How to cite this article:

Author: Piotr Danielczyk
Title of article: „Analiza naprężeń w podcięciu bijaka koła bijakowego" ("Stress analysis in the beater relief of a beater wheel")
Mechanik, Vol. 91, No. 1 (2018): pages 67–69
DOI: https://doi.org/10.17814/mechanik.2018.1.15

Stress analysis in the beater relief of a beater wheel

Analiza naprężeń w podcięciu bijaka koła bijakowego

PIOTR DANIELCZYK *

Presented is numerically efficient finite element discrete model which uses the submodeling technique. The application of the model was to analyze stresses in the beater relief of the beater wheel. Results of the simulation and conclusions as well as the benefits of the adopted modeling methodology in terms of the time needed to find the solution were presented. The relationship between the modeling approach applied and the size of files generated during the analysis was highlighted.

KEYWORDS: beater wheel mill, beater wheel, finite element method, numerical efficiency, submodel

In engineering practice, there is often a need to solve problems with high computational complexity. The use of CAD/CAE packages for this purpose, servicing of which is easier and, above all, preprocessors, largely automating the creation of finite element mesh nets, causes that sometimes computational models are created that do not give a solution in an acceptable time. In many such cases, one can indicate a rational way of constructing a discreet calculation model that is rational from the point of view of efficiency. This article will discuss the stress analysis model in the undercutting of the flail wheel, allowing significant reduction of the task.

Analysis object

The main element of the fan mill used in the furnace of the steam boiler is the flail wheel (fig. 1). The wheel rotates in the spiral-shaped body of the mill, grinding the coal by impacting and abrading it with the beat plates. Between the hub and the ring of the flail wheel, struts are bolted, which are the element connecting the two main parts of the flail wheel. Flail plates – upper and lower – adhere to the strut. They do not adhere side surfaces to the hub and ring (fig. 2), but only support themselves on their edges. They are the most susceptible to erosion of the flail wheel, thus in this type of mill, two plates are used in a stepped arrangement, with a thicker plate on the side more attacked by coal.

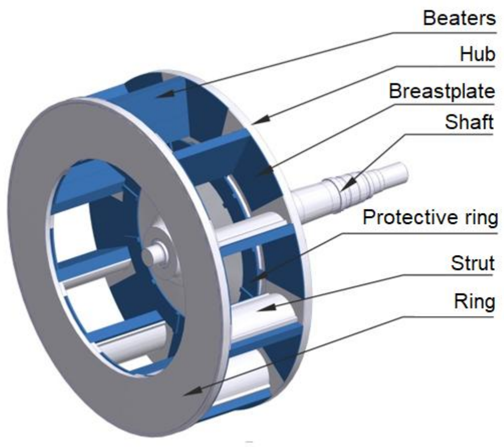

Fig. 1. Construction of the flail wheel

The lower flail plate is protected against protrusion with a protective ring. This construction serves to efficiently replace used flail plates. Fixed wheel elements, like the hub and ring, are protected against excessive wear by special armor.

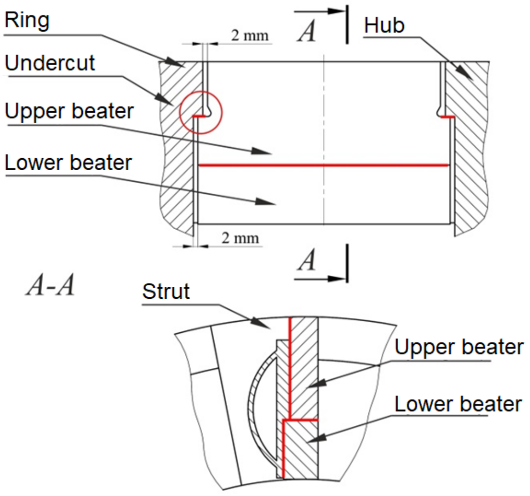

Fig. 2. Way of mounting the beaters

Dr inż. Piotr Danielczyk (pdanielczyk@ath.bielsko.pl) – Akademia Techniczno-Humanistyczna w Bielsku Białej

Parts of the flail wheel that are in contact with the mined wire (beaters, protective elements) are made of wear resistant GX120Mn13, and the hub and ring – made of cast steel intended for operation at elevated temperatures G17CrMoV5-10. S235 steel was used for the other elements of the mill. The working speed for the illustrated design of the flail wheel is 600 rpm. It is assumed that the maximum working temperature can not exceed 400 °C.

The purpose of the analysis

Issues related to the exploitation of flail wheels were the subject of considerations described in several papers [4–6]. The influence of gradual abrasive wear of the hub and ring of the flail wheel on the change of the natural frequency of the assembly and tension in the structure was examined, including the shape of worn beaters obtained from the 3D scanner. The limit values of wear are indicated, at which there is no risk of resonance, and the stresses in the wheel elements reach values close to the permissible values.

Another problem associated with the use of the flail wheel is high local stresses occurring in the undercut of the upper ram (fig. 2). When the material of the beater, containing a small crack or material defect, is subject to sufficiently high stress, the flail plate may break [3], and the result is a serious failure of the coal mill. It is therefore important to determine whether the stresses in the undercutter are at a safe level.

Modeling methodology

From the practical, engineering point of view with reference to the flail wheel analyzed, it is justified to use methods that allow to reduce the task size, namely:

- due to the construction form of the flail wheel – the use of cyclic symmetry constraints,
- due to the local nature of the phenomena occurring at the interface between the beater and hub – modeling using sub-models (sub-modeling), in which the initial task can be first solved based on the coarse mesh of nodes, and then analyze the areas of the key model meaning, reproducing them more accurately on compacted grids – sub-models. Then, the displacements calculated at the model division boundary and the contact surfaces are interpolated using the shape function and treated as marginal conditions for the sub-model [2]. If the cutting limits are located at a sufficient distance from the place of stress concentration, one of the fundamental principles of material strength is met – the de Saint-Venant principle.

The use of symmetry constraints (including cyclic symmetry constraints) in the analysis is common. It is different with the use of sub-models. Relatively rarely described proprietary solutions relate to problems in which significant phenomena are local in nature. Among them, a large group are publications on issues related to fatigue, fracture mechanics and reliability in various fields of technology [7–9, 12]. A lot of publications were devoted to the analysis of phenomena in various combinations: screw [10, 14] and welded [11, 13]. In fact, none of them attempts to assess the effectiveness of such a modeling method. It is assumed there that it will benefit. Therefore, the presented work demonstrates how the application of job size reduction techniques affects the efficiency of computational models.

Discrete model of flail wheel and sub-model

Development of the discrete model was divided into two stages. In the first one, a structural analysis of the beater of the flail wheel was made, and the main purpose was to determine the deformations of the flail wheel under the load resulting from the working conditions so that the results of this analysis could be used as boundary conditions for the next stage of calculations, i.e. calculations using sub-model.

The discrete computational model for finite element analysis using the ANSYS package was built based on a simplified geometric model of the flail wheel. Simplifications consisted in eliminating the beveling, rounding, fasteners and small-sized holes. Due to the possibility of using cyclic symmetry constraints, and thus reducing the size of the task, a single fragment of the flail wheel was considered.

Its discretization was based on an element from the ANSYS – Solid185 program's bibliography. It is an eight-element solid element with three degrees of freedom (displacements in three directions) in each node. At the interface between the flails and struts as well as the beaters, hub and ring (places marked in red in fig. 2), surface-to-surface contact elements (Conta172 and Targe169) were inserted with the coefficient of friction specific to the steel-cast steel set μ = 0.15. The model consists of 565 536 nodes and 124 980 finite elements.

The kineto-static task was solved, assuming that only the inertia forces caused by the movement with the working speed act on the flail wheel. In addition, a thermal load related to the working temperature of the wheel reaching in extreme cases the value of T = 400 °C was set. During the grinding, resistance forces appear, which are the effect of the feed on the part of the flail wheel. Experience shows that they are negligibly small compared to loads from inertia forces.

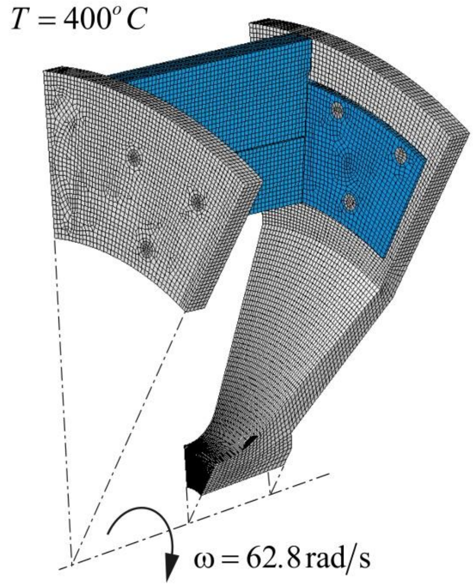

Fig. 3. Discrete model of a flail wheel section

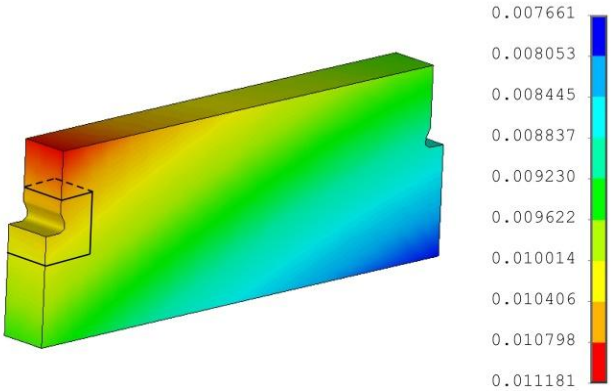

Fig. 4. Displacements of the beater plate m and sub-model boundaries

The results of flail wheel deformation analysis will be used to build a sub-model with appropriately compacted finite element mesh – to reduce the error of shape approximation of the beater.

The sub-model will be a part of the upper beater panel covering, with a slight excess, the place of contact between the upper and the hub and the outline of the undercut – as shown in fig. 4. The displacement determined on this cut will be boundary conditions for the sub-model.

An important step in such an analysis is to determine whether the sub-model boundaries have been defined correctly. For this purpose, the values of reduced stresses at characteristic points at the boundary of the cut with the finite mesh of finite elements were compared (fig. 6) and the results obtained during the analysis of the deformation of the flail wheel (fig. 5). It can be noticed that the values of stresses in both analyzed models are similar (differences do not exceed 6%), which allows to conclude that sub-model boundaries have been correctly determined. Sub-model with compacted net consists of 31 076 nodes and 6864 finite elements.

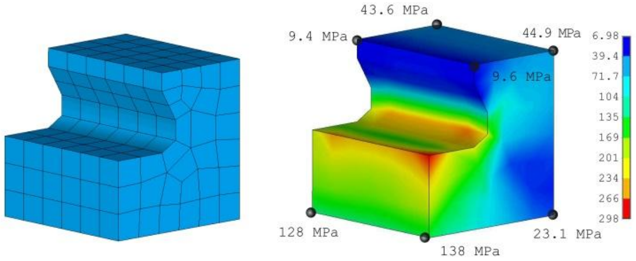

Fig. 5. FEM mesh and stresses from the analysis of a bi-axial sector model, MPa

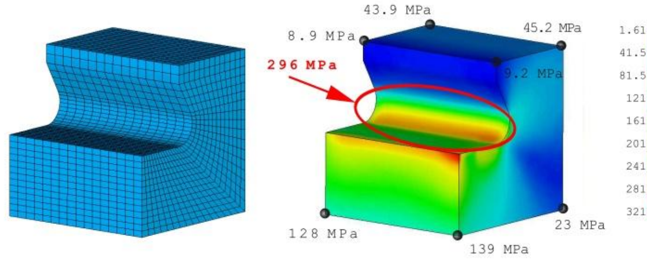

Fig. 6. FEM mesh and stresses from sub-model analysis, MPa

Calculation results. Evaluation of the effectiveness of the presented models

The stresses in the undercut of the beater are 296 MPa (fig. 6) and are lower than the yield point, which is approximately 320 MPa for the hammer material at 400 °C [1]. These stresses are at a safe level, and therefore – with the careful machining of the undercut surface – the risk of cracking the hammer plate is low. The accumulation of stresses appearing in the corner of the fuse (fig. 5 and fig. 6) is irrelevant from the point of view of the conducted analysis. This is the effect of the "blade" created as a result of supporting the corner of the hammer plate on the inner surface of the ring. This place should be treated as a singularity.

To assess the numerical efficiency of the computational model proposed, a graph was made that visualized the disk memory usage during calculations in the time function. The result for the analysis of a single section of the flail wheel (fig. 3) and for the full wheel model (created by copying the slice model ten times) is shown in fig. 7.

It can be noticed that the use of cyclic symmetry constraints allows for more than forty times the calculation time (56 minutes vs. 38 hours), and the peak demand for disk resources during analysis is more than five times lower (23.7 GB vs. 122 GB). After the analysis the size of the working folder in the first case was 4.7 GB, and for the full model 21.2 GB. This gives an erroneous idea of the need to ensure adequate disk space – the instant demand for disk space is several times larger. Sub-model analysis, however, lasted about 2.40 minutes, which is a small fraction of the calculation time for the section model and the entire circle, and the calculations required only 1.05 GB of disk storage. These values confirm the usefulness of the proposed modeling methodology.

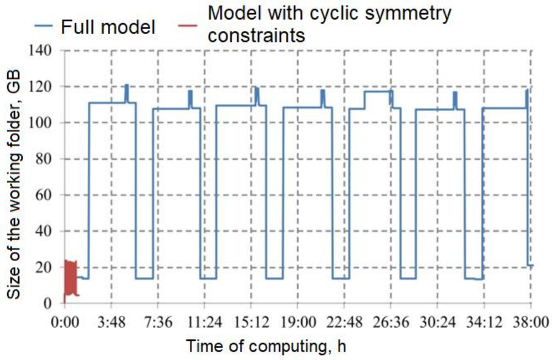

Fig. 7. Summary of the total time of calculations and consumption of disk resources

Conclusions

When preparing a discrete model for analysis using the finite element method, it is worth from the beginning to take into account its computational efficiency. In the described task, a significant advantage in terms of computation time and the amount of necessary disk memory resulted in the use of cyclic symmetry constraints and modeling techniques using sub-models. The advantage of such a modeling method is also the fact that the output, often a very complex task, is solved once, and sub-models with significantly lower complexity are used for subsequent calculations.

In the case of the task discussed, it is possible, for example, to analyze different shapes of undercuts without the need to re-analyze the entire flail wheel assembly, as well as formulate and solve the optimization task.

Referring to the analysis object, it can be stated that the assumed shape and dimensions of the undercut of the wheel beater meet the adopted stress criteria.

REFERENCES

1. Adler P.H., Olson G.B., Owen W.S. „Strain hardening of Hadfield manganese steel". *Metallurgical Transactions* A. 17A (1986): pp. 1725–1737.
2. Ansys Help SYSTEM 2005.
3. Ashby M.F., Jones D.R.H. „Materiały inżynierskie". Warszawa: WNT, 1997–1998.
4. Danielczyk P., Wróbel I. „Wpływ wielkości zużycia elementów koła bijakowego na częstości drgań własnych i naprężenia". *XXII Sympozjon PKM. Gdynia–Jurata* (2005): pp. 255–262.
5. Danielczyk P., Wróbel I. „Zastosowanie inżynierii odwrotnej do oceny bezpieczeństwa eksploatacji kół bijakowych". *Mechanik*. 2 (2014): pp. 1–8.
6. Danielczyk P., Wróbel I. "The choice of the shape and optimal dimensions of the beater relief". *Acta Mechanica Slovaca*. 10 (2009): pp. 89–98.

7. Farragher T.P., Scully S., O’Dowd N.P., Leen S.B. “Development of life assessment procedures for power plant headers operated under flexible loading scenarios”. *International Journal of Fatigue*. 49 (2013): pp. 50–61.
8. Hornikova J., Zak S., Šandera P. „K-calibration of special specimens for mode II, III and II +III crack growth”. *Engineering Fracture Mechanics*. 110 (2013): pp. 430–437.
9. Hou J., Wescott R., Attia M. „Prediction of fatigue crack propagation lives of turbine discs with forging-induced initial cracks”. *Engineering Fracture Mechanics*. 131 (2014): pp. 406–418.
10. Mandal N.K., Dhanasekar M. „Sub-modelling for the ratchetting failure of insulated rail joints”. *International Journal of Mechanical Sciences*. 75 (2013): pp. 110–122.
11. Pettersson G., Barsoum Z. “Finite element analysis and fatigue design of a welded construction machinery component using different concepts”. *Engineering Failure Analysis*. 26 (2012): pp. 274–284.
12. Predan J., Mocilnik V., Gubeljak N. “Stress intensity factors for circumferential semi-elliptical surface cracks in a hollow cylinder subjected to pure torsion”. *Engineering Fracture Mechanics*. 105 (2013): pp. 152–168.
13. Vogt M., Dilger K., Kassner M. “Investigations on different fatigue design concepts using the example of a welded crossbeam connection from the underframe of a steel railcar body”. *International Journal of Fatigue*. 34 (2012): pp. 47–56.
14. Zarzalejos J.M., Fernández E., Caixas J., Bayón A., Polo J., Guirao J., García C., Rodríguez E. „Bolted Ribs Analysis for the ITER Vacuum Vessel using Finite Element Submodelling Techniques”. *Fusion Engineering and Design*. 89 (2014): pp. 1790–1794.

■

Translation of scientific articles, their computer composition and
publishing them on the website www.mechanik.media.pl
by original articles in Polish is a task financed from the funds
of the Ministry of Science and Higher Education designated
for dissemination of science.

Ministry of Science
and Higher Education
Republic of Poland