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Advanced numerical simulations of selected metallurgical units

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Analysis and modelling

ABSTRACT

Purpose: of this paper is to present numerical simulations of large structures in metallurgical industry. Some examples of finite element analysis are presented. The calculations were performed for the determining the stress effort of the metallurgical units mainly blast furnace, throath's gas pipelines, hot blast stoves, etc. during the working conditions and for the repairing purpose.
Design/methodology/approach: The way of conducting simulations and analysis were the finite element method connected with the optimization process.
Findings: Performing the numerical analysis the changes in the structures design were applied what extremely influenced on the state effort and the durability of considered structures.
Research limitations/implications: Development of the presented approach solving the coupled field and CFD problems, the application of the parallel computing and domain decomposition methods in the large structure simulations.
Practical implications: Presented results shows the possibility of application the advanced computational methods in the computer aided engineering processes of designing and analysing the large structure as the metallurgical units are. It can dramatically influence on the recognizing of the effort stets and helps in the monitoring, overhauls and redesigning process. Those methods gives the global very precise information which cannot be obtain in other ways (analytical solutions, experimental methods).
Originality/value: The paper present the original research results comes from the complex numerical simulations of the main metallurgical units in the blast furnace train. The original value of the paper is the introduction of the advanced finite element simulation in the field of iron steel industry structures design and developing.
Keywords: Blast furnace numerical analysis; Finite element method; Metallurgical units analysis; Numerical simulations

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1. Introduction

The paper presents the review of researches undertaken in the Department for Strength of Materials and Computational Mechanics, Silesian University of Technology in cooperation with the biggest steel industry factory in Poland. The main aim of this cooperation over the years were analyses and simulations of the effort state of the main metallurgical units under the heavy work conditions. Some of this simulation was conducted for the purpose of the redesigning of structures, like blast furnace jacket, in order to extend its lifetime and durability, other were conducted for preparing the safety conditions of damaged repair (blast furnace throat's gas pipelines) or for preparing the main directions of the repair process (hot blast stoves). Some of them were conducted after the structure damage situation for redesigning direction of bad designed units (outlet nozzles of electro-filters units, carry-over cooling bed).

More of the main units in the steel industry were produced many years ago when the numerical calculation were not used. According to the specific technical condition those structure cannot be replace too often to moderns one. This is connected mainly with the technical and economical restrictions. One of the way to improve this type of structures are design changes during the repair periods.

The complexity and the difficulty of structures being the subject of the simulations are visualized in Figure 1. Over the years most of the main steel industry units were analysed [1,2,3]. More of them were reconstructed on the base of gathered results and recommendation what significantly raised the safety and lifetime of the structures and its resistance to hard work conditions.

One of the first objects subjected to a thorough numerical analysis was the armor of the blast furnace. It should be noted that the final project after those analyses and simulations was successful with the blast furnace jacket, whose life was significantly extended (2-3 times). Previous designs had provided periods of 3-4 years of work.

There were also conducted works on the modernization of elements such as the dome of the blast furnace, main throat's gas piping, hot blast stoves, dustcatcher, static exhaust manifold and some others. The main goal of analyses was to check the status of their effort, to propose design changes and to determine the impact of changes on the distribution of stresses and displacements in the most stressed elements.

The necessity of modern advanced simulations was dictated in most cases by high failure rate and expensive renovations conditions.

2. Strength analysis and numerical simulations

Typical steel industry units mostly are the large object with extremely complicated geometry. From the mechanical analysis point of view they are under complex loads and boundary conditions both the mechanical and thermal types. The typical design process of fundamental units like blast furnace, convectors, throat's gas pipes was for many years based only on the designing principles and basic calculation. The complex stresses and strains calculation for gathering the global information about effort state was not possible using classical analytical known solutions. Nowadays the typical designing process is based on the computational mechanics method [4]. Using the Computer Aided Designing (CAD) processes connected with the Computer Aided Engineering (CAM) technology it is possible to produced high strength with long lifetime optimal designed structures. Main method which is use for numerical analyses in CAE systems is the finite element method [5]. Those method has become most popular and effective in the computational mechanics and has a strong position in field of numerical simulations and analyses of mechanical structures. The main steps in the finite element method calculations are:

- to build a discrete model using finite elements,
- to apply the loads and boundary conditions,
- to model the material,
- to perform a analysis,
- to interpret results.

Those steps finally lead to obtaining the numerical model for finite element analysis which gives the full displacement and stress filed of analysed structure in to analyse form of colour maps.

2.1. Blast furnace jacket

The main unit in the ironworks is the blast furnace. Those huge structure with approximate dimensions 40 m high and 15 m diameter works under extremely hard mechanical conditions and high temperature. The unit considered in the research was designed on the base of best designer knowledge. But years ago they did not have access to the contemporary computational mechanics methods in form of computer aided engineering.

Before the starting the next campaign blast furnace undergo general repairs. On the base of designer's decisions the computers simulations were involved in the process of re-designing and optimization of the blast furnace jacket. The new geometry shape was looking for what should secure extension of working lifetime.

The strength analysis of the blast furnace jacket construction, then the process of shape optimization and the optimization of the distribution of holes in the plate coolers were the main objective of the performed analyses and simulations in this case.

The analysis had had to indicated how the shape of the jacket (inclination angles in the blast furnace zones), and the jacket weakness by coil holes, flush holes and hot air nozzles holes influence on the reduction of effort state.

In addition, it was necessary to change the distribution of holes in the plate coolers to ensure the optimal stress distribution which does not cause continuous failure of those elements. The outcome results should lead to extend the maximum time of structure continuous operation (periods between blast furnace reline).

Blast furnace jacket construction with a dome is a very complicated mechanical system, whose strength analysis requires the use of advanced computational methods of mechanics. The method, which allows to perform a complex strength analysis, ensuring the high results accuracy is the finite element method [5].

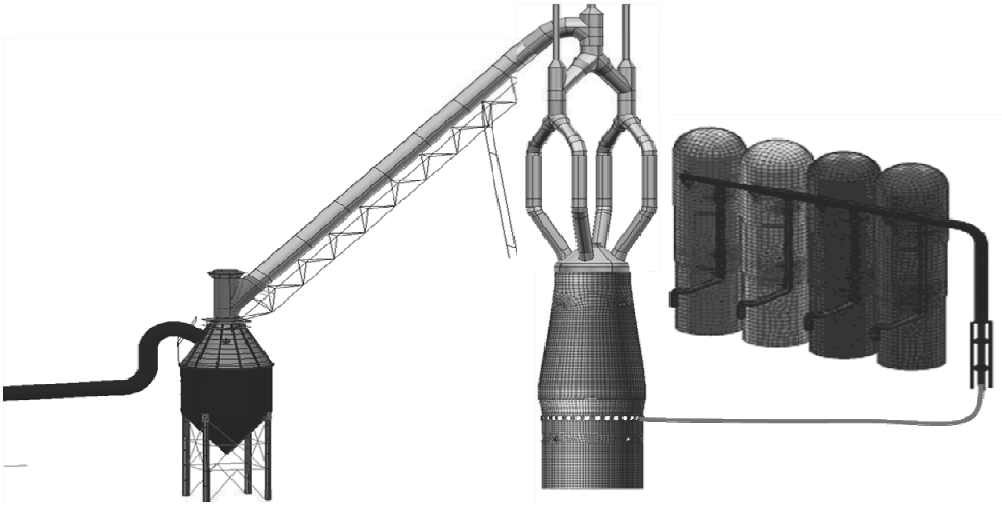

Fig. 1. The blast furnace with main auxiliaries (main technological stream)

The numerical discrete model which is the basement of the numerical analysis was built and is presented in Fig. 2. Loads and boundary condition reflect the real work conditions. Mainly they are: self weight, inner pressure, temperature [6], auxiliaries, weights, inner friction forces between a feed and a brickwork etc. Blast furnace jacket was modeled using 8-noded quad element with quadratic shape function taking into consideration a variable thickness of individual zones.

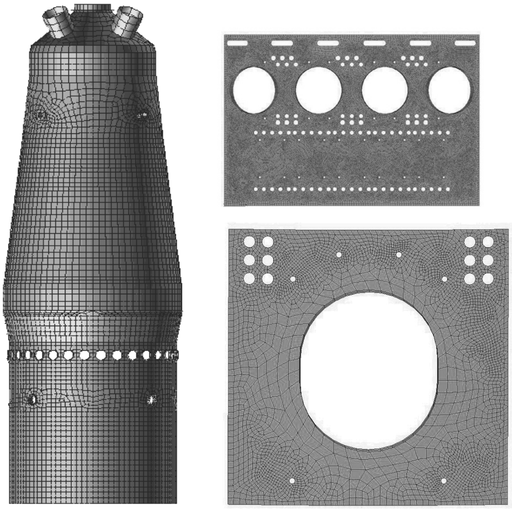

Fig. 2. The numerical model of the blast furnace and cooling plates

In a global numerical model only a large holes: the hot air nozzles (∅970 mm) and flush holes (oval 1120 mm to 1300 mm) were considered. Due to the size of the problem and symmetry, the calculation was done only for a quarter of a blast furnace jacket. The numerical model, called here the "global" has not modeled holes for the coils (∅110 mm and below) and box-holes due to their small size. Their influence, however, was taken into account by introducing the so-called. effective thickness of the zones of their occurrence. The effective thickness of coils and box-holes zones were determined by comparison of the volume of zones, with and without holes. For proposed model the static linear analysis was performed. As a result of the numerical stress analysis of the global model, the distribution of stresses and displacements was determined (Fig. 3).

a) b)

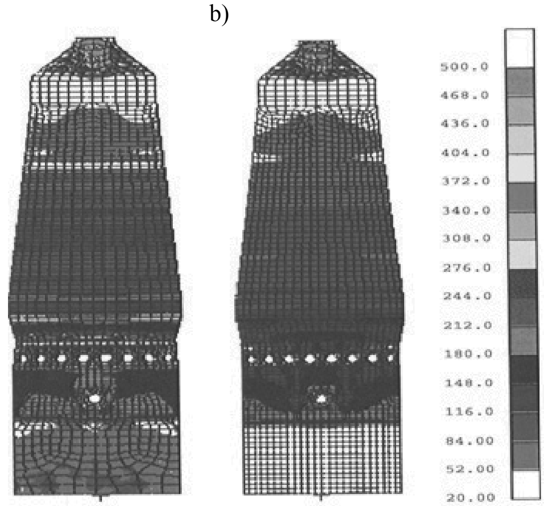

Fig. 3. Blast furnace von misses stress distribution (a) before and (b) after reconstruction

The obtained results present the stress distribution in the whole jacket and show the most stresses zones, but do not give information about the local distribution of stresses around the, for example, coils holes. In order to obtain stresses concentration around holes of small diameter (diameter ≤110 mm), in the holes zones, additional local numerical models of the jacket segments including exact geometry of the holes in the cooling plates in the most stressed zones were prepared (Fig. 2).

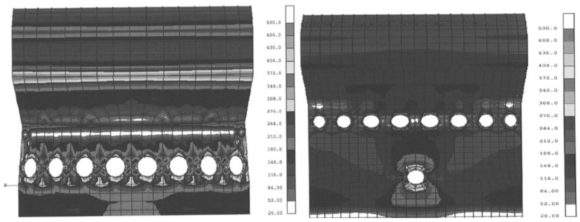

Fig. 4. Detailed stresses state in the most stressed zones: a) before and b) after reconstruction

Analyzing results of numerical simulations for the blast furnace jacket with geometry as shown in Fig. 6a, it was found that in the transition zone from the waist to boshes there is a region of stresses which rich the yield point in the entire cross-section (Re = 380 MPa at 20°C and 340 MPa for Re = 300°C) (Fig. 4a). The existence of such zones in the entire cross-section disqualified the structure from the mechanical safety point of view (Fig. 3a).

Performed variant optimization made it possible to propose the significant modifications of the geometric form of the boshes zone. After changing the geometry, as shown in Fig. 6b, von Misses stress in the crucial areas significantly decreased and did not exceed 180 MPa (Fig. 4b). Based on the results obtained after geometry changes the local fragments with the coils and plate coolers holes were chosen to be analyzed.

Analyzing the results of calculations for different spacing and holes positions it was found that it is more advantageous variant when the holes are located horizontally then vertically. In the case of arrangement of holes along the vertical line there is a significant concentration of stresses along the line connecting holes (Fig. 5).

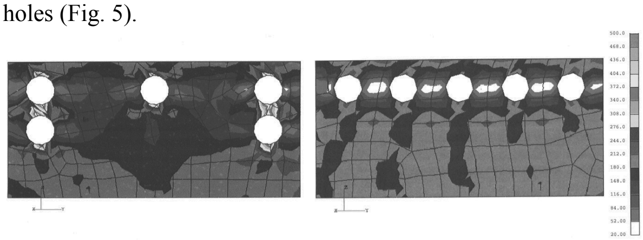

Fig. 5. Different cooling plates holes position

Conducted analyses lead to the optimal outer shape of the blast furnace jacket. The final optimal blast furnace jacket geometry is presented in Fig. 6b. The optimization process determined the holes distribution in the plate coolers what significantly influenced on the stress state in this regions and raise the stress capacity of those zones.

2.2. Blast furnace throat's gas pipelines

Some of simulations for example for main blast furnace throat's gas pipelines, carry-over cooling bed were crucial for conducting the repairing work and refitting the main units technological purpose.

The set of main throat's gas pipeline taking away gas from blast furnace to the filtration system has been analyzed to identify opportunities to extend its service life. The abrasive and corrosive work conditions leads to thickness lost of the pipes shells. It is dangerous for the stability of the structure and required be repaired during blast furnace campaign. The main goal of the simulation was to determine the main steps of running repair and sequence of sheet metal plate replacement in such the way that the hole structure will be still in use and works would be done during short stops of the planned maintenance.

a) b)

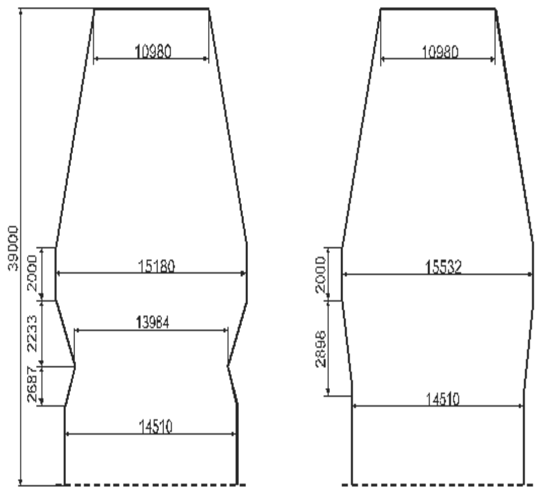

Fig. 6. The old (a) and the optimal (b) shape of the blast furnace jacket

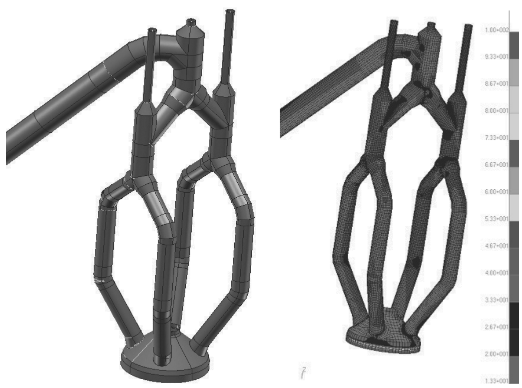

Fig. 7. The numerical model and von Mises stress state of the throat's gas pipeline

Conducted detailed numerical analysis of the main throat's gas pipelines with additional external loads as wind, temperature changes, allowed to determine the effort state of the construction (Fig. 7) with measured thickness of the pipe's wall. It leads to determination of structural changes in critical areas and preparing the system relieving through applying appropriate temporary supports in form of hoods, ropes, elastic supports and expansion joints. The detailed numerical simulation of the structure behavior with removed plates during the repair process allowed to determine the exact stress and displacement state, what is helpful in the plate replacement planning process (Fig. 8). The introduced changes have allowed the operation of the structure until the planning overhaul time.

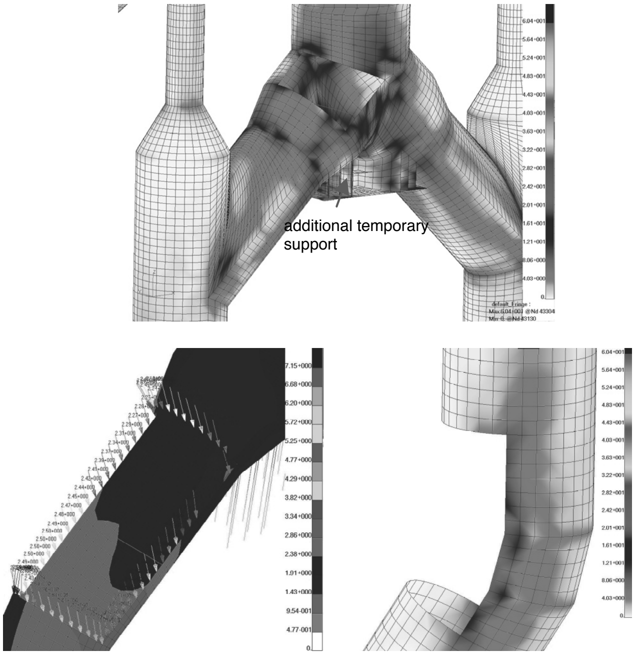

Fig. 8. Repairing places with displacement and stresses state

2.3. Hot blast stoves

A common design error that appears in the analyzed structures is to overstrained the system, binding together two structure working independently, what consequently leads to the formation of a significant stresses with excess of the limit values. This type of structure results in knock-out or breakage of connectors and supporting elements.

An example of this type of construction is a set of hot blast stoves (Fig. 9), where a main gas pipeline was directly attached to stoves. The high working temperature of the stoves and irregular, separate cycle of their work, results of changes in their shapes what caused twisting and knockout connecting parts (Fig. 10 and Fig. 11). The performed computational simulations allowed to fully identify this phenomenon. Analysis of the effort states and the operating states of objects gives grounds for structural changes to ensure the construction correctness and reliable failure-free operation. Major changes relayed on systems separation (stoves and pipes) and creating a new system of fixing and hanging, which meant that the pipeline system has become much more flexible. In conjunction with eliminating factors which caused high stresses the new system of pipes handling was created where stresses were cut by half what secured a safe reliable operation.

The finite element model prepared for numerical simulation is presented in Fig. 9 and the global displacements with stoves deformations are presented in Fig. 10. Those figure presents the nonuniform changes in shapes of stove what was the main reason of a failure.

Rigid support connectors attached directly to the stoves caused the high stresses in those parts what is presented in Fig. 11.

Fig. 9. Hot blast stoves discrete model

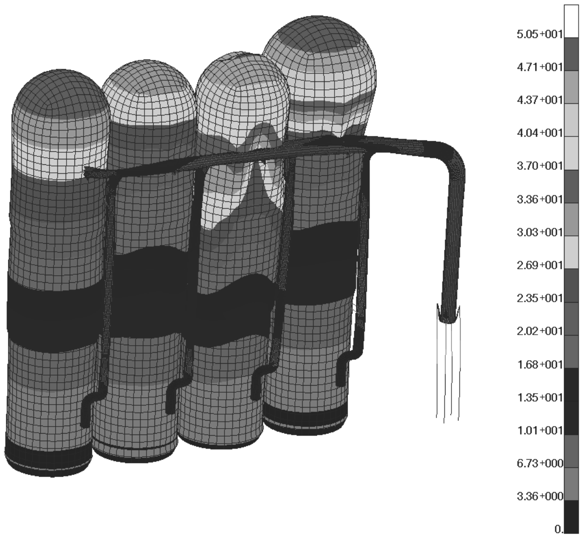

Fig. 10. Hot blast stoves deformations

2.4. Dustcatcher

The last unit in set of throat's gas pipeline is the dust collector, whose main task is to gather the dust from blast furnace gas. The original design did not foresee enough the dust abrasive action and the issue of loss of capacity due to the change in thickness of the plates during the operation of the object has arisen. The computational simulation allowed to determine the minimum value of plates thickness in different areas of the plating. On this basis it has became possible to monitor the facility and conducting any renovation work. The finite element model prepared for numerical simulation is presented in Fig.12 and the global von Mises stresses distribution are presented in Fig. 13 in the cold-hot scale value.

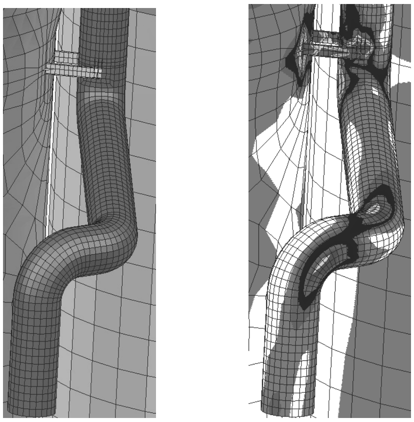

Fig.11. High stresses in supports generated by rigid connection to the stoves

Fig. 12.The detailed finite element model of the dustcatcher

Fig. 13. The von Mises stresses distribution in the dustcatcher (cold-hot scale of values is applied)

3. Conclusions

It is known that there are a very small possibilities to determine the exact state of the structure in case of complex objects working under a complex state of loads using traditional analytical methods of solution. There are of course defined calculations procedure by standards computational schemes typical for some structures (e.g., drums, shafts, etc.) but they do not offer the possibility of globally focus on the issue. In the case of non-standard constructions working in the complex state of loads in hard environments an accident often occurs, shortening the operation time and in a extreme cases, to completely destroy the structure.

The application of computer aided engineering systems is currently the only way to safe design. These systems offer great opportunities to simulate the behavior of structures under realistic conditions. The results are a thoroughly modern structures, sometimes with surprising shapes, but first of all meeting the strength and functional requirements.

The appropriate newest regulations giving the structure operation permission require verification by numerical methods of the object effort. Most of them considered as a standard the conducting the fatigue calculation time of "life" of the structure.

Presented examples clearly demonstrate a great potential of application of the advanced computational methods, mainly finite element method, in the high structure analysis which are closely connected with the iron and steel industry.

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