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The use of numerical methods in cutterhead dredger excavation unit optimization

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Abstract

Year by year higher infrastructure development is noticed, including the increase of work in the construction sector as well As a consequence, increase in sand and gravel raw materials demand is observed. Due to that fact, significant parts of open deposits of this type were exploited, which resulted in a huge increase in interest in extracting aggregates from the water. Until the seventies of the twentieth century, the share of aggregates extracted from the water was not even fifty percent [1][2]. Since then significant increase is observed reaching today over seventy-five percent [1][2], where Poland is still low in this ranking, for highly developed European countries in terms of the amount of extraction of raw materials in this way. The appropriate exploitation technologies are selected depending on the mining and geological conditions, the depth of deposition and the place of extraction. Excavators, cutterhead dredger, hydro-pneumatic excavators and scrapers are used for extraction from under water [3].

The article presents a problem encountered during the exploitation of the cutterhead dredger, which is equipped with a cutting disc with teeth on a rotating double bucket wheel mounted on the boom, and the entire construction of the dredger is placed on the barge. Positioning of the dredger is carried out by ropes anchored to the shore [3]. They also allow the dredger to make basic movements on the water. The excavated material taken using the cutterhead is carried out using a suction pipe. The continuous character of this technological system should characterize by high efficiency. Inappropriate selection of teeth for the cutting disc for the specific mined material can significantly reduce the expected efficiency of the machine [5,6,7].

Authors present a numerical and experimental approach to determine the reasons for not achieving required efficiency of cutterhead dredger, not resulting from mining technology, but the wrong selection of tools in the dredging process. Research were carried out on HAARD dredger. The view of the dredger in the operational environment and the detailed view of the cutting tool are shown in Figures 1 and 2.

Fig. 1. HAARD dredger

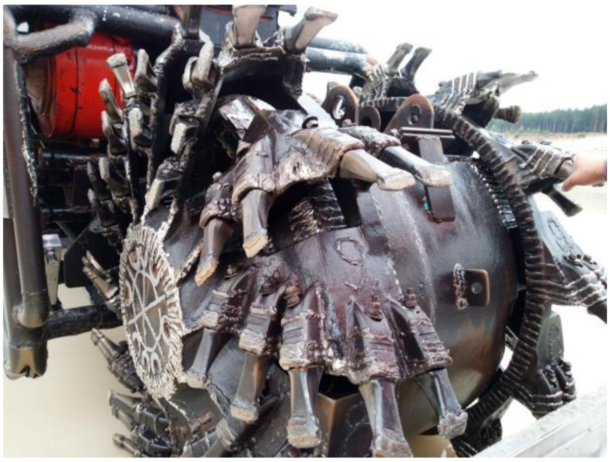

Fig. 2. Cutterhead of the dredger

Due to the need to accurately recreate the dredging process, it was very important to develop a virtual model of a cutting disc fully compatible with this mounted on the dredger. The scan was performed using a 3D scanner and this approach allowed to accurate reproduct the cutting disc. The scanner had position accuracy of 3 mm at 50 m and 6 mm at 100 m and angular accuracy of 8 "horizontally and 8" vertically. Scans were made in five positions: 0 °, 45 °, 90 ° in relation to the side surface of the disc and mirror position for 0 ° and 45 ° angles, where the example is shown in Fig. 3. Based on the generated surface model (generated from the cloud of points), a solid model of the cutting disc was laboured. The virtual 3D model of the cutting disc compared to the obtained 3D scan is shown in Fig. 4. Significant discrepancies in the method of assembly of teeth regarding the documentation were observed.

Fig. 3. Scanning the cutting tool geometry

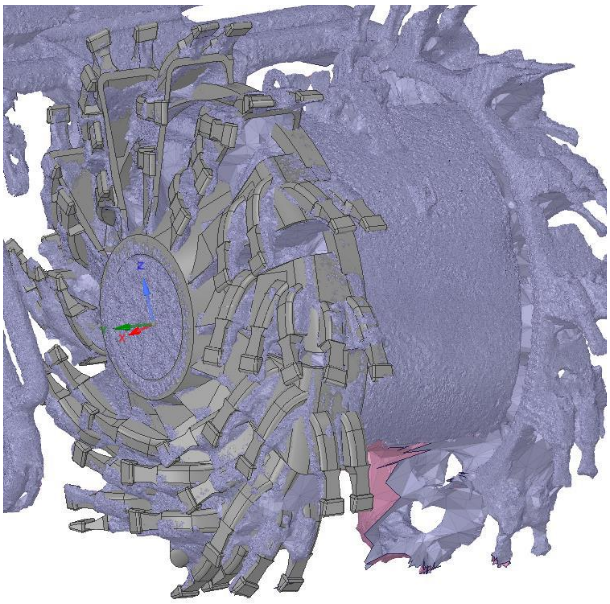

Fig. 4. Comparison of obtained 3D models

In author's method, in order to determine the efficiency of the dredger with respect of the cutting tool, numerical methods were implemented: Discrete Element Methods (DEM) and Rigid Body Dynamics (RBD) [4]. By means of the RBD analysis, the trajectory of the teeth attached to the bucket wheels of the dredger was determined from the measuring points attached to the tooth adapters. The simulation was carried out in accordance with the parameters of the real object in the sense of rotation of the wheel and the machines boom. The analysis took into account the ideal position of the centers of rotation of individual elements, in this case the wheel and the machines boom. Thanks to the implementation of the Discrete Elements Method, mined material model has been built. The correctness of this model was verified by means of a comparative analysis of numerical simulation and pressure measurements at the cutting wheel pump. The values of the load from the simulation were compared with the values measured on the real object. Parameters related to the contact between discrete elements have been changed to properly calibrate the numerical model. A well-prepared numerical model was use as a reference to subsequent numerical DEM-RBD simulations, allowing to determine the method of improving the dredger's efficiency. The RBD and DEM model described earlier is shown in Figures 5 and 6.

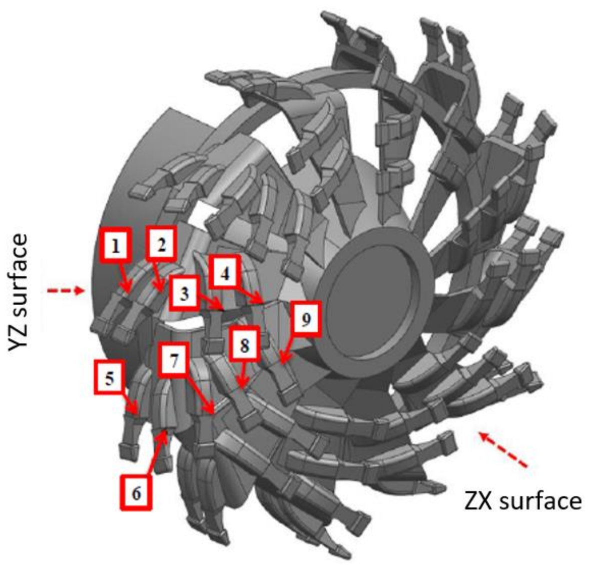

Fig. 5. Selected measuring points

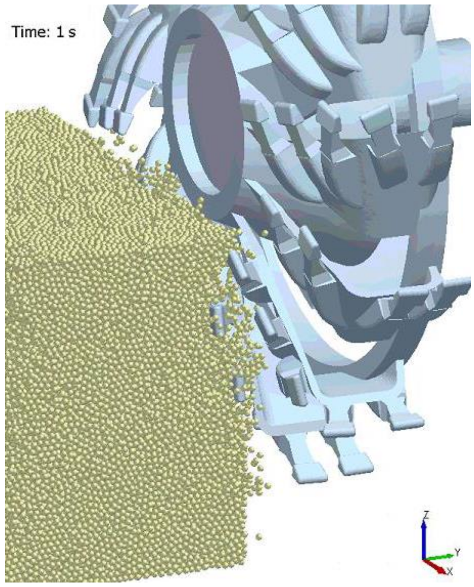

Fig. 6. Simulation of RBD-DEM

Authors proposed to determine the efficiency of the dredger as a measure of the change in the load of the cutting disc, thus changing the moments on the wheel and the boom. For the pre-verified numerical model with new teeth position, another numerical simulation were performed. Diagrams of moments for the cutting wheel shaft and the boom for different tooth positions and the refinery model are shown in Figures 7-8.

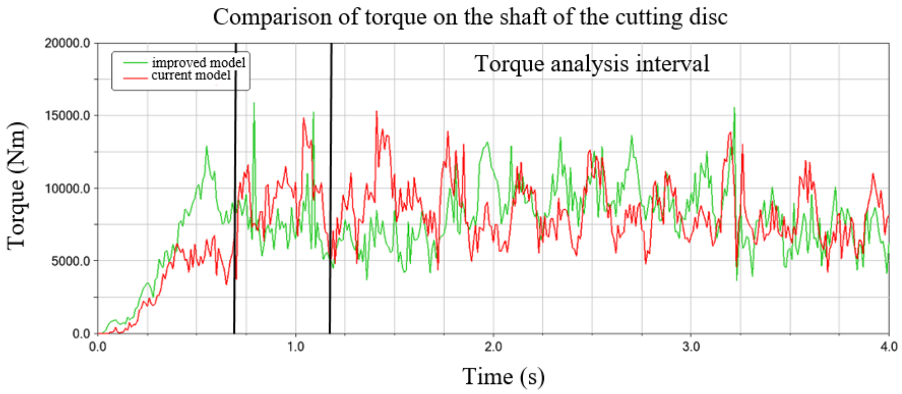

Fig. 7. Comparison of torque on the shaft of the cutting disc

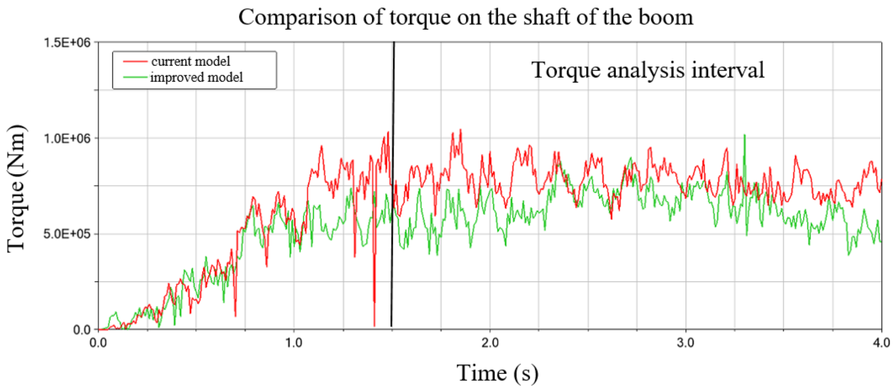

Fig. 8. Comparison of torque on the shaft of the boom

To assess the value of the torque difference, their effective values, measured from the moment the cutting disc was started, were analyzed. A significant decrease, approximately 18% in the value of the torque at the rotation of the boom was observed. Changing the attachment of the teeth on the bucket wheels causes a drop in the torque on the arm. Authors decided to carry out numerical simulations with changed position of teeth in relation to the model exhibiting lower resisntance forces. It was decided to deviate the teeth in the positive and negative direction in relation to the corrected model. This approach enabled finding the optimal angle of tooth position on the bucket wheel of the cutting disc. The dependencies allowing to determine the optimal value are shown in Figures 9 and 10.

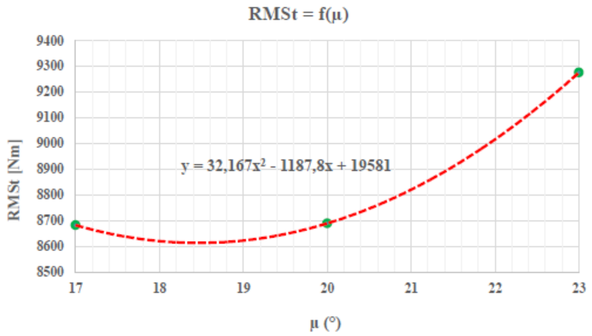

Fig. 9. The optimal tooth position angle depending on the torque of the cutting wheel

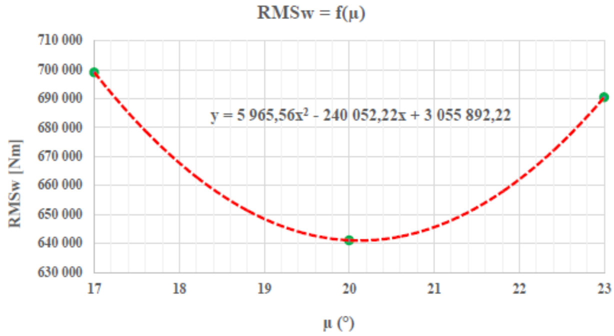

Fig. 10. The optimal tooth position angle depending on the torque of the boom

Authors presented a numerical approach for assessing the efficiency of the HAARD dredger. To assess the efficiency parameter, it was necessary to determine the boundary condition, which was the geometry of the cutting wheel itself, which should be exactly as it is on the real object. A numerical model was prepared with the use of DEM and MBD, verified by means of values measured on the pump during dredger operation. Conducting a number of analyzes allowed authors to verify their thesis regarding the improvement of the machines efficiency, proposing the correct placement of the teeth on the cutting wheel and at the same time gave the opportunity to determine their optimal alignment for a specific work technology.

Keywords: dredger, discrete element method, Rigid-Body Dynamic, 3D scanning

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