

The effect of the gantry crane beam cross section on the level of generated stresses

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Abstract. The gantry cranes are currently one of the most popular devices to transporting loads. They can be used in many industries. This study focuses on the numerical analysis of only the portable gantry crane. The mathematical and numerical model of mechanical phenomena in the gantry crane beam was presented in this paper. This problem was solved by using of the Finite Element Method (FEM). The analysis was made to the cross-section of gantry crane beam which was the I-beam or box beam. The numerical simulations are limited to numerical analysis of strength of the gantry crane beam which was loaded by the motion of the load force along its length. As a result of the calculations, the stresses and displacements of the structure of gantry crane were obtained. The influence of beam shape change and changing the loading force position on generate the equivalent stress in the crane beam was evaluated. The research performed, which allows the estimated of the stress state, pointing out the critical areas and values, were made in order to increase the strength of the structure of the gantry crane.

Keywords: numerical modelling, stresses analysis, gantry crane beam, FEM

1 Introduction

Manipulation of material is an essential component of any production and distribution system. The important mechanical elements of these systems are different cranes, which are used to lifting and lowering a load and moving it horizontally. They are mainly used in car factories, heavy industry and shipyards. Their construction features vary widely according to their main operational specifications, such as: the type of movement of the crane and the crane trolley, the weight and type of load, the location of the crane and the geometric features [1]. They are called overhead cranes or gantry cranes. The usual distinction drawn between the two cranes is that with gantry cranes, the entire structure is usually wheeled (often on rails) [2]. The main component of crane is girder beam which transfers the load on its other elements therefore it is tested for strength. The construction of the overhead crane with a double girder is often analyzed [2-4], while a single beam is usually used in the gantry crane [5] and analyzed in this paper. The gantry cranes with a single girder are often used in the auto workshops, they are smaller and about simple design [5, 6]. Usually, the gantry cranes are made with steel [2-5], but they can be making with selected

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aluminium alloys because they have good mechanical properties and enhanced corrosion resistance. The main advantage of such structures is the reduced mass with retained strength parameters. Taking into account the dynamic parameters of the analyzed structures, it must be noted that those made of aluminium alloy show much less stiffness. Therefore, for larger bridge spans and larger load capacities, their use may be illegitimate because of the permitted deflection of the girder [6].

Literature review helps in a way to get the information regarding structural analysis of crane girder and it is the main source in setting new trends in design from the early stage of project. It turns out that the finite element analysis software offers inexpensive solutions to failure problem of crane girder and is an essential tool to help us in determining the cause of problem, it also recommends the solutions. Therefore the numerical simulation should be assumed as standard tool in failure [1, 2]. Usually, the solid and shell elements are used in FEM for getting best results of numerical simulations [2, 3]. After a comparison results of the finite element analyses with the conventional calculations it was found that only the analysis using quadratic shell elements give realistic results. It is believed that the reason of this situation was too large element dimension along the beam in case using the solid element [3].

The problem of moving the load is very important topic in the design of large gantry cranes. Dynamic effects in case of problems with moving loads are not often considered [7]. Usually, the load movement is neglected and numerical analysis is performed for its one position in the center of the beam length [2-4, 6]. Numerical simulations that allow analyze of mechanical phenomena in subsequent positions of load force, over the entire length of beam range, can be found in [5] and will be presented in this paper.

The destination of this article is to provide information about the strength of the crane beam of different cross-section loaded with moving load force, so that it has not been damaged. The problems of stress concentration and the extreme deformations localization will also be discussed. For this purpose, the numerical simulations were performed to get the distributions of stresses, strains and displacements in the gantry crane beam. The value of the calculated stresses is compared with the permissible stresses of beam material. If they are smaller than the permissible stresses, it is supposed that the construction is safe.

2 Mathematical description

The mechanical phenomena analysis in the elastic range was made using the equilibrium equations (1), which are supplemented by constitutive and Cauchy's equations (2), and boundary conditions (3). The mathematical model is based on solving the following system of equations [5, 8-11]:

$$\sigma_{\alpha\beta,\beta} = 0, \quad \sigma_{\alpha\beta} = \sigma_{\beta\alpha}, \quad (1)$$

$$\sigma_{\alpha\beta} = D_{\alpha\beta\gamma\kappa} \varepsilon_{\gamma\kappa}, \quad \varepsilon_{\gamma\kappa} = \frac{1}{2}(u_{\gamma,\kappa} + u_{\kappa,\gamma}), \quad (2)$$

$$\sigma_{\alpha\beta} n_{\xi} = p_{\xi} \Big|_{\Gamma}, \quad u_{\kappa} = u_{\kappa} \Big|_{\Gamma}, \quad (3)$$

where $\sigma_{\alpha\beta}$ is stress tensor, $\varepsilon_{\gamma\kappa}$ - strains tensor, u_{κ} - displacement vector, $D_{\alpha\beta\gamma\kappa}$ - tensor of material properties (Young's modulus (E) and Poisson's ratio (ν)) and p_{ξ} - components of force per unit area acting on a plane (Γ) with normal n_{ξ} .

Displacement boundary conditions are used in the discussed problems [2-6, 8-11]. The nodes located on the contact surface of the gantry crane beam with the support column on

the right side of the beam can not displace in three directions ($u_x=u_y=u_z=0$) and the left side in two directions ($u_x=u_y=0$) (Fig. 1).

The numerical model uses finite element method in the weighted residuals formulation [5, 8-12]. Equation (1) is multiplied by the weighting function and integrated over the entire region. As the result of using Ostrogradsky-Gauss-Green's theorem and Galerkin's method, which were described in the work [12], the following matrix equation is obtained [5, 8-11]:

$$\mathbf{K} \cdot \mathbf{u} = \mathbf{R}, \quad (4)$$

where \mathbf{K} is the stiffness matrix, \mathbf{u} - sought displacement vector, \mathbf{R} - vector associated with the loads and boundary conditions. The solution of the matrix equation (4) is obtained as a nodal displacement in the examined area. Then, using the equation (3) and (2) are obtained the sought fields of stresses.

3 Description of the problem

For the analysis the effect of beam shape change and the position of load force on the stress distribution in the gantry crane beam, the static system of single-span beam is presented in Figure 1. The gantry crane beam with the length 4.8 m is attached on two supporting column with a width of 0.6 m. One end of the beam (left) is free to shift along the z -axis (Fig. 1) and the second end can not move in three directions. Cross section of the beam is I-beam with dimensions 300x125x10 mm, box beam with dimensions 300x125x5 mm and thick-wall box beam with dimensions 300x125x10 mm.

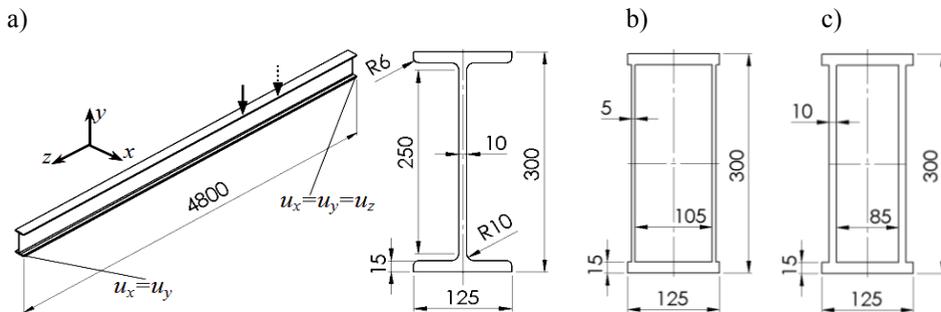


Fig. 1. The considered beam of the gantry crane with cross section of the: a) I-beam, b) box beam, c) thick-wall box beam

The structure is loaded by the pressure perpendicular to the upper flange of the beam and directed downward, i.e. contrary to the y -axis. The pressure value is the result of the total weight of the loaded crane trolley that can travel along the upper flange of the gantry crane beam. The movement of the crane trolley performed by moving the pressure which acts on the contact surface of the trolley wheels with the beam, to consecutive positions along the crane beam, ignoring inertia effects. The assumed pressure value of $13\ 513\ 513.514\ \text{N/m}^2$ multiplied by the contact surface of the trolley wheels with the beam corresponds to the load force of 50 kN. The loadings have been considered in the elastic range and therefore the elastic constants were assumed, corresponding to the steel S235: Young's modulus (E) equal to $2.1 \times 10^5\ \text{MN/m}^2$, the Poisson's ratio (ν) of 0.28 and the yield strength (R_e) of $235\ \text{MN/m}^2$ [2-6, 8]. The value of the allowable stress the beam material (σ_{all}) amounts to $120\ \text{MN/m}^2$. The value of this stress is calculated by dividing yield strength by the safety factor is assumed that is 1.98. The safety factor should be between 1.5 and 3 for the crane girder design as recommended [2, 3].

The analysis of the stresses of the gantry crane structure was carried out using the professional program (SolidWorks) with additional force movement procedure where the move trajectory of the force was divided into the set of temporary positions. Then the calculations for the each position were performed with the use of loop to obtain the stress distribution. This aspect of presented work is a new contribution developed by the authors. The gantry crane beam has been divided into 19 224 finite elements that are defined by 39 003 mesh nodes when the beam has the cross-section of I-beam or 26 763 elements and 53 206 nodes if the beam has a cross-section of the box. In this investigation a parabolic tetrahedral solid element is used. Numerical tests carried out to increase the structure strength of the gantry crane make it possible to assess the state of stresses, indicating critical areas and values.

4 Results of numerical calculations

In this study, the numerical analysis of the strength of portable gantry crane is made. As the result of the computations performed, the stresses, strains and displacements of the gantry crane structure were obtained. The effect of beam shape changes and change of load force position on the creation of equivalent stress (σ_{eq}) in the gantry crane beam was assessed.

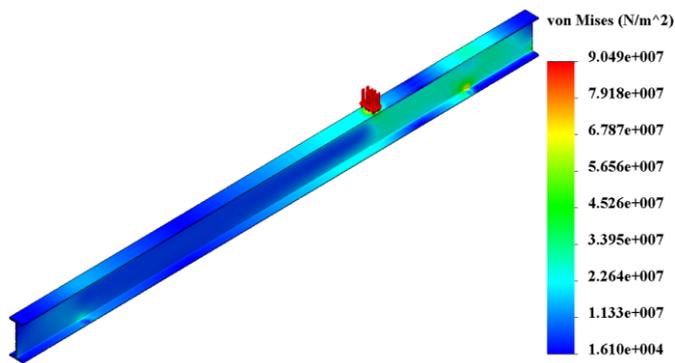


Fig. 2. Von Mises equivalent stress distribution in the I-beam of gantry crane for location of the load force $z = 1.5$ m

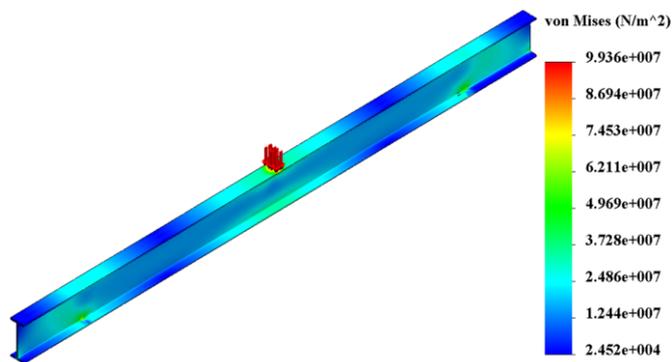


Fig. 3. Von Mises equivalent stress distribution in the I-beam of gantry crane for location of the load force $z = 2.4$ m

The distribution of von Mises equivalent stress in the gantry crane beam whose cross-section is the I-beam is shown in Figures 2-4 or if it is the box beam is shown in Figures 6-8 and if it is the thick-walled box beam is shown in Figure 10.

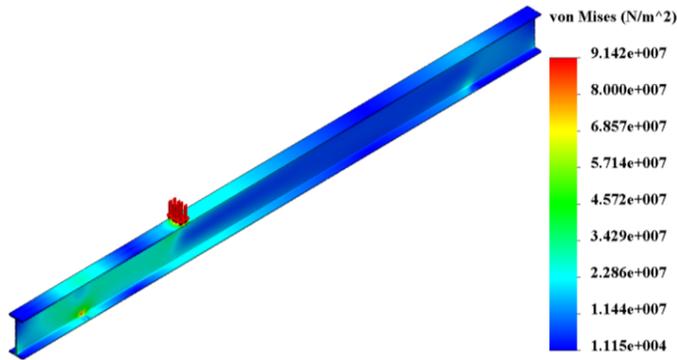


Fig. 4. Von Mises equivalent stress distribution in the I-beam of gantry crane for location of the load force $z = 3.3$ m

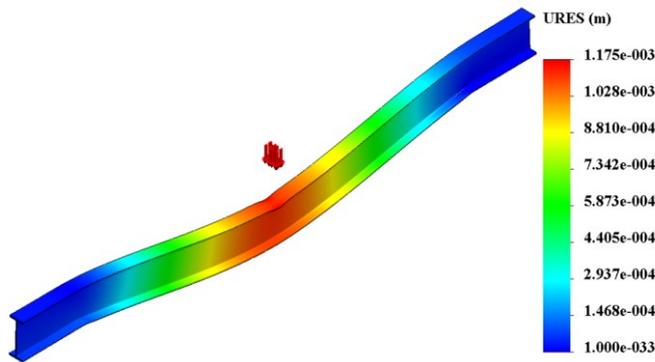


Fig. 5. Displacement field in the I-beam of gantry crane for location of the load force $z = 2.4$ m

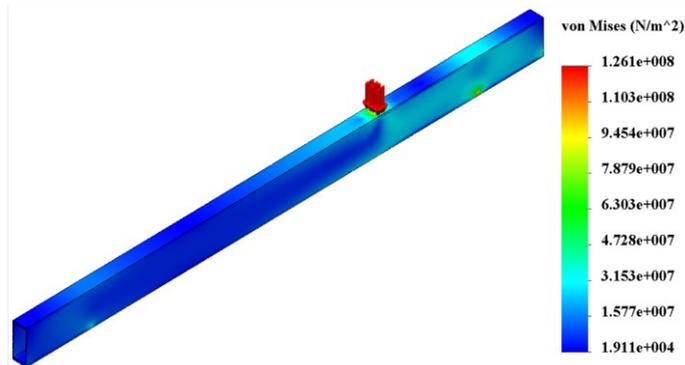


Fig. 6. Von Mises equivalent stress distribution in the box beam of gantry crane for location of the load force $z = 1.5$ m

The strength condition is verified by using the stresses induced in the beam in successive load force positions. It sought to that the maximum value of von Mises

equivalent stress generated in the gantry crane beam was less than the strength of beam material ($\sigma_{eq} < \sigma_{all}$), because then the construction is safe. However, the strength condition was not met when the gantry crane beam had the cross-section of box because the stress peak was in place where the beam was attached (Fig. 6).

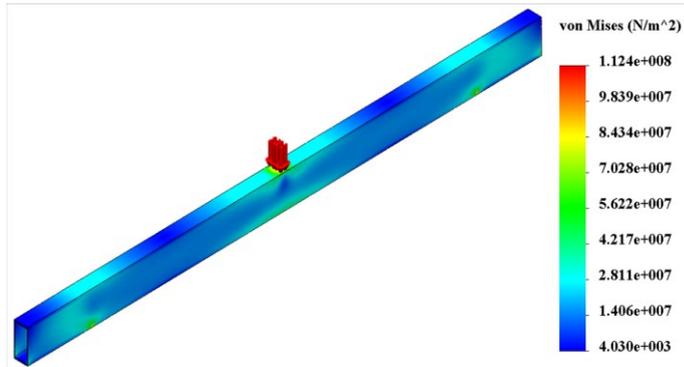


Fig. 7. Von Mises equivalent stress distribution in the box beam of gantry crane for location of the load force $z = 2.4$ m

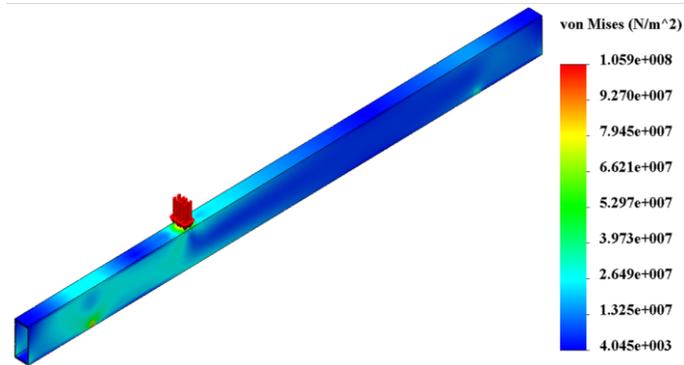


Fig. 8. Von Mises equivalent stress distribution in the I-beam of gantry crane for location of the load force $z = 3.3$ m

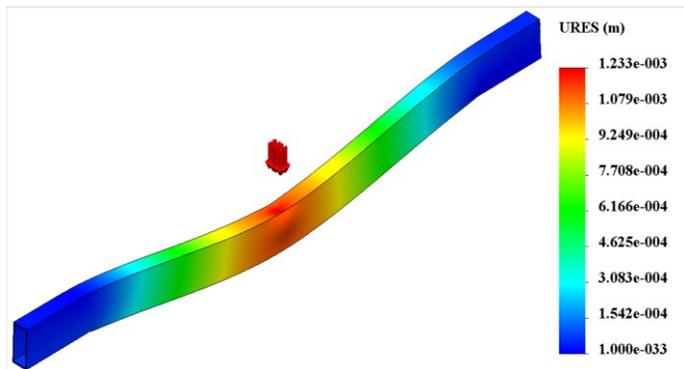


Fig. 9. Displacement field in the box beam of gantry crane for location of the load force $z = 2.4$ m

In general, the region of increased stress is related to the current location of the load and moves with it, resulting in a maximum value in the center of the beam length. The displacements field of the gantry crane structure is shown in Figure 5, 9 and 11, when these magnitudes reached the maximum value for the central position of load force. In order to verify the value of the displacement obtained, the ratio of vertical maximum displacement to beam length should be examined. The largest displacement value can be found in Figure 9 (box beam) and then this ratio is equal to 2.56×10^{-4} . These researches were performed to estimate the strength of the gantry crane structure depending on the cross-section used.

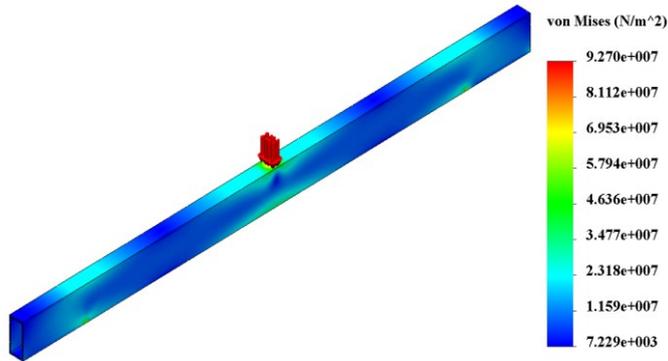


Fig. 10. Von Mises equivalent stress distribution in the thick-walled box beam of gantry crane for location of the load force $z = 2.4$ m

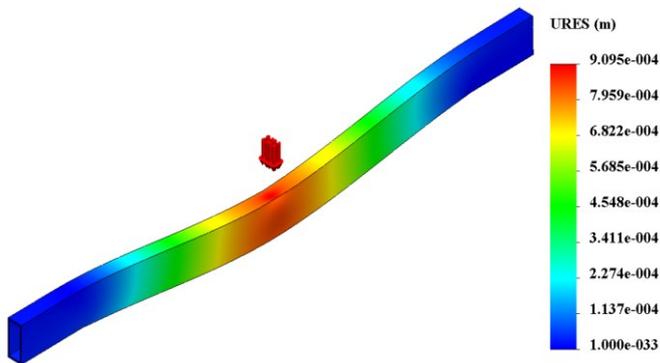


Fig. 11. Displacement field in the thick-walled box beam of gantry crane for location of the load force $z = 2.4$ m

Conclusions

The mathematical model and numerical simulations of the mechanical phenomena in the gantry crane beam are presented in this paper. The strength analysis of the gantry crane beam whose cross-section is the I-beam or the box beam was performed. As a result of the numerical calculations carried out, the stresses and displacements of the gantry crane structure were obtained. The influence of beam shape change and changing the loading force position on generate the von Mises equivalent stress in the crane beam was evaluated. The area of increased stresses is associated, to the current position of the load force and moves with it (Figs 2-4, 6-8). Generally these stresses reach the maximum value in the

center of the beam length under the force load (Figs 3, 7, 10). The maximum von Mises equivalent stress in the middle of the gantry crane beam length whose cross-section is I-beam amounted to 99.4 MN/m^2 (Fig. 3), in the box-section beam was 112.4 MN/m^2 (Fig. 7) and in the thick-walled box beam was equal to 92.7 MN/m^2 (Fig. 10). These stresses are less than the allowable stress of the beam material. In addition, a peak of stresses is located at the points where the beam is attached (Figs 4, 6). The strength condition in this place is not met when the gantry crane beam has the cross-section of box (Fig. 6). Analyzing the distribution of displacement (exemplary results in Figs 5, 9, 11), the ratio of the maximum displacement to the beam length is checked and it is within acceptable limits [6]. It should be noted that results of numerical simulations are consistent with the results found in literature of the subject [2-5]. In these papers, the stress peak is located at the points where the beam is attached, as in this paper. The authors of paper [4] recommended reducing stresses near the end of the crane beam by improving the construction of gantry crane. The use of the I cross-section in the gantry crane beam design seems to be a better solution in terms of strength and therefore this cross section is usually used in real gantry crane structures.

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