USAGE OF TOPOLOGICAL OPTIMIZATION IN DESIGN OF MECHANICAL FORGING PRESSES

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This article deals with the usage of topological optimization method in the design of mechanical forging press. This area of industry is worldwide without significant development changes for long time. Topological optimization is used here for minimizing weight of forging press and maximizing stiffness of whole machine. Mechanical press with nominal force 80 MNis used as an example. Frame of press is made from two separate crossbeams and two preloaded columns. The article describes application of optimization methods for welded and also for casted frame of press. Remodeling and verification is performed for welded steel frame.Three optimization tools (FEM codes Tosca, NX Nastran and Frustum) were used for optimization.Main focus is here on upper and lower crossbeam. Optimization theory and parameters (design area, design objective and design variables) are described here from computational point of view. Method called “compliance” and “weight minimizing”was used with respect to considered machine. The simulation model for optimization is considering whole assembly of forging press. Submodeling was used as second step for refinement of results. Loading cases were considering centric and eccentric loading of press. All results were used to create new design of crossbeams for mechanical forging press with nominal forging force 80 MN.

KEYWORDS

mechanical press, topological optimization, deformation, weight, forging

1 INTRODUCTION

There are special demands in industry, which are applied on every production machine during design process. These demands are dependent on technological process (here it can be forging parameters, accuracy, force, etc.). Stiffness is important parameter for forging machines, which are working with forces higher than 10 MN. Direct dependency between stiffness of forging machine and accuracy can be found. Total deformations and clearances of machine are influencingproperties of final product. It can be said, that higher stiffness of forging machine leads to more accurate product. [Chval 2016]

Frame of forging press is most important part with respect to total stiffness. This is reason, why is frame of mechanical forging press chosen as part for optimization in this article. Increasing of weight is sometimes negative aspect of higher stiffness. Topological optimization is modern tool for finding new design solutions. [Raz 2015]

Designer is trying to make machine with highest stiffness and lowest weight. This task is dependent mainly on creativity, sensitivity and experiences of designers. There are new computational methods, which can be used in this area. Optimization of upper and lower crossbeam was used here as an example. Whole optimization process is described in this paper. Topological optimization is used here for minimizing weight of press and maximizing stiffness of whole press. Mechanical press with nominal force 80 MNis used as an example. [Raz 2016]

2 THEORY OF USED OPTIMIZATION METHOD

Topological optimization was used in generally described steps as follows:

- Creating of finite element model and topology solution.
- Defining of the design objective, such as minimizing weight or compliance restriction.Minimizing of weightwas mainly used during our simulation.
- Defining design area (it means the FEM elements to be considered in the optimization process).Maximal area was used here, where can be individual crossbeam placed. Areas, which has to remain in model (contact areas with other parts), have attribute “frozen”. It means that are not considered in optimization.
- Defining design constraints (lower and upper boundaries for weightor displacement in the optimized structure). Maximal displacement was used in our simulation. Point of maximal displacement was detected from analysis of initial design. Restriction was used as maximal displacement of new design have same value as initial design. These parameters are used for objective function definition (1) and volume restriction (2).
- Manufacturing constraint definition (if necessary)
- Solving of model.
- Remodeling of initial design and verification.

Objective function of optimization is described as minimization of compliance C combined with volume restrictions according following equations.

Objective function:

$$min\, C(x) = u(x)^T f(x) = u(x)^T K(x) u(x) \quad (1)$$

Volume restriction:

$$\frac{V(x)}{V_o} - V_r = \frac{\sum_{e=1}^{N} V_e x_e}{V_o} - V_r = 0 \quad (2)$$

, where:

f - global load vector containing the nodal forces
u - global displacement vector
K - global stiffness matrix
V(x) - volume of structure, whichis formed according to input variables “x”.
V(o) - total volume of structure
Vr- limiting value for volume. This value can be between 0 and 1 and it is representing optimal volume. [Siemens 2018]
Compliance is condition for optimization and it is inverse value of stiffness. The structure with highest stiffnesshas to be found within specified maximal volume. [Cechura et al. 2011]

3 DIFFERENT APROACHES TO OPTIMIZATION

There are different possibilities and solvers, which can be used for topological optimization. Our aim is to use more of them, compare them and according to results create optimized model of forging press. Main difference between approaches is in complexity of simulation model (it can considеronly one optimized part or whole assembly). It is obvious, that all approaches will lead to various computational time. Topological optimization is generally highly time and hardware dependent process. It has to be done in iterations and for complex model such this one is necessary to perform at least 100 optimization iterations. [Kubec 2014]

It is necessary to use finite element mesh with elements, which have same size through optimized volume. There was used advanced 3D hybrid mesh here. 3D mesh with brick elements CHEXA20 was used ininternal area of crossbeams. Tetrahedral elements CTETRA10 were used at surface of crossbeams. Transition between these two meshes is done by pyramidal elements CPYRAM13.

3.1 Submodeling by Tosca solver

The main aim of this paper is new design of mechanical forging press with usage of topological optimization. Two main parts (upper and lower crossbeam) were chosen. Our task was to minimize weight of whole machine with same and highest stiffness. First optimization approach was using Tosca solver (available is Siemens NX 11 software). Individual optimization of both crossbeams was performed here.

Input geometry for optimization is described in the Fig. 1. It is initial design of upper crossbeam with all inside cavities filled by material. Only upper crossbeamwill be shown as an example in following text. Lower crossbeam will be described as final optimized design at the end of paper. Optimization area is marked by orange colour in the Fig. 1. It was possible to use some boundary conditions (manufacturing conditions) for optimization such as extrusion vector. This allowed to have optimized rib in vertical direction and it is possible to manufacture them. Optimized design with ribs directions is shown in the Fig.2. Stiffness of this design is same as initial design and weight is 5% lower.

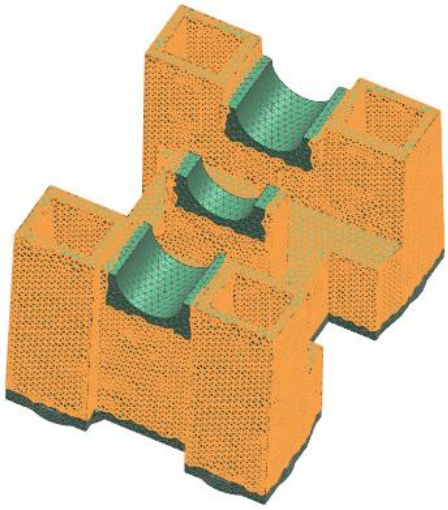

Figure 1. Design area for topological optimization of upper crossbeam

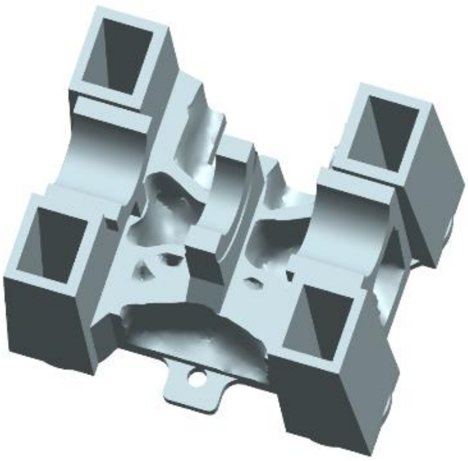

Figure 2. Optimized upper crossbeam- results from Tosca solver

3.2 Model of whole assembly

Optimization tool of NX Nastran software was used in next optimization approach. This allowed usage of whole assembly and considering influence of connected parts. Solution of individual parts without considering assembly in not completely correct.

Optimization method with considering assembly has one significant problem. Considering contacts will lead to solution, which will be extremely time-consuming. Reason are two iteration processes performed in one solution. One iteration processis donefor contacts (up to 20 iteration steps) and another is performed for optimization analysis (up to 200 iteration steps). Total number of iteration can be up to 4000. Computational time for one iteration (it depends on used hardware) is around 30 minutes. Total computational time will be than around 84 days. It is therefore necessary to simplify assembly for optimization. For our solutions were contacts replaced by manual couplings. This replacement neglects clearances and it was necessary to determine influence of clearance size on performed optimization process.

This was done by structural analysis of press. It is possible to see results in the Fig.3, where is performed displacement analysis with considering clearances in contacts (especially in guidance of ram) and with usage of manual couplings without clearances. Displacement and stress are comparable and error caused by couplings is not significant for topological optimization. Difference in deformation caused by replacing contacts by couplings is less than 0.3 mm.

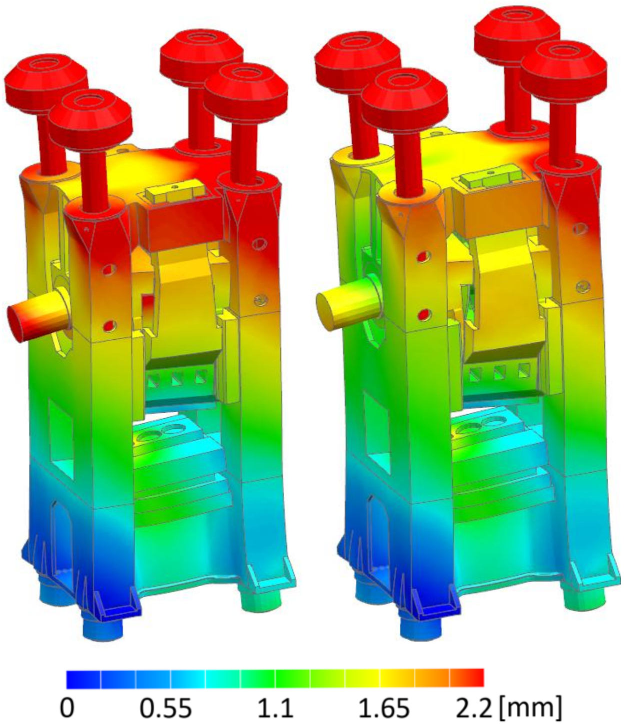

Figure 3. Comparison of deformations with respect to boundary conditions (left- coupling without clearances, right- contact with clearance)

Results of topological optimization with NX Nastran solver shows main orientation of material in upper crossbeam (Fig.4). Boundary condition of extrusionis not usedin this solution process, but it is possible to see same orientation of material as with Tosca solver. The material is oriented from central bearing to area of anchors in corners.

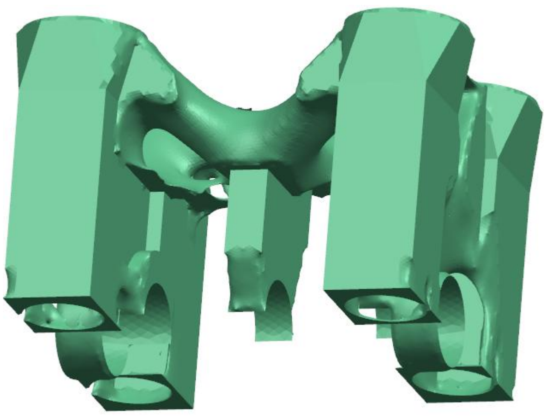

Figure 4. Optimized upper crossbeam- results from NX Nastran

3.3 Submodeling by Frustum optimization solver

Frustum optimization solver was used as last optimization method. This solver doesn't allow complex assembly (multibody model) bit it is simpleand fast optimization tool. It is obvious, that all results corresponding with previous simulations. Frustum solver allows in easy way to set up maximal thickness of each optimized member. Results in Fig. 5 shows optimized shape with maximal member size 150mm.Optimized shape without thickness restriction is comparable to previous method with Tosca solver.

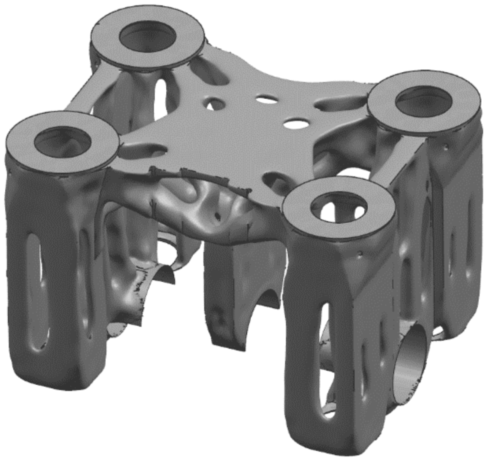

Figure 5. Optimized upper crossbeam- results from Frustum solver with maximum member size 150mm

Topological optimization of crossbeams can be summarised:

Upper crossbeam:

- Preloaded area in corners has to be in similar design.
- Support (or ribs) from central bearing has to be in X-shape from central point to corners. This will ensure stiffness for vertical and eccentric forces.
- Additional guidance of ram (placed in upper crossbeam) is not transmitting significant forces. It can be lighter.
- Preloaded corner areas (where are anchors placed) should have variable cross-section, which will be changed from rectangular to circular.

Lower crossbeam:

- Big influence of forging tool and forging table can be noticed. These geometries are stiff, heavy and are not changed in optimization.
- Forging table should have supports in corners and vertical support in the middle.
- Outline of lower crossbeam should correspond with outline of forging table and tool.
- Preloaded corner areas should have variable cross-section, which will be changed from rectangular to circular.

4 REMODELING OF OPTIMIZED PARTS AND VALIDATION OF DESIGNS

Remodeling of upper and lower crossbeam was used for validation of new design. New parts were created with respect to manufacturing possibilities (mainly to welding technology).

4.1 Upper crossbeam

New design of upper crossbeam was created with weight 98.4t . Weight of initial design was 105t (6.6 t was saved). Optimized crossbeam doesn't have upper plate and new ribs has constant thickness. Optimization showed ribs with variable thickness, but it is hard to produce them by conventional production methods. Direction of ribs is from central area to corners. Variable cross-section of corner areas (rectangular to circular) is also used here (Fig. 6). These design features were not usedin forming machines up to now.
Structural analysiswas used for simple evaluation of new crossbeam, where loading was simplified to vertical acting force 80MN. Initial (previous) design has deformation 0.23mm, optimized design has deformation 0.08mm (measured at central bearing). This means stiffness increasing by 65%.

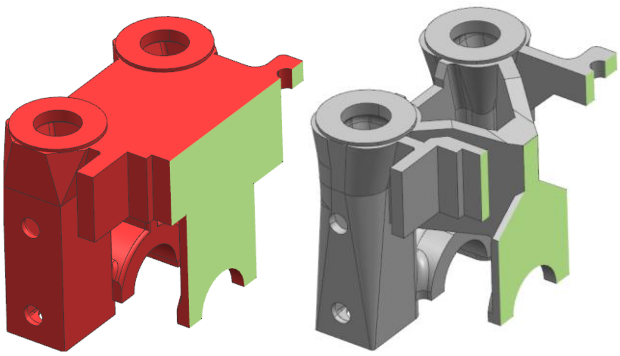

Figure 6. Comparing of actual (left) and optimized (right) upper crossbeam (half-section)

4.2 Lower crossbeam

Initial weight 86.2t was optimized to 76.8t. Main changes are in ribs orientation and in new supports for forging table. There is used same cross-section for preloaded areas in corners as at upper crossbeam (Fig. 7). Centric loadingseparate crossbeam was usedfor first evaluation of new design. The stiffness is comparable to initial design.

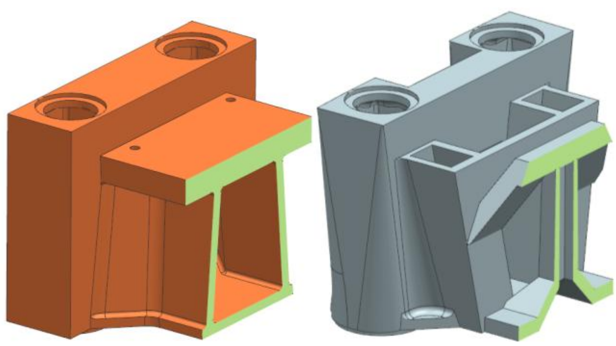

Figure 7. Comparing of actual (left) and optimized (right) lower crossbeam (half-section)

4.3 *Evaluation on assembly level*

Complete evaluation of new design was done by structural analysis of mechanical press with new upper and lower crossbeams. Other parts were used from initial design.

Figure 8. Von-Mises stress at initial (left) and optimized design (right)

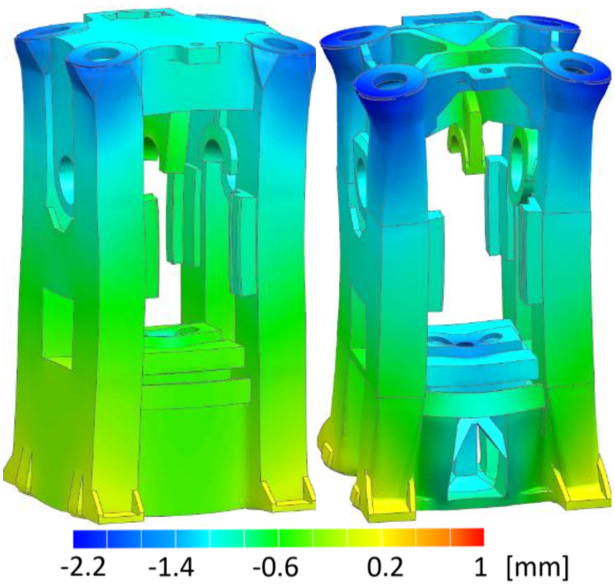

Figure 9. Vertical displacement of initial (left) and optimized (right) design [mm]

Optimized frame of mechanical press is up to 16.6t lighter comparing to initial design. It possible to see here, that stiffness of upper crossbeam is higher for optimized design. Lower crossbeam is not as stiff as in initial design (when considering loading in assembly), but is lighter. Total stiffness offrame is at same level as in initial design (Fig. 8).

Stress distribution has same range for both designs. Optimized design doesn't have anysignificant stress peaks (Fig. 9).

5 CONCLUSIONS

This work shows new approach to mechanical forging press design. Topological optimization was used here as an advanced tool for this task. Three different optimization approaches were used for comparing. Results from all optimization tools are comparable.

Results from lower crossbeam show that actual design is suitable and significant changes are not necessary. Changes are more important for upper crossbeam and influence of these changes is significant.

It is obvious that results from topological optimization are not possible to fullyapply to new design. Manufacturing possibilities and connections to other parts in presswere considered during remodeling of crossbeams.

Topological optimization is highlytime consuming process and therefore this article shows only optimization of crossbeams. Same approach can be applied to other parts.

New optimized press was loaded by force 80 MN and compared with initial design. Results showed differencein boundary conditions considered in optimization of separate parts and optimization of whole assembly. Total deformation of assembled frame was at comparable level with initial design, but weight is by 16.6t lower.

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REFERENCES

[Cechura et al. 2011] Cechura, M., Kubec, V., Raz, K., Stanek, J., Chval, Z. Development of New and Innovations of Existing Construction Solutions of Forming Machines (in Czech), Report 43904873, Pilsen, University of West Bohemia in Pilsen, 2011.

[Chval 2016] Chval, Z., Raz, K. Effect of heat load on a mechanical forging press. Proceedings of the 27th DAAAM International Symposium, DAAAM International Symposium 2016, 2016, pp. 344-348. ISBN: 978-3-902734-08-2 , ISSN: 1726 9679

[Kubec 2014] Kubec, V., Cechura, M., Raz, K. Dynamic Behaviour of the Hydraulic Press for Free Forging. Procedia Engineering, DAAAM International Symposium 2014, 2014, pp. 885-890. ISSN: 18777058

[Raz 2015] Raz, K., Cechura, M., Chval, Z. Upper Crossbeam of Free Forging Press Optimization in Order to Improve Mechanical Properties and Durability. Proceedings of the 26th DAAAM International Symposium, DAAAM International Symposium 2015, 2015, pp. 524-529. ISBN: 978-3-902734-07-5 , ISSN: 1726-9679

[Raz 2016] Raz, K., Cechura, M. Influence of hydraulic press columns connection on dynamic properties. MM Science Journal, 2016, pp. 1354-1357, ISSN: 18031269, DOI: 10.17973/MMSJ.2016_11_2016120

[Siemens 2018] Siemens.Topology optimization workflow. 2018,[online]. 19.07.2018. Available from https://docs.plm.automation.siemens.com/tdoc/nx/12/nx_he p/#uid:xid1323082

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