# AMONG THE WORLD'S LEADERS IN FORGING MACHINES: CKV 17000 DOOSAN PRESS

**MILAN CECHURA, VACLAV KUBEC**

University of West Bohemia, Faculty of Mechanical Engineering, KKS-CVTS, Plzen, Czech Republic

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***cechura@kks.zcu.cz***

This paper presents the largest hydraulic press for open-die forging ever made in the Czech Republic. Its capacity of 170 MN combines with a workspace of 8.5-metre height and 9.8-metre width. In each case, the result is a unique machine, a prototype made to customer requirements. Designing machines of this size always involves a great deal of ingenuity and experience which cannot be taught. The paper describes designs of mechanical parts, namely methods of joining individual parts into structural details which comprise the machine frame. The designs were developed with the use of numerical modelling. The two purposes included finding the stress distribution and perform weight optimization of individual parts. The weights were near manufacturability limits.

**KEYWORDS**

hydraulic press, free forming, design, finite element method, optimization.

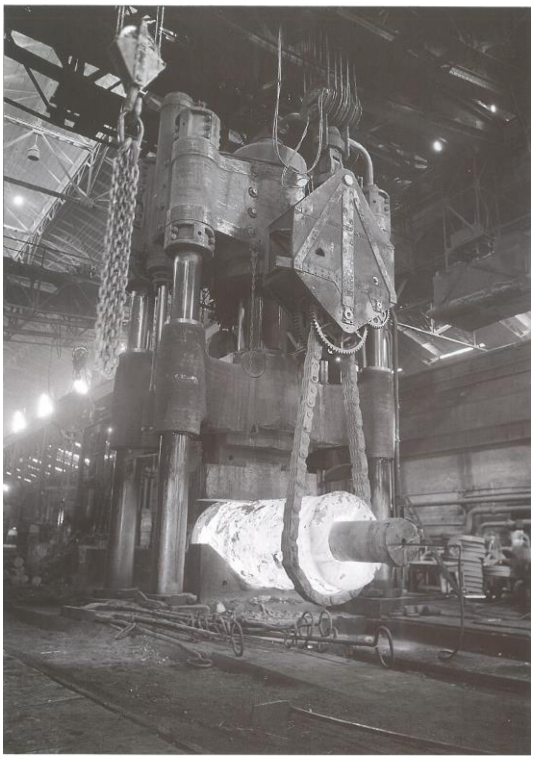

**Figure 1.** Steam-hydraulic Skoda CKV 5000 press (put in operation in the first quarter of the 20th century) [Kratky 2006]

## 1 INTRODUCTION

Forging equipment has traditionally been a cutting-edge sector in the Central-European regions of Bohemia and Moravia, now parts of the Czech Republic. At the time of the Austro-Hungarian empire, the Czech lands produced the largest presses and power hammers in the monarchy. Superior mechanical presses were manufactured by the factory Štorch in the city of Brno, later renamed Šmeral Brno and by Kolben – Daněk in Prague. Hydraulic presses, power hammers and rolling equipment were made by Škoda Plzeň and in the factory complex at Vítkovice.

Forming machines have always been the foundation of the country's industry. Bohemia and Moravia have therefore become the industrial heart of the Austro-Hungarian Empire and its largest arms manufacturer during World War I.

To manufacture large gun tubes, the most powerful forming machine had to be developed. Since local engineers succeeded in these tasks, this production formed a traditional and strong sector of industry.

It was maintained for many years, through World Wars I and II, even until today. There have been a series of large hydraulic presses for open die forging (CKV-series), serving as crucial pieces of manufacturing equipment for arms production, operated in Czech factories over the years: a 5000 t press at Škoda Plzeň – forge shop (Figure 1), CKV 12000 t at Vítkovice (Figure 2), and a CKV 10000 t press (in place of an earlier CKV 5000 press) at Škoda Plzeň (Figure 3), in which forged parts for Czech Temelín nuclear power plant were produced. The press was rebuilt and later replaced with a new CKV 12000 t press in the company Pilsen Steel, a successor to Škoda Plzeň – forge shop (Figure 4). All of these large presses were designed and manufactured by the company TS Skoda, later renamed TS Plzen.

**Figure 2.** Skoda CKV 12000 press (manufactured in 1953-4 – operated at Vitkovice factory) [Macha 2015]

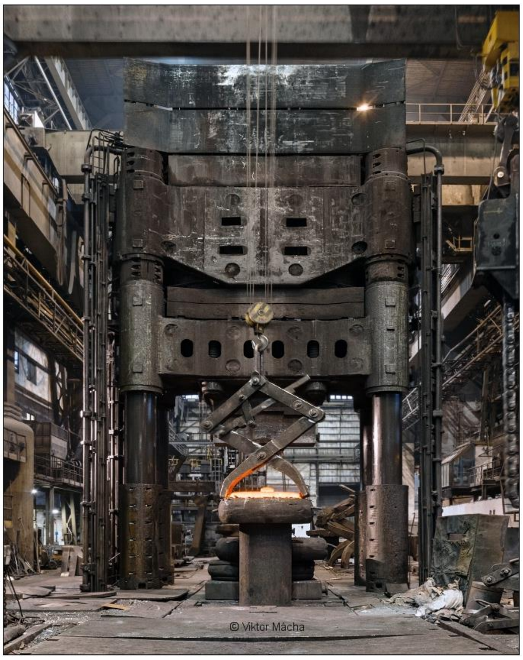


**Figure 3.** Skoda CKV 10000 press (put in operation in the 1970s, Skoda Large Forge Shop) [Macha 2005]

**Figure 4.** CKV 12000 press from TS Skoda (manufactured in 2010, operated at Pilsen Steel in the place of the earlier CKV 10000 machine) [Macha 2010]

Foreign companies therefore continue to approach Czech manufacturers, requesting design and manufacture of the largest forming machines available, mostly hydraulic presses.

## 2 SUCCESSFUL DESIGNS OF LARGE HYDRAULIC PRESSES IN TODAY'S CZECH REPUBLIC

We can be proud that in the face of stiff international competition, the Czech manufacturer TS Plzeň (former TS Škoda Plzeň) was able to build on its tradition and acquire contracts for constructing several large presses in recent years: CKV 90 MN (9000 t) (Areva, France – put in operation in 2012), CKV120/140 (14000 t) (SUNAN, China – 2013) and CKV 140/170 (17000 t) (DOOSAN Korea – put in operation in 2017). [Cechura 2017]

Even though an old tradition forms a basis for these efforts, today's technologies for designing and computations as well as the engineering thinking have see profound changes and led to completely different requirements for design solutions.

Above all, today's solutions must be computation-based in line with what advanced computing technology, simulations, and optimization virtual modelling tools have to offer.

Tasks of this scale are unthinkable to be completed by a single experienced engineering designer. Viable solutions can only be attained by an entire team under this designer's leadership.

The above-listed successful design solutions were products of the collaboration between TS Plzeň and the Research Centre of Forming Machine Design (RCFMD) at University of West Bohemia. RCFMD constructed all virtual models, performed virtual diagnostic tasks and proposed all the design optimizations. As a result, stress concentrations were suppressed and stress levels equalized throughout the structure of the press in order to ensure that the amount of material used is utilized effectively.

In the end, the work undertaken by RCFMD led to savings of several dozen tonnes of material. In addition, longer life was attained all components thanks to reduced stress levels.

With each press representing a unique solution, designers put all their efforts and expertise into developing an optimum design.

## 3 THE LARGEST PRESS EVER DESIGNED IN THE CZECH REPUBLIC: CKV 17000

The contract for developing the CKV 17000 DOOSAN press deserves a special attention.

It involved designing the largest forging press in the history of the country, and one of the largest machines of its kind in the world.

Conventional design process routes were irrelevant because the components of the press were too large to be made as single solid parts - or would be very difficult to make - and to be machined, transported and handled. Hence, all load-bearing components had to be manufactured as split parts, which led to new and unusual requirements for the design.

The crosshead, crossbeam and crown were therefore assembled from several parts joined with keys and pre-stressed tie rods. The configuration had to be verified and explored in detail by developing virtual models and making several iterations involving shape and arrangement changes.

## 4 TECHNICAL CHARACTERISTICS

### FORCES OF PRESS

| | | |
|---|---|---|
| nominal forging force | 140 | MN |
| forging force – I grade | 47 | MN |
| forging force – II grade | 94 | MN |
| forging force – III grade | 141 | MN |
| nominal upsetting force | 170 | MN |
| upsetting force | 177.83 | MN |
| permissible eccentricity (diameter) during forging with a press force of 140MN | 1 000 | mm |
| maximal eccentric load moment | 70 | MN m |

**WORKING PRESSURE OF MAIN CYLINDERS**

| | | |
|---|---|---|
| forging pressure of main cylinders | 35 | MPa |
| upsetting pressure of main cylinders | 42 | MPa |

**MAIN CYLINDERS**

| | | |
|---|---|---|
| no. of pressing cylinders | 3 | pcs |
| diameter of pressing cylinders | 1 310 | mm |

**WORKING STROKE**

| | | |
|---|---|---|
| stroke of moving crosshead | 4 500 | mm |
| daylight of the press | 8 500 | mm |

**BASIC DIMENSIONS**

| | | |
|---|---|---|
| forging table - length | 12 000 | mm |
| forging table – width | 4 800 | mm |
| table support for press load in lower crossbeam-140MN | 12 000 | mm |
| distance between column axes | 9 850/3 090 | mm |
| height above the floor | 23 000 | mm |
| press depth under the floor | 6 500 | mm |
| total press weight | 5 857 | t |

### *4.1 Design configuration*

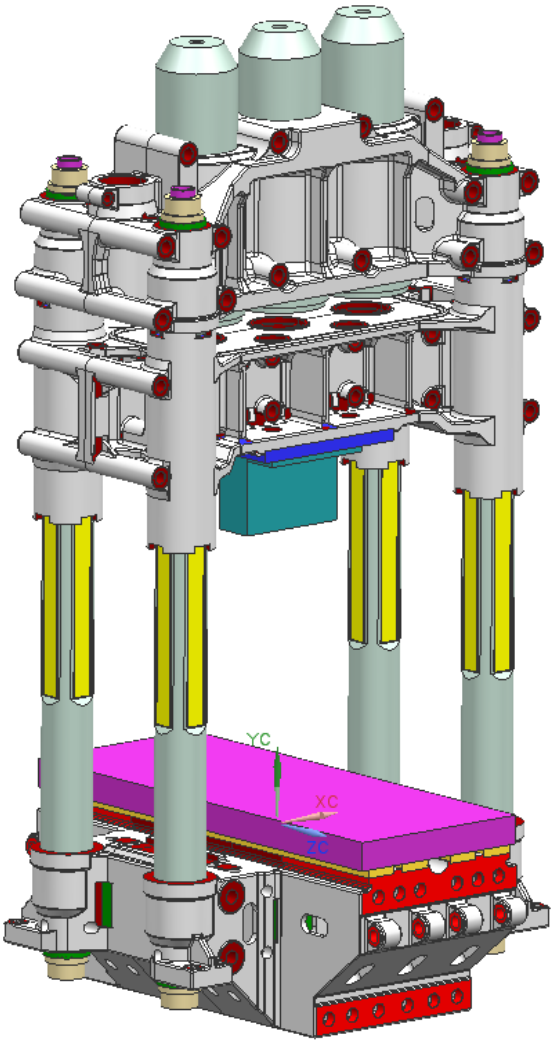


**Figure 5.** A model of CKV 17000 DOOSAN Korea press [Cechura 2015]

Figure 5. shows a simplified virtual model of CKV 17000 press (elements which are irrelevant to stress analysis are not shown). The figure shows how the split parts and the ways they are joined together. Lower crossbeam is made of five parts, movable and upper crossbeam are made of two parts. Keys are provided between the parts (not shown in the model) which secure the relative positions of mating parts and transmit all shear forces acting on the parting plane. The positions of parting planes were chosen in a way which prevented severe stress concentration. The highest stress concentrations occur in the vicinity of the keys. This called for design changes to remove them (a patented solution). The parts connections is realized by screws (there are sixteen connecting screws in each crossbeam).

Figure 6 compares the stress of a part of the bottom crossbeam (a – the first variant is constructed based on experience, b – the optimized variant) and shows the fundamental design modification of the bottom crossbeam. When solving an assembly of such dimensions, it was important to find the correct distribution of the material for its optimal use and this is the standard goal of our weight optimization. Newly solved task concerned the keys, which was 9 meters long. It was necessary to design the correct stiffness of the keys to avoid overloading the material around the groove and in the contact surfaces when the parts are bent in the direction of the machine width. The deflection is not negligible for such dimensions and therefore the strength problems arise with this design solution.

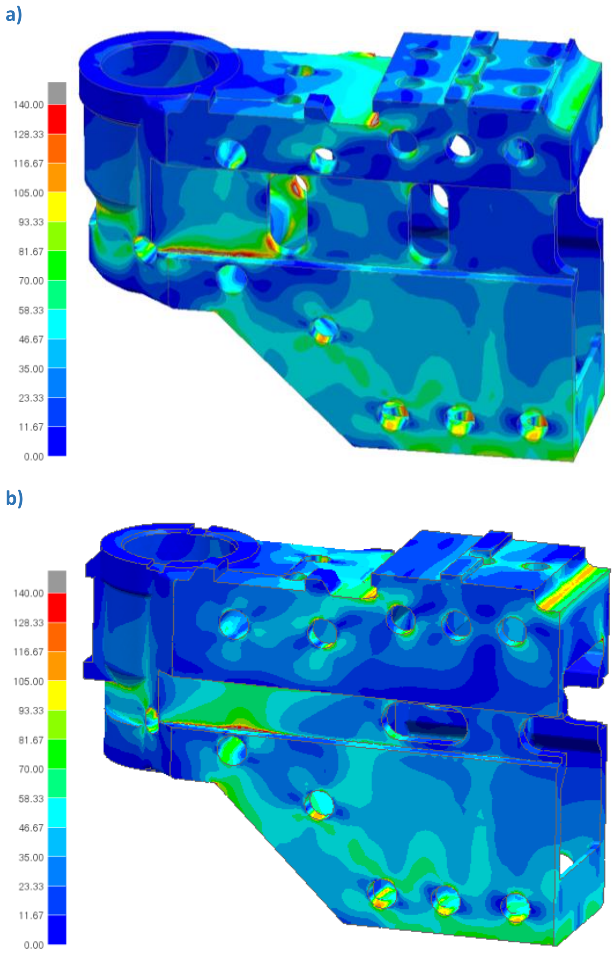


**Figure 6.** The bottom crosshead under central load comparison: a – first variant, b – optimized variant (von Mises stress [MPa]) [Cechura 2015]

The model displayed here represents the final solution in which stress concentrations were eliminated and stress levels equalized within the frame, while aiming for maximum utilization of the structural material. Reducing (optimizing) the weights of individual press components was another aim of the effort. Results of a calculation of bottom crosshead parameters is shown in Figure 7.

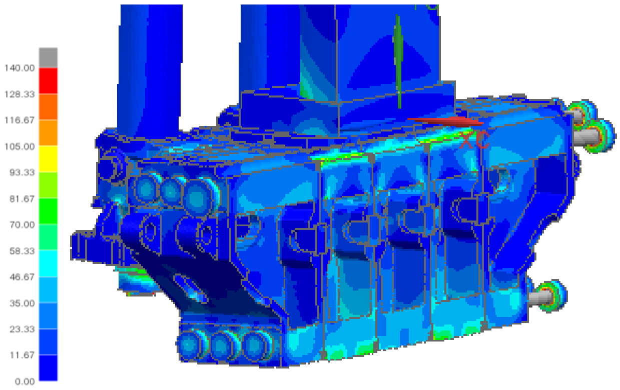


**Figure 7.** Stress distribution in the bottom crosshead under central load (von Mises stress [MPa]) [Cechura 2015]

Several computational optimization iterations led to several dozen-tonne reduction in weight.

The finite element solutions were performed using Siemens NX software. The mesh quality setting was aimed at a suitable description of the stress distribution in the each parts, taking into account the length of the calculation. Parabolic tetrahedral elements were used, with the proviso that the each wall must be at least two elements. However the calculation time for the full models was over ten hours.

The press frame was loaded in four load cases:

1) Center load – force 170 MN and cylinder pressure 42 MPa
2) Eccentric load (500 mm) in the transverse direction – force 140 MN and cylinder pressure 35 MPa
3) Eccentric load (500 mm) in the longitudinal direction – force 140 MN and cylinder pressure 35 MPa
4) Load at forging of a rings on mandrel (support distance 8 m) – force 140 MN and cylinder pressure 35 MN

Virtual optimization has made it possible to reduce the weight of some parts by 15% compared to the original design. This virtual optimization had to be performed in several computational steps because each design modification at the exposed location resulted in a response (often negative) at another location, which necessarily had to be solved again.

**Figure 8.** CKV 140/170 DOOSAN Korea press

## 5 CONCLUSIONS

The present paper gives a historical and chronological overview of large hydraulic presses operated in factories across the Czech Republic. It shows that the country has been one of world leaders in heavy press forming equipment capable of manufacturing the largest and most intricate forgings. A great majority of these machines have been designed and manufactured by TS Škoda Plzeň.

TS Škoda Plzeň maintains a century-old tradition of manufacturing large hydraulic presses. One of its tangible results is an extensive engineering design knowledge base which is handed down through generations.

Across the globe, numerous products - large CKV-series presses - are operated, making TS Plzeň a renowned manufacturer.

This paper presents a handful of recent design solutions used in large hydraulic forging presses which were supplier to reputed forge shops where they deliver trouble-free service.

It is a testament to the expertise and engineering skills of the company's designers in constructing state-of-the-art large hydraulic presses.

The paper attempted to demonstrate that each large press is a unique prototype, which is built to client specifications and that designing large presses involves far more intricate problems than ordinary small presses.

The largest press ever designed in the Czech Republic (CKV 17000, Figure 8) offers examples of difficulties which engineering designers face.

Two years of its trouble-free operation provide evidence of the excellent job done by the designers.

We can be proud that this machine (as well as the earlier ones) was developed by seasoned Czech designers from TS Plzeň and RCFMD at the University of West Bohemia and that it now belongs to world's top design solutions.

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**CONTACTS**

doc. Ing. Milan Cechura, CSc.
University of West Bohemia in Pilsen, Faculty of Mechanical Engineering, KKS-CVTS
Univerzitni 22, Plzen, 301 00, Czech Republic
+420 37 763 8256, cechura@kks.zcu.cz, www.cvts.zcu.cz

doc. Ing.Vaclav Kubec, Ph.D.
University of West Bohemia in Pilsen, Faculty of Mechanical Engineering, KKS-CVTS
Univerzitni 22, Plzen, 301 00, Czech Republic
+420 37 763 8256 vkubec@kks.zcu.cz, www.cvts.zcu.cz