# Optimization of the metal masts construction with taking the advantage of ANSYS® Mechanical™ and IOSO® software.

Dmitry Frolov
*PLM Ural – Delcam-Ural Group Of Companies, Russia*

## Abstract

Sooner or later each manufacturer, because of the rising level of competition on the market, will have to find a way to decrease the expenses and to increase the profit. Optimization is the way to make that. In this paper optimization of metal masts construction using ANSYS Mechanical and IOSO algorithms will be discussed. Loads are automatically calculated according to the Code of Rules 20.13330.2011 and load-bearing elements are checked for strength and stability according to the Code of Rules 16.13330.2011. After the optimization run a Pareto set is created which allows to manually choose an optimal variant of construction.

*Keywords*: Optimization, construction, mast, ANSYS, IOSO.

## 1 Introduction

Nowadays most of the industry enterprises and manufacturing companies have implemented computer-aided engineering software (CAE) into their work and production cycles. This software is often used on the stage of technical project to estimate if the structural decisions were correct. The next step is to use CAE on earlier stages of development of the product. This step is caused by escalating competitiveness on inner and outer markets.

One of the ways of reducing the expenses on the stage of developing a product and rising its competitiveness is to use the contemporary instruments of optimization and automated CAE tools. This technologies allow to find the best constructive decisions, meanwhile with thanks to various mathematical methods walk away from direct search through the whole field of project parameters.

With raising in geometric progression coverage area of cellular communications, more and more points with aerial equipment are needed. Sometimes there are no chimney shafts or similar high structures, that are suitable for placing the equipment, that's why building of a new object is often necessary. Such constructions must meet all the quality standards and at the same time their production must be economically based and effective, but often these two criteria are mutually exclusive.

In this article we will consider the process of estimating the optimal construction of a metal mast with the help of ANSYS software and IOSO optimization algorithms. The aim of the optimization is to find the most economically effective parameters of the tower-type mast construction. This algorithm can also be used to estimate the most effective construction of the tower cranes or various cable-stayed structures.

## 1.1 *Software used*

### 1.1.1 ANSYS

ANSYS products family in the sphere of deformable body mechanics allow either to run general approximate solutions or to perform a deep detailed analysis. ANSYS products are widely used in different sectors of industry by people with various knowledge and level of expertise, from constructors to science-engineers. A great range of capabilities can be used to perform all types of analysis, from pure linear to highly non-linear coupled-physics analysis and due to adaptive architecture ANSYS's instruments have flexible workspace that allow to implement 3rd party software.

### 1.1.2 IOSO

New high-performance technology for multicriterion optimization IOSO (Indirect Optimization on the base of Self-Organization) (by prof. Egorov) from «Sigma Technology» company is based on its own unique algorithms of optimization, that allow to estimate the optimum in cases that were too complex to solve without an effective method. The strategy of performing the optimization is based on different principles then other well known approaches of non-linear programming. According to the logic of IOSO algorithms the response surfaces of optimization criteria and bounding parameters are arranged on each iteration. After that IOSO uses the obtained surfaces to determine the extremum and the solves the mathematical model in that point. During the optimization run the information about the explored system is gathered into one source, which leads to higher quality of the final response surfaces.

# 2 Description

## 2.1 *Model*

The model is a spatial truss-type construction with 20 meters in height that consists of ten identical sections. In plan view the section is a square, all the elements in the construction are equilateral L-bars. One cross-section is used for struts, second for all braces and spacers. Direction of the braces and diagonal spacers is reversed each segment of the section to give the construction an extra stiffness (Figure.1). Steel 245 was used for the material of the mast (one of the most frequently used in producing hot-rolled metal).

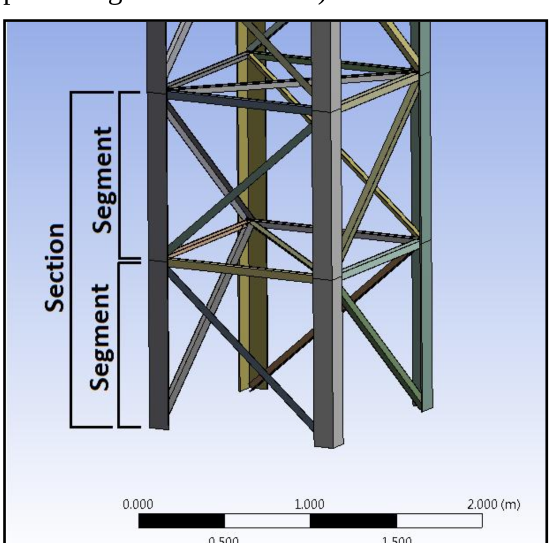


Figure.1 Construction of the mast.

## 2.2 Analysis

For this analysis an ANSYS Workbench project is used. Project schematic consist of four modules: one is a modal analysis, two for linear static analysis with applied loads and the last one is used only for making code checks proceeding from output data of previous three analysis (Figure.2). This project allows an automated creation of the geometry, generation of the finite-element model, calculating and applying the wind loads, solving the model and post-processing the results. Also it produces several output parameters that allow to quickly understand if the load-bearing elements meet the criteria for strength and stability.

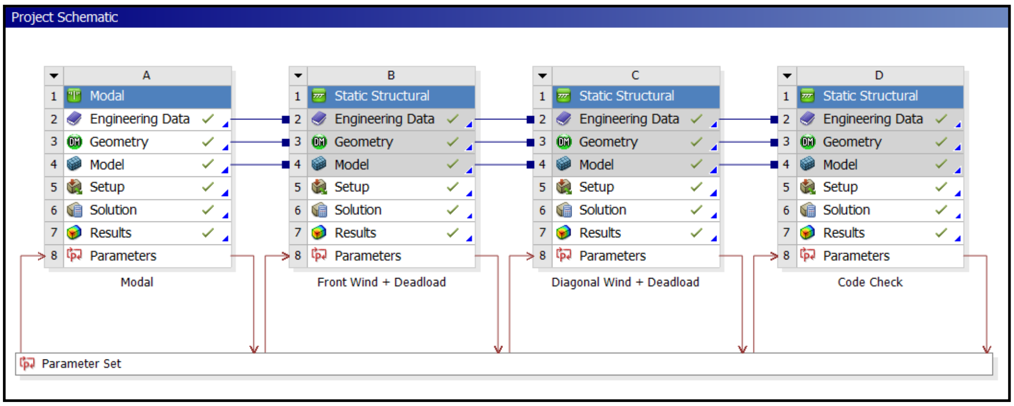


Figure.2 Workbench project schematic.

Loads for the mast are: dead weight, weight of equipment, wind pressure on construction and equipment. Weight of the equipment was taken equal to 200 kg and the wind area equal to 3 $m^2$. Density of the mast's material is 7850 $kg/m^3$, but according to the Code of Rules 20.13330.2011 (actualized version of SNIP 2.01.07-85*) it was taken with a coefficient 1.05. Wind load was also calculated according to this document. It was chosen that the mast is situated in the first "area" where the wind pressure is equal to 0.23 kPa (Moscow), "B" was set for the type of territory that is used for cities, woodlands and other territories that are uniformly covered with obstacles not higher than 10 meters. Static and oscillatory (pulsation) components of the wind load were calculated with a glance of changing of the construction and were defined as point loads, applied to each section. Oscillatory component was calculated according to the formula (11.7) in Code of Rules 20.13330.2011, so for each variant a modal analysis with the influence of the equipment's weight was ran to obtain the first natural frequency that is used in calculations of the load. To find the maximum stresses and deflections in the construction two variants of wind load were calculated - frontal and diagonal.

Check of the load-bearing elements was made according to the Code of Rules 16.13330.2011 "Steel Structures" (actualized version of SNIP II-23-81*). Braces and spacer were checked as centrally compressed elements, struts - as elements with axial force with bending. Also a check for deflection from wind load was made, where deflection must be smaller than 1/100 of the height of the construction, and a check for maximum flexibility of the elements.

During the solution run of the project, ANSYS Mechanical performs a modal analysis to find natural frequencies and shapes, two linear static analysis with different combinations of loads to find stresses and strains and an additional solution to implement code checks. In every analysis to perform a number of parameterized operations a command snippet with different APDL macro was used (Figure.3). Because ANSYS Mechanical uses Mechanical APDL solver, such snippets fits well in the project. Finite element model was generated with BEAM188 elements. Mesh density insignificantly affect the results, so to decrease the solution runtime only one beam element was used through the length of the strut, brace and spacer.

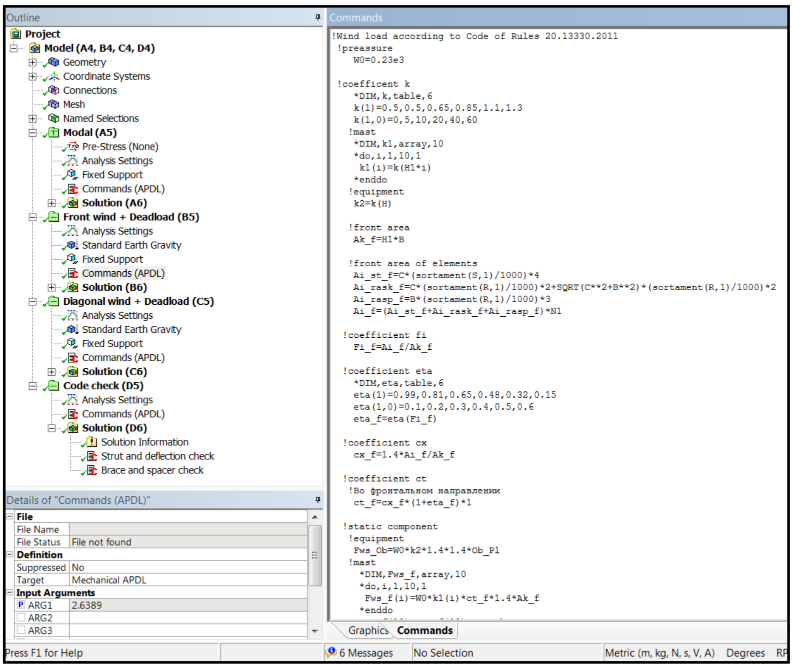

Figure.3 APDL macro in ANSYS Mechanical.

## 2.3 Parameters

Altogether there are 4 different input parameters, 84 inner parameters that are calculated with using the tabular data from Codes of Rules and 7 output parameters in the project. Input parameters are: width of the section, number of segments in one section and numbers of shapes from hot-rolled assortment for elements. They are used to create the geometry of the section (Figure.4). Inner parameters are used to automatically calculate the loads and perform the cycle of code checks. After that seven output parameters are generated to estimate the goodness of the masts variant. They are: mass of the whole structure, three parameters are strength criteria for the most loaded strut, brace and spacer, two parameters that control the flexibility of strut and brace (because brace is always longer than the spacer, a check for spacer is not required) and a parameter that checks maximum deflection of the structure.

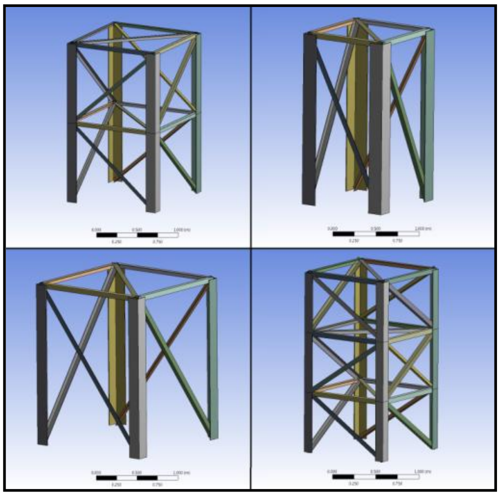
Figure.4 Different variants of the masts section.

# 3 Optimization

Starting from version 2.1.60 IOSO software supports a combination with ANSYS Workbench (as well as Mechanical APDL) and interacts with it without using the interface. All what needs to be done is to define the input and output parameters and optimization criteria. In this case optimization criteria were minimization of mass and deflection to provide the most stiff and lightweight construction. Input parameters were discreet: section width varied from 0.4 to 1.5 m with 0.01 m step, number of segments in the section varied from 1 to 4 and number of shapes from hot-rolled assortment varied from 15 to 99. Altogether these parameters give about 3 million of different variants of masts construction. Number of iterations, elapsed time or two of them together can be used as the criteria for stopping the optimization run.

Estimating the results from one variant of mast take about 1-2 minutes on 8 cores with 8 gb of RAM. To speed up the optimization run, a parallel version of IOSO (IOSO PM) can be used. It allow simultaneous processing of several variants and can be used on multi-core computers, workstations and clusters. That can significantly decrease the total time of optimization.

During optimization run IOSO doesn't perform a direct search through all the sets, but it performs an intellectual selection of variants according to its algorithms, that as much as possible approaches to the goal functions - decreasing of construction's mass and deflection with limitations from code checks. In this case ~1000 iterations were made and a Pareto set from 12 optimal points was created (Figure.5). Pareto set is a diagram that shows the dependence of goal functions, and shows how the saving of material affects on deflection of the mast. According to it user can choose the most suitable variant.

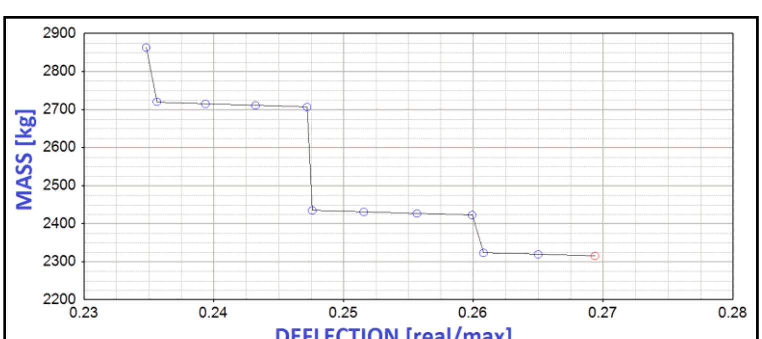

Figure.5 The Pareto set.

As an optimal one a mast with width of 0.95 m, 3 segment in a section, with 100x15 L-bar for struts and 35x3 L-bar for braces and spacers was chosen (Figure.6). The weight of construction without the weight of equipment is ~2300 kg. Stresses in elements don't exceed 95% of the maximum allowed according to Code of Rules 16.13330.2011.

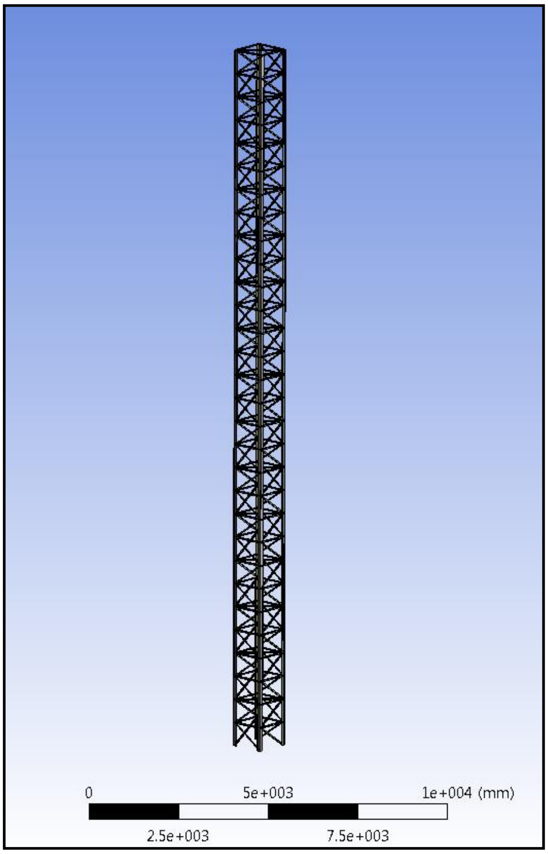


Figure.6 Optimal variant of masts construction.

# 4 Conclusion

Of course in comparison with classic methods this approach demands some experience and precision in APDL language and basic knowledge in optimization algorithms, but it opens a structural engineer a great field for activity and gives a new level of confidence that his decisions are optimal for the construction.

This example shows only one example of using an optimization during the design of a construction in civil engineering, but in reality the sphere of its application is almost unlimited. In the present time ANSYS together with IOSO is also successfully used in motor industry and turbomachinery.

Sooner or later each manufacturer, because of the rising level of competition on the market, will have to find a way to decrease the expenses and to increase the profit. Optimization is the way to make that. On one side optimization can help to find the most effective construction of a unique building or a part of a machine, on the other it will give great savings in a long term after optimizing a standard part or construction. Optimization is the future of designing and production.

# References

ЦНИИСК ИМ. В.А.КУЧЕРЕНКО - ИНСТИТУТ ОАО "НИЦ "СТРОИТЕЛЬСТВО" и др., 2011. СП 16.13330.2011: "Стальные конструкции"Актуализированная редакция СНиП II-21-81*.

ЦНИИСК ИМ. В.А.КУЧЕРЕНКО - ИНСТИТУТ ОАО "НИЦ "СТРОИТЕЛЬСТВО" и др., 2011. СП 20.13330.2011: "Нагрузки и воздействия"Актуализированная редакция СНиП 2.01.07-85*.

ANSYS INC. ANSYS 14.0: Release documentation.