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Optimization of the box section of the main girder of the single-girder bridge crane by applying biologically inspired algorithms

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ABSTRACT

The paper considers the problem of optimization of the box section of the main girder of the single-girder bridge crane. Reduction of the girder mass is set as the objective function. The constraint functions are the criteria of strength, local stability of plates, lateral stability of the girder, stiffness, dynamic stiffness, as well the constraints of cost effective design. Methods of the following biologically inspired algorithms were used for the optimization: Firefly Algorithm (FA), Bat Algorithm (BA) and Cuckoo Search algorithm (CS). The obtained results of optimization were compared with several solutions of single-girder bridge cranes, which verified the optimization method. The paper presents the advantages and weaknesses of the methods applied to the concrete solutions of single-girder bridge cranes.

1. Introduction

Single-girder bridge cranes are widely applied in industrial systems. The box section of the main girder is most often used for medium and high carrying capacities of these cranes. The mass of this girder has the largest share in the total mass of the single-girder bridge crane, and that is the reason why it is very important to reduce it in order to obtain a lighter structure, which also reduces the market price of the crane. However, it should be taken into account that the main girder is at the same time the most responsible part of the crane, and therefore the level of reduction of the mass must be strictly observed in order not to jeopardize the reliable operation of the crane. In case of damage of the main girder of the single-girder bridge crane, the consequences may be fatal, both for the employees in the plant and for the equipment below the crane. A failure of any other assembly does not jeopardize the employees and the installed equipment to that extent.

Taking into account the above mentioned, the fact that there are a large number of papers which deal with the problem of analysis of stresses of main girders of cranes as well as with their optimization is not surprising. Most papers treat the problem of optimization or stress analysis of double-girder bridge cranes. It is known that double-girder cranes are intended for lifting and transportation of large loads and for larger spans than single-girder cranes. However, the number of single-girder cranes installed in plants is significant so that optimization of their main girders is justified.

The paper [1] used analytical methods and the finite element method for closer determination of the stress state which then served as the basis for proposing optimization of the girder mass for the case of placing the rail above the web and for the case of placing the rail in the middle of the box girder [2]. These papers point to the advantage of using finite elements relative to analytical methods, which is seen in more accurate calculation because it takes into account longitudinal and transverse stiffeners, thus achieving savings in the material consumed.

The paper [3] showed that successful use of the FEA method can indicate a series of phenomena which are important during optimal shaping of the structure of the main girder of the crane. For that purpose, it defined the corresponding equations which more precisely define stresses and displacements of elements of the structure. The paper [4] performed optimization of the main girder of the crane by inserting horizontal and vertical stiffeners. The influence of proper installation on the optimization of the box girder and reduction of its mass was also treated in [5] showing that considerable savings in the mass of the girder can be obtained in that way.

The paper [6] performed optimization of the main girder of the crane based on the load which occurs as a consequence of the

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rolling resistance. The paper [7] conducted a comparative analysis of dimensioning the main girder by using the conventional way of calculation, with the use of appropriate standards, and then the analysis was done by changing the type of finite elements. It was followed by providing guidelines for the use of the corresponding type of finite element. The paper [8] carried out theoretical analysis, then the analysis by applying the finite element method and, finally, experimental analysis by using gauges. That is how the behaviour of a structure after a certain period of exploitation is monitored, which provides the possibility of optimization of the structure. The paper [9] performed numerical and experimental simulation on a model of double-girder bridge crane, with a special reference to the influence of friction and seismic loads. It was shown that the finite element method provides good results and the guidelines for changing the analytical model were given. The paper [10] pointed to the importance of the cost of manufacturing the main girder of the crane and introduction of economic criteria of optimization.

The paper [11] performed optimization of the box section of the crane by applying five methods of optimization and presented comparison of optimization results for a concrete example.

In [12], the efficiency of a neurocomputing prediction scheme incorporated into three metaheuristic algorithms for the optimum design of real-world structures is presented. The importance of optimization of single-girder cranes is shown in the paper [13]. The single-girder crane is loaded with two loaded trolleys. The performed optimization showed there can be savings in the mass of the main girder. Optimization of the main girder of the crane is shown in the paper [14], too. This is the paper which, for the first time, uses particle swarm optimization to optimize the structure of the main beam for the bridge crane. The optimization in the paper [15] included the constraint of values of natural frequencies of oscillation of the crane. Multi-criteria optimization was also conducted in the paper [16] for the purpose of reducing the crane mass and the costs of manufacturing, using the program based on the Davidon-Fletcher-Powell (DFP), and the solution was verified using ANSYS software. The paper [17] considered the problem of optimization of the box section of the main girder of the bridge crane with the rail placed above the vertical plate. Criteria of strength, local and lateral stability of the girder were applied as the constraint functions. The paper [18] carried out the analysis of elastic stability and rigidity of bridge cranes by using Polish standards, which were later compared with the results of analysis performed according to European standards. The paper [19] performed optimization of the box section of the double-girder bridge crane with the rail placed above the web.

The mentioned papers point to the importance of optimization of the main girder of the crane and creation of the model which can allow a more real description of the crane behaviour in operation. Also, the analysis showed that the investigations into optimization of girder of cranes are mostly directed to double-girder bridge cranes. Having in mind that there are a large number of single-girder bridge cranes in industry, this paper deals with the investigation into optimization of a closed cross-section of single-girder bridge cranes. As it can be seen in the mentioned papers, there are different constraint functions so that it can be concluded that a better objective function, i.e. smaller girder mass is obtained for a larger number of constraints.

Taking into account the above mentioned results and conclusions, the aim of this paper is to define optimum values of parameters of the geometry of cross-section of the box girder that will lead to the reduction of its mass. It is also necessary to define more closely the relationships between the main parameters of the cross-section which represent the starting point for designers while designing box girders.

Definition of optimum parameters of the cross-section of the box girder in concrete examples in this paper is a very complex task. Namely, taking into consideration all the constraints introduced for the given problems, there arises the question of selection of the optimization algorithm. Due to the complexity of the problem, and based on previous research, traditional optimization methods and the methods of direct search cannot give a successful solution in the region of the global optimum. Fortunately, modern biologically inspired optimization algorithms allow finding of the optimization solution in the region of the global optimum in a very successful way.

In order to solve the problem, the authors of this paper decided for three biologically inspired algorithms, i.e. Firefly Algorithm (FA), Cuckoo Search algorithm (CS) and Bat Algorithm (BA). In 2008, Yang developed the Firefly Algorithm (FA) in [20]. In 2009, the same author, together with S. Deb [21], introduced the Cuckoo Search algorithm (CS), and in 2010 the Bat Algorithm (BA) in [22].

The aim was to solve the task by applying different algorithms for global optimization in order to check the quality of the solution.

2. Mathematical formulation of the optimization problem

The general look of the single-girder bridge crane is shown in Fig. 1. The carrying structure of the single-girder bridge crane is made of the main girder (position 1, Fig. 1) and two cross girders (position 2, Fig. 1). The main girder of the crane is of box section that consists of two vertical and two horizontal plates (Fig. 2), which, in a general case, have different thicknesses. As the optimization task represents mass minimization, it is necessary to determine the values of geometrical parameters of the cross-section of the girder which define its minimum area.

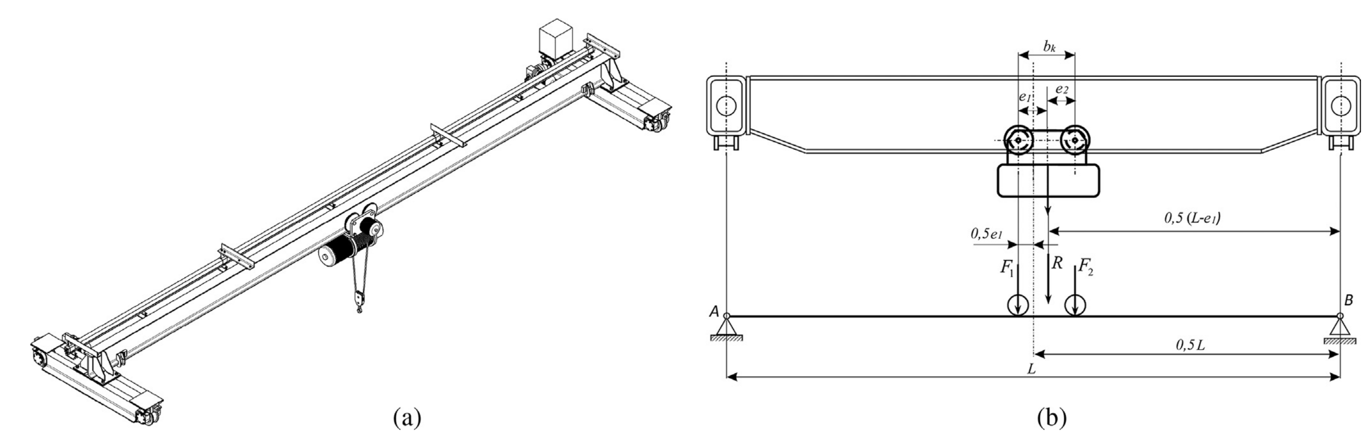

Fig. 1. Single-girder bridge crane (a) appearance and elements of the structure and (b) load of the main girder of the crane.