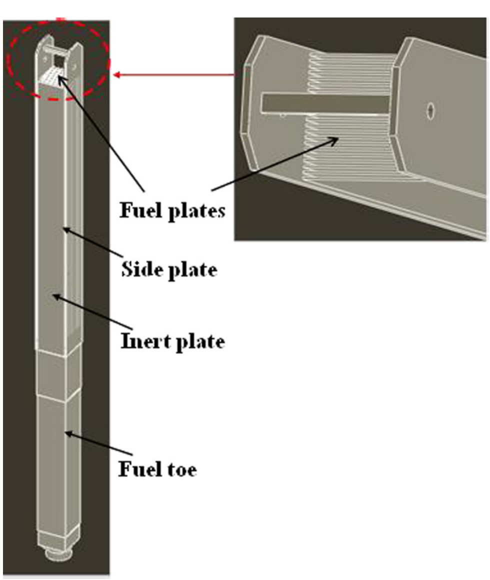


Fig. 1. Typical plate-type fuel assembly.

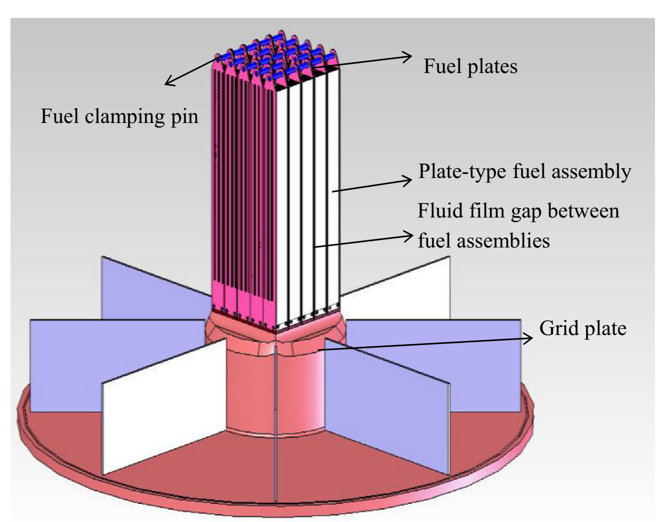


Fig. 2. Typical plenum of research reactor.