Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 199 (2017) 540–545

Procedia Engineering

www.elsevier.com/locate/procedia

X International Conference on Structural Dynamics, EURODYN 2017

Assessment tools for numerical resolution of a contact dynamic problem with modal basis reduction.

T.Catterou[1,3], V.Blanc[1], G. Ricciardi[2], S.Bourgeois[3], B.Cochelin[3]

[1] *CEA Cadarache – DEN/DEC/SESC/LC2I, 13108 Saint Paul lès Durance, France*
[2] *CEA Cadarache – DEN/DTN/STCP/LHC, 13108 Saint Paul lès Durance, France*
[3] *Aix Marseille Univ, CNRS, Centrale Marseille, LMA, Marseille, France*

Abstract

This paper is devoted to the study of the modal basis reduction method in the framework of the dynamical behavior of a mechanical system with multiple joint clearances. The final objective is to estimate contact forces in a confined tube bundle during a dynamic loading for nuclear components sizing. The modal basis reduction combined with an explicit integration scheme is envisioned to deal with the large number of tubes and potential contact zones. In this paper, method is first applied to the example of a clamped-free beam impacting on a spring on its free edge. A semi-analytical resolution allows assessing the validity of the modal basis reduction method depending of some parameters, like frequency truncation and ratio between the bending stiffness and the spring stiffness. This study leads to criteria on numerical parameters which have to be respected to ensure stability and accuracy of results.

Keywords: Dynamic; modal analysis; contact; finite-element.

Nomenclature	
$\boldsymbol{u}(x,t)$: Beam's bending	$\boldsymbol{M},\boldsymbol{C},\boldsymbol{K}$ **:** Mass, damping and stiffness matrices – physical basis
u_0, v_0: Initial displacement and velocity	$\boldsymbol{\Phi}$: Eigenvector matrix
$\boldsymbol{q_i}(t)$: Modal contribution - mode i	$\boldsymbol{\Phi_i}(\boldsymbol{x})$: Mode shape – mode i
Γ: Power spectral density	K_s, K_b : Shock stiffness and damping, Bending stiffness
SR_f: Ratio of contact force integer	R_k : Ratio of shock and bending stiffness. (K_s/K_b)
f_i: frequency – mode i	f_{trunc}: Frequency truncation of numerical computation
ξ_i : Structural damping – mode i	R_{ftrunc}: Ratio of f_{trunc} and first natural mode frequency

1. Introduction

1.1. Contacts in dynamical simulation

Multibody collisions are one of the strongest non-linearity in mechanics. Contact modelling is an ancient topic, which started with works of Hertz in 1882 [1] on the contact between two optical lenses. Many authors have expanded thereafter this theory by introducing friction, tangential force and dynamic effects [2],[3]. But, the numeric implementation of contact condition remains

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the organizing committee of EURODYN 2017.
10.1016/j.proeng.2017.09.154

very complex, whereas it is usually met in industrial context. Impacts occur during very brief time, and cause high forces and accelerations [4]. Standard numerical methods struggle to converge or to remain stable, leading to inaccurate or very slow calculations [5]. Several dedicated integration schemes have been created to solve contact problems, using a time-step cutting [6], energy consistency [7] or high frequency damping [8]. There are two main kinds of integration schemes, implicit ones which require an iterative process minimizing the error, and the explicit ones where the calculation is direct. In most cases, explicit schemes are more relevant to deal with contact issues, because they are faster than implicit ones and remain stable as long as time step is short [5]. But implicit schemes are sometimes used because of their accuracy for contact problem ([9], [10]).

The integration scheme choice and the manner to model contact are linked. Reference [4] summarizes main ways to model contact in structural dynamics; they are two major categories: non-smooth laws for which the contact is instantaneous and the velocity is discontinuous versus smooth laws for which the solids in contact will be able to interpenetrate each other. In non-smooth contact dynamics, a restitution parameter is introduced to model the damping ([11], [12], [13]) but does not allow to estimate contact forces. In smooth contact dynamics, a non-linear force is added to the other loads depending joint clearance between solids in contact [14]. Several formulations of the contact laws can be found in literature [4], from the expression of Hertz [1] until the most complicated formulation of Thornton [13]. These laws have been confronted to solve the Newton's cradle [15]. For now, a linear formulation is considered. Then, a modal basis reduction is used to decrease the size of the model [16] even if it's not commonly done for non-linear problem.

1.2. Industrial issue

In sodium fast reactor (SFR), the fuel is enclosed in pins, composed of slender steel tubes (the sleeve) and a helical spacer wire around the sleeve. (Figure 1-a)

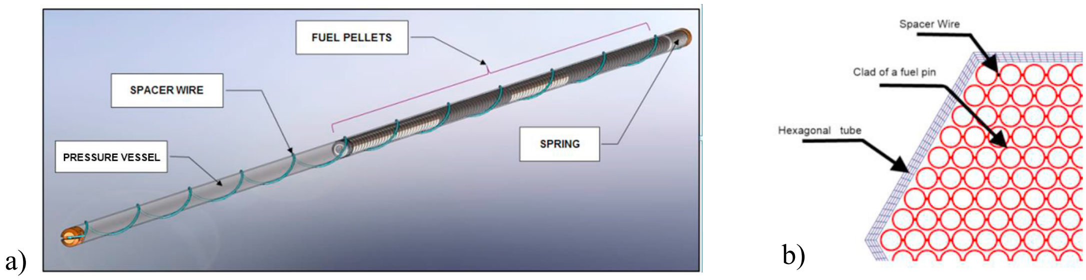

Figure 1 – ASTRID fuel pin (a) and cross section of the pins bundle in its hexagonal tube (b)

Fuel pins are arranged in a bundle enclosed inside a hexagonal tube (Figure 1-b). The whole forms fuel assemblies which are main constituents of the reactor core. During a dynamic load, assemblies impact each other locally on spacer pads. The shock generates acceleration on pins and cause dynamic stresses. At virgin state, clearances are nearly homogeneous in the bundle. During irradiation, clads swell due to thermal and pressure loads and clearances are also modified unevenly. The industrial aim is to develop a calculation methodology to identify contact forces caused by dynamic loads (earthquake, handling or transportation), throughout the life of assembly. Then, a local model will allow assessing maximum stresses in pins and sizing them. All calculations shown in the follow-up have been made with the finite-element software CAST3M [17] for numerical aspects and Scilab for reference computations.

This paper is the first step to simulate dynamic behavior of large structures made of large number of sub-structure in contact with clearance similar to our industrial case. First studies are made on a standard problem presented §**2**, for which semi-analytical results can be established (§**2.2**). Comparisons between analytical results and the modal basis reduction method result are made (§**2.4**) leads to identify the validity domains of the numerical methods with respect to key parameters.

2. Analysis of the numerical method on a simple contact problem

2.1. Presentation of the issue

A simple contact problem is first considered: a cantilever beam initially bent at rest with null velocity and comes to impact on a spring at its free end (Figure 2) which has a stiffness K_s. The initial bent configuration is taken as the first vibration mode. . This case is similar to experiments realized at the CEA on the shock of an assembly filled with a tube bundle on a hard stop. Semi-analytical results are established and will be compared to numerical results obtained with the modal basis projection method.

All results will be observed according to the dimensionless factor R_k, ratio of spring and bending stiffnesses (K_{shock}/K_{bend}), with $K_{bend} = 3EI/L^3$. Numerical application are made for a beam with the following properties: $K_{bend} = 4{,}5.10^5 N/m$, total mass $m = 127kg$.