Numerical-Experimental Approach to the Design of the Mounting System for Fast Clamping of the Equipment of the Electrical Demolition Machine

Jakub Andruszko(✉) and Eugeniusz Rusiński

Faculty of Mechanical Engineering, Department of Machine Design
and Research, Wroclaw University of Science and Technology, Łukasiewicza 5,
50-370 Wroclaw, Poland
`{jakub.andruszko,eugeniusz.rusinski}@pwr.edu.pl`

Abstract. Currently, there are many types of connectors that ensure secure mounting of machine tools, increasing their versatility by the possibility of connecting a large number of different tools. Bolts, quick couplings, adaptive plates for light machines and devices using wedge connections are used. In electric demolition machines, joints using wedge connections are used due to the possibility of their quick disassembly of the elements. As a result of insufficient durability of the currently used joints, the authors presented a numerical-experimental approach to their design, which allows to determine the actual loads acting on the designed element, and thus to improve the existing solution.

Keywords: Demolition machine · Electric machine · Arm working system · Mounting tool · Numerical-experimetnal studies · Construction works · Testing · Finite element method

1 Introduction

The first device using the pin connection to assemble the working system with the tool was a Brokk company patent. This device is used to connect the equipment of work machines such as loaders, excavators and other tools of the broadly defined heavy industry [8]. Defining the shortcomings occurring in existing joints was a key aspect in the approach to designing a new element. As a result of the machine's operation due to vibrations, the coupling system lost its compactness, and the distance between the pins were increased. Another drawback was the inaccuracy in the execution of the holes for locking linchpins, which made it difficult to fit the pine hole with the hole in the fastening beam. The project of the mounting system was started by setting the dimension between the pins, which are fixed in the adaptive plate. This dimension was changed accordingly, so that the structure, even after some changes in the geometrical features resulting from the impact hammer work, remained compact. The mounting system was provided with protection against its bending in the form of a protruding end in Sheet I. After designing the preliminary mounting system to secure it, a wedge-shaped model was made consisting of a wedge track and two opposing wedges securing the mount

E. Rusiński and D. Pietrusiak (Eds.): CAE 2018, LNME, pp. 29–35, 2019.
https://doi.org/10.1007/978-3-030-04975-1_4

(Mounting module). The wedge connector is protected by special locking pins. It was decided to use two wedges symmetrically to increase the pressure exerted by the pins on the calibration plate. The above-described structure is shown in Fig. 1.

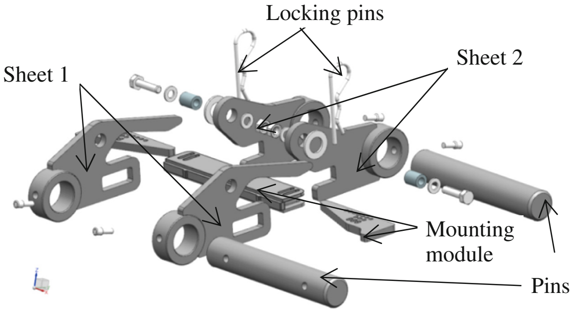

Fig. 1. Device for quick coupling of the equipment of the electrical demolition machine

2 Experimental Tests

In order to determine the actual loads acting on the fastening element, it was decided to perform measurements on the prototype of the Advanced Robotic Engineering machine in real working conditions. A high-speed camera was chosen for the measurements, which allows for safe measurements in the machine's working environment, by putting away the measuring device from the place of danger and giving an uncomplicated measuring system [1, 2]. As a result of measurements using high-speed camera, we can determine the displacements of individual previously selected points on the machine structure. It was decided that the point located in the center of gravity of the hydraulic hammer, determined on the basis of data from the manufacturer, will be the point for measurements. In order to correctly carry out measurements on the hammer structure, reference points with high contrast were placed so that as a result of the camera being put away from the machine's work place, after recording the image, it was easy to read the measuring points in the image processing program. The distance between the attachment points of the robot arm was also determined in order to properly calibrate

Fig. 2. Measuring point and test stand

the object during data analysis. The selected point and the working environment of the machine together with the measurement stand are shown in Fig. 2.

For the measurement the speed of the camera was 10 000 frames per second and the density of sampling of displacement signal was 0.001 m. The element that underwent the process of breaking was a block of reinforced concrete, which was a part of the foundation of the building. In the case of such the most frequently used position of the machine during breaking, so that the cylinders are maximally extended, the greatest torque is generated at the rotating element of the working system [3]. This case is the worst possible case of the work system in this work environment. It was decided to measure during breaking the working material, but only with initial crushing, which causes large vibrations of the working system and may cause loss of the tightness of the mounting system [4]. After the breaking measurements, where the hammer hit the concrete block causing its destruction, the relationship between the displacement of the measuring point and the time has been plotted. Analyzing the measurements, it turned out that the largest displacements of the hammer occur in its axis, so it was decided to omit other components generating small displacements and it was decided not to apply them to numerical analyzes. The vertical displacement graph is shown in Fig. 3.

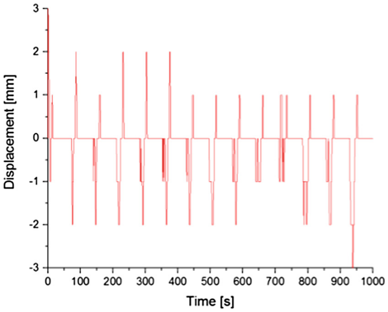

Fig. 3. Diagram of vertical displacement of the hydraulic hammer point

3 Determination of the Loads of the Mounting System

In order to determine the load of the mounting system, a geometric model of the demolition robot's working system was built and a mounting model was applied to it, giving the appropriate bonds in the form of kinematic pairs [5]. The approach to simulation was used as the Rigid Body Dynamics (RBD) in the first stage, and then, thanks to the information on the forces acting in the kinematic pairs, a computational calculation model was built, and forces derived from the RBD analysis were applied. Rigid Body Dynamic is based on the second law of motion in classical mechanics. In the three-dimensional arrangement of orientation RBD can be described in various ways. The most popular are: Euler angles, Tait-Bryan angels, Orientation vector, Orientation matrix, Orientation quaternion. To consider rigid body dynamics in three-dimensional space, Newton's second law must be extended to define the relationship between the movement of a rigid body and the system of forces and torques that act on it. In this article, authors determine forces in kinematic pairs using RBD analysis, in which forces are determined in the following way:

$$F_j = m_j a_j \tag{1}$$

The dynamics of an interconnected system of rigid bodies, B_i, j = 1,…, M, is formulated by isolating each rigid body and introducing the interaction forces. The resultant of the external and interaction forces on each body, yields the force equations The model used for RBD analysis is shown in Fig. 4.

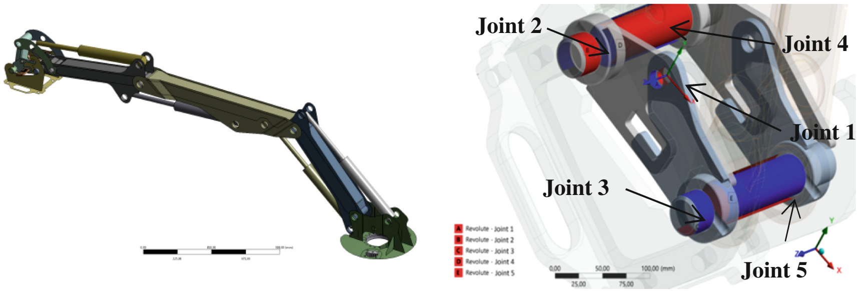

Fig. 4. The model used for RBD analysis with specified kinematic pairs

Thanks to the RBD analysis, the values of forces in the kinematic pairs of the mounting system were obtained, which have been applied to the calculation model. The force graphs in kinematic pairs are presented in Fig. 5.

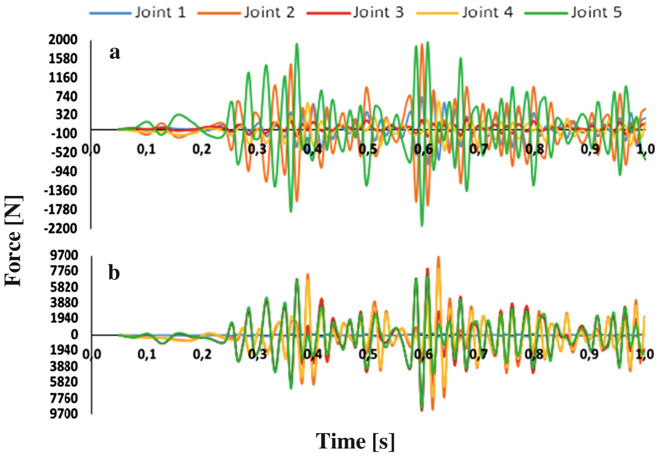

Fig. 5. Graphs of forces in the kinematic pairs of the fastening system: a - horizontal axis, b - vertical axis

4 Numerical Calculation

In order to conduct a strength analysis using the Finite Element Method, a discrete model with a division into finite elements was built based on a geometric model [6]. HEXA8 type elements with a linear interpolation function were used for the analysis. In order to accurately represent the behavior of the system, during the operation contacts between the mounting elements has been given [7]. The beam element was used to model the screw connection between the fixing plates. Due to the limitation, already at the stage of analysis of experimental data, the values of displacements only to values in the symmetry plane of the working system, its symmetry has been used for the computational model. The discrete model is shown in Fig. 6.

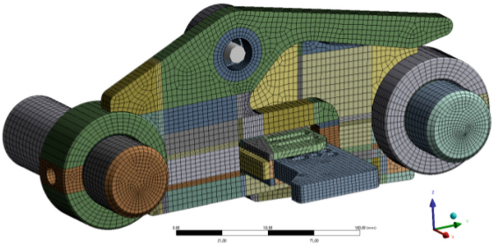

Fig. 6. Discrete model with division into finite elements

Thanks to the forces obtained from the RBD analysis and the discrete model built, a computational model with boundary conditions was built. Due to the dependence of forces on time, a quasi-static analysis was performed. The calculation model with boundary conditions is shown in Fig. 7.

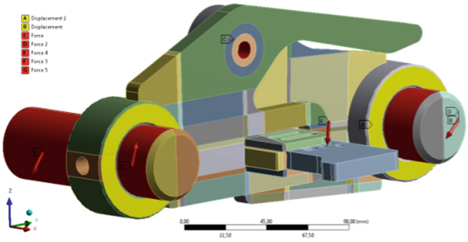

Fig. 7. The calculation model of the mounting system with boundary conditions

As a result of applying the forces obtained from the RBD analysis over time, the dependence of stresses on the time occurring in the structure during machine operation was obtained, which are shown in Fig. 8.

Stress distribution for the maximum effort of the structure occurring in 0.58 s of individual components are shown in Fig. 9. The maximum stress is 142 MPa.

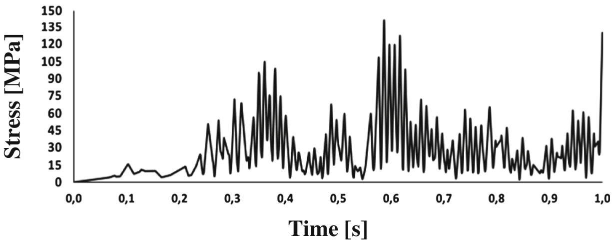

Fig. 8. Dependence of stresses in time on the structure

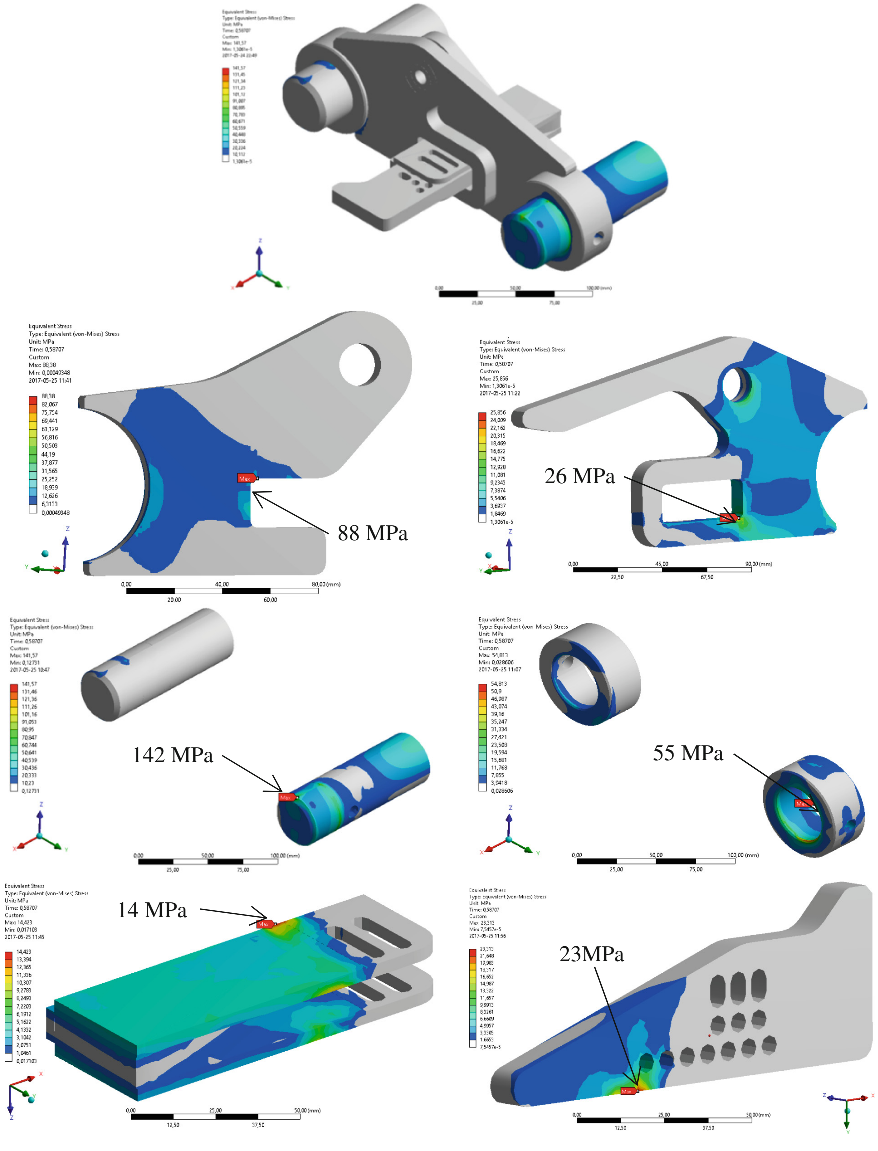

Fig. 9. Stress distribution according to the H-M-H hypothesis

5 Summary and Conclusions

The authors showed a numerical and experimental way to determine the effort of elements of working systems of machines for construction works. The main problem when designing such a device is to obtain a good compactness of the structure so that it does not quickly degrade. It was found that the components of the device do not carry heavy loads. Studies using a high-speed camera to measure displacements of the determined points of the machine's working system allowed to determine the input parameters for the RBD analysis, which gave the input parameters for the strength analysis using the Finite Element Method.

It can be stated that the numerical and experimental approach with the use of a high-speed camera and appropriate combinations of numerical techniques gives the possibility to determine the effort of elements of the working system of demolition machines. The use of a high-speed camera to determine the displacement of defined points limits the number of measuring instruments used to a minimum.

Acknowledgments. The project was carried with the support of the National Centre for Research and Development in Poland under the "Szybka Ścieżka" program no POIR.01.01.01-00-0582/15-00, in cooperation with Advanced Robotic Engineering Ltd. company.

References

1. Derlukiewicz D, Ptak M, Wilhelm J, Jakubowski K (2017) The numerical-experimental studies of demolition machine operator work. Lecture Notes in Mechanical Engineering. Springer, pp 129–138
2. Derlukiewicz D, Cieślak M (2017) Study of the causes of boom elements cracking of electric demolition machine with use of experimental and numerical methods. Lecture Notes in Mechanical Engineering. Springer, pp 109–119
3. Karliński J, Rusiński E, Lewandowski T, (2008), New generation automated drilling machine for tunneling and underground mining work. In: Automation in Construction, pp 224–231
4. Piszczek K, Walczak J (1982) Drgania w budowie maszyn (wyd. 3). Warszawa
5. Rusiński E (2002) Design principles supporting structures of motor vehicles, in Polish. Wrocław
6. Rusiński E, Czmochowski J, Smolnicki T (2000) Zaawansowana metoda elementów skończonych w konstrukcjach nośnych, Wrocław
7. Zienkiewicz, O, Taylor R (2006) The finite element method for solid and structural mechanics (6th ed., 3rd repr.. ed.). Amsterdam
8. Global Construction Robots Market 2016–2020 with Brokk (2016) Fujita & ULC Robotics Dominating. https://www.businesswire.com/news/home/20160524005815/en/Global-Construction-Robots-Market-2016-2020-Brokk-Fujita