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A new tube/support impact model for heat exchanger tubes

M.A. Hassan[a,*], D.S. Weaver[b], M.A. Dokainish[b]

[a]Mechanical Engineering Department, University of New Brunswick, Fredericton, Canada E3B 5A3
[b]Department of Mechanical Engineering, McMaster University, Hamilton, Ont., Canada L8S 4L7

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Abstract

Heat exchanger tubes are often loosely supported at intermediate points by plates or flat bars. Flow-induced vibrations result in fretting wear tube damage due to impacting and rubbing of tubes against their supports. Prediction of tube response relies on modelling the nonlinear tube/support interaction. The evaluated response is used to predict the resultant wear damage using experimentally measured wear coefficients. An accurate prediction of impact forces and work rate is therefore paramount. The analytical models available in the open literature generally assume tube/support contact occurs at a single point. In this paper, a computational algorithm is proposed to describe tube/support impact considering a finite support width. The new model provides a means of representing tube/support contact as a combination of edge and segmental contact. The proposed model utilizes a distributed contact stiffness to describe the segmental contact. The formulation also incorporates a stick/slip friction model. The model developed is utilized to simulate the dynamics of loosely supported tubes.

Keywords: Impact; Heat exchangers; Finite elements method; Nonlinear dynamics

1. Introduction

Many industries, such as process and power plants, utilize high thermal efficiency shell and tube heat exchanger designs. Performance requirements often dictate high coolant velocities and flexible tubes, which in turn may cause tubes to experience excessive flow-induced vibrations. A great deal of research has been devoted to flow-induced vibrations due to their practical significance (Païdoussis, 1982; Chen, 1991; Weaver et al., 2000; Pettigrew and Taylor, 2003). These research efforts have led to many improvements in understanding the mechanisms of flow-induced vibrations.

Parameters that affect tube wear can be measured during wear tests. In practical cases, however, analytical techniques are necessary to estimate these effects from flow and vibration information. These techniques mainly utilize the nonlinear time-domain simulation of tube dynamics via the finite element method. This includes modelling the tube/support contact and friction forces. Modelling contact, in general, is a complex task due to the unknown contact interface and friction conditions. The solution of such problems involves complex searching algorithms and iterative procedures. However, such a general approach is not feasible in a flow-induced vibrations study in which large time

*Corresponding author.
E-mail address: hassanm@unb.ca (M.A. Hassan).

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records are required to obtain meaningful response average parameters. In such cases, the nonlinearity is localized and the contact region is reasonably defined. Based on this fact, several codes, such as VIBIC (Rogers and Pick, 1977; Fisher et al., 1989), H3DMAP (Sauvé and Teper, 1987; Morandin and Sauvé, 1999), GERBOISE (Axisa et al., 1988) and INDAP (Hassan et al., 2002, 2003) have been developed to simulate tube/support interaction. These codes have been utilized in the analysis of multispan tubes under simulated fluid forces and have yielded reasonable response and impact force results. The tube/support interaction models available in the open literature generally treat impact by introducing a spring at the support node. This greatly simplifies the modelling and results in a very efficient algorithm. Therefore, the support node is the only node that has to be monitored. In other words, the support is assumed to be a knife-edge type of support. However, in reality the support has a finite width which may not be well simulated using the traditional model because this model permits the tube to overlap with the support along the support width, as long as the contact node is within the support space. In addition, it is not possible to investigate the local distribution of contact pressure or the effect of the support width on tube dynamics and wear. Most of the published models make these kinds of assumptions. One approach to overcome this deficiency is to perform tube/support interaction computations by defining complex finite-length support geometries in terms of several contact locations along the support width. The single-point impact algorithm must be applied at each support a number of times (equal to the number of contact nodes per support). In addition, in the presence of significant axial motion (for example, in-plane motion in a U-bend tube) the algorithm may fail to handle some of the designated contact nodes being moved out of the support space.

This paper addresses the above shortcomings of the traditional formulations. This is accomplished by introducing an enhanced tube/support interaction model which recognises the effect of the support width. A brief review of the development of this model and its appropriateness is presented. For the most part, this paper is restricted to analysing lattice-bar supports. However, the same model can be applied to any other support types.

2. New tube/support contact model

There are several classifications of tube motion within a heat exchanger. Tube motion may be classified as impact, sliding, or combined impact and sliding (Ko, 1985; Kim et al., 1988). The existence of any of these motion types depends on the support geometry, the excitation level and the tube-to-support clearance. For example, when the preload is large enough to prevent tube/support separation, tube motion is basically the classical sliding type. On the other hand, when the clearance is large with a small preload, intermittent contact occurs. The tube/support contact configuration may change with the heat exchanger operating conditions. Tube/support interaction may also be categorized based on the type of contact. This is illustrated in Fig. 1 and includes two main types

(i) tube/support contact at the support edge (point contact);
(ii) tube/support contact over a line (segment contact).

The tube/support contact configuration may be a combination of the afore-mentioned components. The contribution of each of these components depends on the preload, support alignment, and tube-to-support radial clearance. Another classification categorizes the tube motion at the support location as rocking motion (point contact), and tube vibration with anti-nodes at the supports [segment contact (Kim et al., 1988)].

Traditionally, tube/support contact is modelled by introducing an equivalent contact stiffness at the support node. In such a model, the displacement of the contact node is monitored and impact takes place when the normal component of the displacements exceeds the radial clearance. As a result, if the radial clearance is small, the support provides a knife-edge type of support (Fig. 2). This model will be referred to herein as a single-point contact model (SPCM).

In the current work an attempt is made to model the tube/support contact in more accurate detail. In this section, the new formulation of the two contact configurations (edge and segment contact) will be presented separately. Within the finite element solution, however, they have been computed simultaneously.

2.1. Edge contact model

A generalized edge contact model is developed to model the situation in which the tube contacts the support at the edge (point contact). This situation is shown in Fig. 3 and is characterized by an overlap between the line connecting the principal contact node (PCN) (A), the neighbouring contact node (NCN) (E), and the support. This type of contact cannot be detected or modelled using the SPCM since the PCN (A) lies within the support clearance.