International Journal of Mechanical Sciences 88 (2014) 162–174

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

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

Dynamics of telescopic cranes with flexible structural components

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ARTICLE INFO

Article history:
Received 12 March 2014
Received in revised form
30 June 2014
Accepted 26 July 2014
Available online 12 August 2014

Keywords:
Crane flexible components
Time domain analysis
Fast Fourier transformation
Window function
Frequency domain analysis
Finite element method

ABSTRACT

Today's crane numerical models are devoid of some of the simplifications that were used in the past. These changes primarily take into account flexibilities of those structural components that used to be treated as non-deformable. Consequently, various studies analyse the same working movements based on different models.

The paper presents ten variants of a computational model for a telescopic boom crane that differs in number and selection of flexible components. It has been analysed how the above-mentioned differences affect the correctness of mapping the dynamic properties of real structures via their computational models. Modelling and numerical simulations were conducted using the finite element method. The compatibility of the numerical simulation results and test results of a real structure was qualitatively and quantitatively assessed. Time characteristics and frequency characteristics after application of the discrete Fourier transformation were analysed. The analyses showed that the parameters of the modified components should be determined by taking into account their interactions with their surroundings in order to ensure correctness of the solutions. A comparison of the shape and position of spectral lines with respect to changes in the overall flexibility of the models facilitates in deciding which components should be modified and which should be omitted in order to correctly imitate the dynamic properties of a real structure.

1. Introduction

Cranes with telescopic booms are dynamic systems in which individual components may experience significant displacements, both linear and angular, and which may be subject to deformations. These displacements and deformations result from working movements, the method of transferring loads and from the design solutions that are adopted. The complexity of design solutions causes a number of problems that occur during crane operation. These problems are primarily connected with the need to ensure safety and with adequate precision of load movements.

Crane operators are assisted, sometimes even replaced, by automation systems in order to reduce the number of problems as described above. However, applying automation systems requires accurate diagnosis of the phenomena occurring during crane operation. Numerical analysis is the primary tool that is used for this purpose. Numerical models of cranes are devoid of some of the simplifications that were used in the past. These changes were implemented to improve the accuracy of mapping the dynamic properties of real structures and their primary aim was to take into account the flexibilities of those structural components that used to be treated as non-deformable.

As a result of these changes, in various studies the same working movements are analysed based on different models. Sample configurations of computational models, according to the selection of components considered as flexible or non-deformable, are shown in the Tables. Two-dimensional models (2D) which are used to analyse for lifting and lowering of a load and changes in a crane radius are presented in Table 1. Three-dimensional models (3D) used to analyse load lifting and lowering, crane radius changes, rotation of the body and of the movement sequences are summarised in Table 2.

The information in Table 1 shows that configurations which contain three flexible components [1–3] are most commonly used in 2D crane models. Structural components most often considered as flexible are the boom [1–5] as well as the outriggers and the hoisting rope system [1,2,4].

Three flexible components are also frequently used in 3D models [6] (a version of the model used to analyse the rotation of the body), [7,8] (a simplified version of the model), [9–11]. A comparison of these models is shown in Table 2. Flexible components most frequently taken into consideration in 3D models are

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http://dx.doi.org/10.1016/j.ijmecsci.2014.07.009
0020-7403/

the outriggers [6–8,10–16], the boom [6–10,12–14,17] and the hoisting rope system [6–8,10–12,14,15,18].

A comparison of the 2D models shows that differences in the selection of flexible components were present in four out of five cases in the papers that were reviewed. However, in 3D models of cranes with telescopic booms, differences in the selection of flexible components appeared ten times in the thirteen papers that were reviewed.

Unfortunately, changes in the selection of flexible components were most frequently made without verification of the models. Among the reviewed papers, a comparison of the results of numerical analyses and the test results of real structures was carried out only in two cases [5,13]. However, in [11,19,20] the comparison was performed with respect to the research results of crane laboratory models.

Yet the author was not able to find a paper that would explain whether computational models properly map the dynamic properties of real structures regardless of the number and selection of flexible components. Therefore, it was decided to check the influence of changing the number and selection of flexible components in a computational model on the compatibility of the numerical analyses results with regard to a real object. It was also decided to determine whether knowledge about the stiffness of the elements allows to modify their number without the need for model verification.

In order to achieve this aim, a numerically efficient and at the same time universal 3D crane model was developed using the finite element method (FEM). The computational model was developed based on the documentation of a hydraulic truck crane with a three-member telescopic boom. Many model variants with a different number of flexible components were considered. A qualitative and quantitative assessment was made of the compatibility of the calculation results and test results of the real structure.

Table 1
Flexible and non-deformable components of telescopic cranes in 2D models.

F – flexible component	Type of analysed motion					
N – non-deformable component	Lifting and lowering			Changing the crane radius		
Reference Structural component	[4]	[1]	[2]	[4]	[3]	[5]
Outriggers	**F**	**F**	**F**	**F**	–	–
Support frame	N	N	N	N	–	–
Boom support system	N	–	–	N	–	–
Luffing hydraulic cylinder	**F**	–	–	**F**	**F**	N
Telescopic boom	**F**	$\mathbf{F_1}$	$\mathbf{F_1}$	**F**	**F**	**F**
Slide blocks	–	–	–	–	**F**	–
Rope system	**F**	**F**	**F**	**F**	–	N
Winch drive	N	N	N	N	N	N

F_1 – Non-deformable boom is connected to the support frame through a torsion spring of properly selected substitute stiffness.

2. Telescopic crane model

2.1. Model building

The computational model was developed based on the design of a hydraulic truck crane, the HYDROS T-161, with a three-member telescopic boom and a displaced axis of rotation (Fig. 1(a)). Building of the model was preceded by a detailed analysis of the design documentation. Relationships between the structure components were determined and components that were either important or unimportant from the point of view of the assumed objective were singled out. Then a decision was made about the assumptions simplifying the real structure.

First, the possibility of omitting deformations of selected components and of taking into account deformations of the outriggers, the boom and the hoisting rope were taken into account. The same assumption was made for the luffing hydraulic cylinder and the telescopic mechanism, i.e. a hydraulic cylinder and a rope system (i.e. the components that were rarely taken into account in computational models). Moreover, the model included the possibility of analysis of element deformations of the boom support mechanism, i.e. the slide brackets of the slewing platform and connecting links.

Other assumptions were chosen so as to allow for the best representation of the dynamic properties of a real crane. Thus, the masses of most of the components mounted on the boom were taken into account (including, among others, slide blocks, rope

Table 2
Flexible and non-deformable components of telescopic cranes in 3D models.

F – flexible component	Type of analysed motion																			
N – non-deformable component	Lifting and lowering					Changing the crane radius					Rotation							Sequence of movements		
Reference Structural component	[6]	[12]	[7]	[13]	[14]	[15]	[12]	[17]	[14]	[8]	[9]	[6]	[12]	[10]	[13]	[14]	[11]	[12]	[16]	[18]
Outriggers	**F**	**F**	**F**	**F**	**F**	**F**	**F**	N	**F**	$\mathbf{F_3}$	–	**F**	**F**	**F**	**F**	**F**	$\mathbf{F_4}$	**F**	**F**	N
Support frame	N	N	N	**F**	N	N	N	N	N	N	N	N	N	N	**F**	N	N	N	N	N
Slewing bearing	–	–	–	**F**	–	–	–	–	–	–	–	–	–	–	**F**	–	–	–	–	–
Slewing platform	N	N	N	N	N	N	N	N	N	–	N	N	N	N	N	N	N	N	N	N
Boom support system	N	N	–	–	N	–	N	–	N	–	–	N	N	–	–	N	–	N	–	–
Luffing hydraulic cylinder	**F**	**F**	–	**F**	**F**	–	**F**	**F**	**F**	N	N	**F**	**F**	–	**F**	**F**	N	**F**	N	N
Telescopic boom	**F**	**F**	$\mathbf{F_1}$	**F**	**F**	N	**F**	**F**	**F**	$\mathbf{F_2}$	**F**	**F**	**F**	$\mathbf{F_1}$	**F**	**F**	N	**F**	N	N
Slide blocks	–	–	–	–	–	–	–	–	–	–	**F**	–	–	–	–	–	–	–	–	–
Rope system	**F**	**F**	**F**	N	**F**	**F**	**F**	N	**F**	**F**	N	**F**	**F**	**F**	N	**F**	**F**	**F**	N	**F**
Winch drive	N	N	N	N	**F**	N	N	N	**F**	N	–	N	N	N	N	**F**	N	N	N	N
Rotation drive	N	N	–	N	**F**	N	N	N	**F**	–	**F**	N	N	N	N	**F**	**F**	N	N	N

F_1 – Non-deformable boom is connected to the support frame through a torsion spring of properly selected substitute stiffness.
F_2 – Non-deformable boom is supported flexibly by a spring placed along the luffing cylinder.
F_3 – Outrigger flexibility is taken into account only in the vertical direction.
F_4 – Outrigger flexibility is taken into account only in the horizontal plane.