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Stress analysis in contact zone between the segments of telescopic booms of hydraulic truck cranes

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ABSTRACT

This paper presents the analysis of local stress increases at the contact zone between the inner and outer segments of telescopic booms of truck cranes. A portion with a relevant length was singled out of the outer segment and a mathematical model was created describing its stress–strain state as a function of geometrical parameters. The obtained results were verified by the finite element method as well as by experimental testing of the truck crane TD-6/8. Comparison of results revealed high compliance between the analytical model and the results obtained by the finite element method and experimental testing, which confirmed all the hypotheses. The presented methodology as well as the verified analytical expressions give guidelines for optimum design of box-like telescopic segments and other structures with local stress increase in contact zone.

1. Introduction

The most important element for payload lifting and transport by telescopic hydraulic truck cranes is the boom. The telescopic boom consists of segments that retract or extend during operation. By changing its position in space, the boom of the truck crane transfers load onto the substructure of the crane and the vehicle and represents its most responsible part. Reduction of dead weight of the boom opens the possibility for increasing the payload, the lifting speed as well as the speed of retraction and extension of the segments.

In recent years, world manufacturers of truck cranes have been assigning great importance to the determination of an optimum form of the boom cross section, which would provide an increase in bending and torsional stiffness along with the reduction of mass. However, during overhaul and regular checks of telescopic booms of truck cranes, certain deformations and damages in the characteristic zone of boom segments have been noticed. That characteristic zone is located at the contact zone between the inner and outer segments when the inner segment is extended to the maximum position. This fact indicates that stresses at those zones are considerably higher than the stresses along the boom segment. Determination of values of those stresses is the subject of this paper.

Two model types of telescopic booms of the truck crane can be found in literature: mathematical models of the entire boom and mathematical models of interaction in contact zones between segments, which is the subject of this research, too.

Papers [1,2] pay special attention to the contact zones between the segments as well as the connection between the first (outer) telescope segment and the hydrocylinder. These models consist of the corresponding equivalent masses and springs, where [1] considers the boom with two telescopic segments, while [2] has three telescopic segments and a modal analysis done.

Paper [3] points out the importance of contact zones between the segments as well as the change of stresses at those points for various boom crane designs. The model which covers the influence of sliding and the inner telescope extended length at different elevation angles of the boom is presented in paper [4]. The location of sliding contacts in relation to the outer and inner telescope segment is particularly emphasized. The paper [5] analyzed the influence of the extension length on loads distribution through sliding contacts along the boom. Paper [6] analyzes the problem of contacts between box-like segments of the telescopic truck crane by using the software package ANSYS, with the presentation of the load transfer problem and buckling shapes. The mentioned papers examine interaction between the segments and load transfer from the inner telescope segment to the outer

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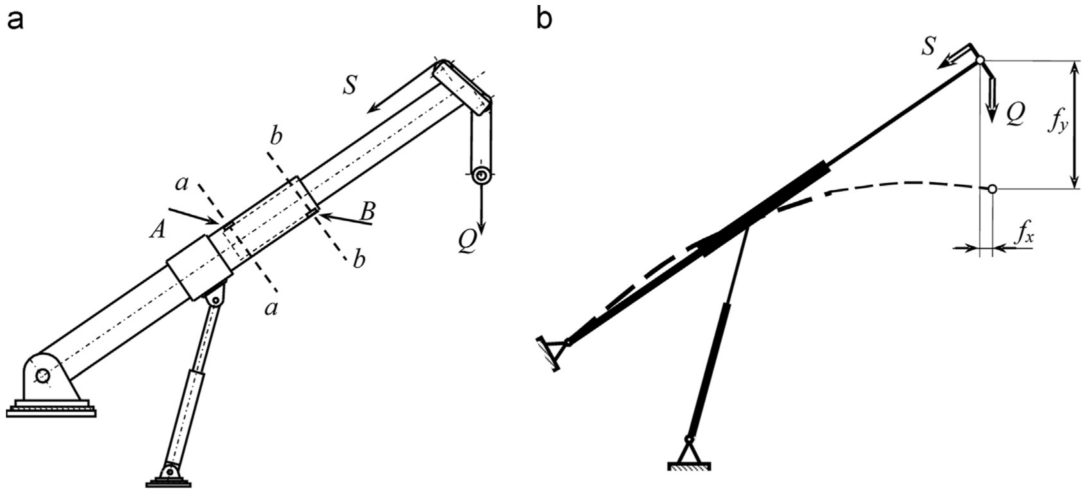

Fig. 1. Model of truck crane telescopic boom: (a) generalized, (b) simplified.

one. The generalized model of the telescopic truck crane (Fig. 1) is frequently considered by a large number of authors.

Paper [7] presents the mathematical model of the truck crane that defines the control mode for reducing the oscillations of the system. It shows the global model of the boom and does not take into account the influence of load transfer between the segments. Paper [8] also presents a mathematical model of the truck crane, which defines the way for reducing the oscillations and precise positioning of payload. Paper [9] gives another mathematical model of the truck crane and defines the influence of lifting the boom by a hydro cylinder on dynamic reactions. Minimization of forces values in the hydro cylinders as well as their control while lifting and transporting the payload in the working position are presented in paper [10]. Similar problems are discussed in paper [11], where the accent is put on restricting the lifting load for the purpose of safe crane operation. Paper [12]considers the influence of different parameters on motion of the payload and structure load. The influence of hydraulic drive system as well as the manner of its control on dynamic behavior of truck cranes is the subject of paper [13]. Paper [14] presents a dynamic model of truck crane emphasizing the control of change of the telescope length, change of the angle of inclination and rotation of the boom. The influence of flexibility of soil on dynamic stability of the truck crane as well as on positioning of payload during rotation is presented in paper [15]. Dynamic stability of a laboratory model of a truck crane was examined in paper [16]. The model presented in this paper enables determination of load conditions and geometrical characteristics at which there may occur a loss of stability. The paper [17] analysed dynamic stability of truck crane depending on the angular ball bearing deformation at connection between the substructure and superstructure through dynamic model with five degrees of freedom. A discrete model of truck crane and examination of oscillations while lifting the payload, depending on the length and the angle of inclination of the boom, are presented in paper [18]. Minimisation of load in relation to oscillation while lifting the payload and rotation of the boom was presented in paper [19].

Papers [20,21] also present modelling and simulation of a truck crane as a complex model which takes into account all motions (load lifting, extension of the telescope, rotation of the boom without damping) using the Bond Graph method. Experimental testing and simulations were performed for the actual model and the correctness of the created model was confirmed. Paper [22] puts a special accent, in operation of cranes with the boom, on the influence of wind, which is often neglected although it is very important for the global stability of the crane in operation.

Paper [23] presents the manner of decreasing the load at the tip of the boom by reducing payload pendulations, i.e. excitation at the tip of the boom, by using two-dimensional and three-dimensional models. It is shown that significant reduction can be accomplished by appropriate selection of cable speeds and length.

Analysis of load transfer from the inner telescope segment to the outer one is very important because it is the zone with the highest stress values. This is also a conclusion of many investigations conducted not only on cranes but on other structures as well. The conclusions obtained in those investigations are important for the hypotheses and creation of the model presented in this paper. The results in [24–33] show the approaches in modelling and influence of local stresses at the contact zones of various types of beams. Also, they underline the importance of defining maximum loads that will not cause any plastic deformations of the beams and, hence, will not endanger the functionality of the object.

The generalized and simplified models of truck crane telescopic boom are presented in Fig. 1, with marked contact zones between the inner and outer segments of the telescope (lines *a*–*a* and *b*–*b*).

2. Definition of analytical model

During payload lifting, load is transferred from the inner movable segment to the outer segment through the corresponding sliding pads, Fig. 2. The sliding pads are placed at the front end of the outer segment and at the rear end of the inner segment. Therefore, the sliding pads placed at the outer segment are treated as stationary, while the sliding pads placed at the inner segment are treated as movable. Taking into account that the segment is considerably longer than the sliding pad, this paper starts with the assumption that the load from the inner segment sliding pad is transferred to the outer segment as continuously distributed load of a constant value (Fig. 3).

As the inner segment moves, position of the sliding pads changes in relation to the front end of the outer segment (coordinate *x*-Fig. 3). Therefore, the absolute value of continuous load changes with the change of the coordinate *x*. Still, remains constant on the sliding pads surface.

This paper considers the influence of local bending of the outer segment during load transfer. To make a successful research of the local stress increase due to contact load, the paper introduces the following assumptions: