EXPERIMENTAL AND NUMERICAL DETERMINATION OF PRESS FRAME ELASTICITY

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Abstract: In this paper elastic deflections of press frame when symmetric load is applied have been investigated and press stiffness calculated. The commercial FEM package ABAQUS was used to estimate elastic stress and elastic deformation of press frame in case of 6.3 MN hydraulic press. For validation of FE results both axial and radial displacements of the press frame were measured by means of universal displacement transducers. Obtained results are compared and discussed.

Keywords: PRESS STIFFNESS, FEM, ABAQUS, DISPLACEMENT MEASURING

1. Introduction

Today, one of the goals of forming industry is production of complex components with high dimensional accuracy ready for directly assembling without any machining. It is very demanding task since great number of factors, individually or in combination, affect part’s dimensions. In addition, the relationship between some parameters and part accuracy is not always known enough or it changes with changing process conditions. Therefore, for proper design of forming process identification of those factors and their effects on the (in)accuracy of the final part is of great importance. Results given in [1] indicate that forming machine (press) is one of the main causes of dimensional errors occurrence of formed components and that there is direct correlation between press related inaccuracies and part dimensional errors. If mechanisms and, elastic deflections of press frame under load. The load comes from deformation resistance of workpiece material, the inertial forces due to successive press loading and unloading, press frame pre-stressing, and, the weight of elements attached to press frame. Hence, the press -tool system derive s from the guideway clearance, the forces due to successive press loading and unloading, press frame continual processing such are rolling, wire drawing, and, tube extrusion machines.

The elastic deflection of press frame is the main source of inaccuracy at press system [4]. It causes tilting of both press ram and table, i.e. deviation of tool nominal position since it is firmly attached to these elements. Result of this are form and dimensional errors of workpiece as it shown in Fig.1. Investigations [1] shown that press ram and frame contribute more than 90% of total press deflection, and that horizontal displacement and table tilt can be up to 5 mm. Furthermore, press nonlinear deflections, originated from guideway clearance and contact gap between press members (in case of mechanical press), superimpose tool deviations and additionally reduce accuracy. The size of press frame elastic deflections is influenced not only by load intensity, but also depends on of press type, frame design and its material properties, forming process, load character, guideway system, design of tool in terms of eccentric load occurrence etc. [5].

Basically, there are two ways to increase punctuality of forming machine. The first one is based on the reduction of press frame elastic deviation. This can be achieved by robust design i.e. by increasing press stiffness Press stiffness is quantitative parameter of the load-deflection relationship. It can be calculated as the ratio of the elastic deflection and the corresponding force component.

\[
C = \frac{F_{\text{max}}}{\Delta l_{\text{max}}} \tag{1}
\]

where is:
- \(F_{\text{max}}\) – maximum force
- \(\Delta l_{\text{max}}\) – maximum deflection

Press stiffness is constant for certain machine. By knowing press stiffness one could approximately estimate the size of press geometry errors and elastic deviations, and accordingly that predict risk of part inaccuracy due to errors in machine system. This is why the correlation between the press stiffness and the nominal capacity has been often recommended as a guideline in selection of presses for different forming processes. The second way involves simultaneous procedure of the errors detection and correction in press-tool system. Due to improvement of sensors for the process monitoring and measuring equipment this approach is nowadays increasingly employed, but principally in case of machines with continual processing such are rolling, wire drawing, and, tube extrusion machines.

Doege [6] was among the first investigated press load-deflection relationship and influence of press stiffness and press members on accuracy and quality of workpiece employing both numerical and experimental methods. More complex quantitative relationship between the press and die elastic deflections and the form errors in forging of an aerofoil blade is presented in paper [2]. The members of press and tool system were integrated into the Finite Element (FE) model as spring elements and general stiffness matrix with six degree of freedom which represent the linear press load –deflection (FE) model as spring elements and general stiffness matrix with six degree of freedom which represent the linear press load –deflection (FE) model as spring elements and general stiffness matrix with six degree of freedom which represent the linear press load –deflection (FE) model as spring elements and general stiffness matrix with six degree of freedom which represent the linear press load –deflection (FE) model as spring elements and general stiffness matrix with six degree of freedom which represent the linear press load –deflection (FE) model as spring elements and general stiffness matrix with six degree of freedom which represent the linear press load –deflection (FE) model as spring elements and general stiffness matrix with six

Fig. 1 Relation between some characteristics of press and accuracy of formed part [3]

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characteristic of the press-tool system was developed [7] based on the
dependence of the workpiece dimensions on the actual punch
stroke in case of a combined full-forward/backward can extrusion
process. With other hand, paper [8] elaborates methods of modeling
the press-tool system in order to improve the accuracy of FE
simulations of metal forming processes in term of better prediction
of forging errors caused by the elasticity of press and tool system.
According the authors best results are obtained when coupling the
process simulation with external simulation models of the press-tool
system. The parameterization of the external models can be done by
results from measurements or simulation.
In this paper both approaches (numerical simulation and
experimental measurements) for characterization of elastic
properties of a press-tool system were used. Except determining
deflection of the press frame under different loads the aim of the
research was to check accuracy of a simplified FE model of the
press-tool system. Based on measured displacements press stiffness
in axial direct is also determined.

2. FE simulation

The object of FE modeling was double action hydraulic press
Sack&Kiesesselbach, 6.3 MN (see Fig.2-left). The press frame (“O”
type) is a monolith and robust construction made by casting.
Moveable press table is in contact with two press columns of
constant cross section used as a guideways. Due to very low
velocity but very high nominal force, this press is mainly applied
for cold extrusion and indenting operations.

The press geometry was modeled in SolidEdge CAD software,
and then it was exported to ABAQUS program package using STL
file format. Dimensions of the press elements were mainly imported
from the press technical data sheet and completed by the
measurement data of the real construction. In CAD modeling some
simplification of the press geometry has been made by omitting
technical holes, elements of guideway system, axillary components.

Program package ABAQUS used for the simulation is a general
purpose FE software by which it is possible to solve both linear and
non-linear problems of mechanics, heat transfer, electronic etc. FE
model was created in accordance with the software procedure, and
ABAQUS explicit mode was chosen for calculation. Here, only
model of symmetrical loading of the press frame has been analyzed
and load was set as static due to low velocity of the press ram (there
is no an impact load). In FEM modeling only the cylinder load as
the major force acting on the frame is taken into account, as the
weight of the cylinder is omitted. A model of planar forces acting
on the press frame was applied with the value equal to the press
nominal force (6.3 MN). Discretization of the press frame was done
using ABAQUS solid standard elements. It was composed of
112129 tetragonal elements and 25669 nodes (Fig.2-right). As
material, cast iron with elastic modulus of 208MPa and Poisson’s
ratio 0.3 was selected. Post processing of obtained results was done
in ABAQUS/Viewer module, which offers wide possibilities of the
data displaying.

3. Experiment

Experimental investigations of elasticity of the press (press-tool
system) consist of measurement of both axial and radial deviation of
the press frame under load. For that purpose inductive displacement
transducers WI5 (HOTTINGER BALDWIN MESSTECHNIK
GmbH – HBM) with a resolution of 1 μm were employed [9]. The
sensors were placed on special supports (out of the press) in order to
register absolute displacements of the press bed, press frame, and
press columns. Axial displacement of the press bed was measured at
few points as measuring point for radial displacement of the press
frame was mid-point of the column height (Fig.3). The experiment
(press loading) is performed using a tool consisting of two flat
plates mounted to press ram and bed. The plates were in direct
contact (there was no workpiece) as the load was continually
increased up to max. value of 2 MN after that the press is gradually
unloaded. Absolute pressure transducer P3M (HBM) is used to
measure load-force. Signals from all sensors are processed by
means of eight-channel amplifier SPIDER 8 (HBM) and recorded
by CatMAN Easy 4.0 software package.
4. Results

FE model of deformed and undeformed press frame under 6.3 MN load is shown in Fig.4-right, and distribution of von Misses effective stress in Fig.4-left. It can be seen that the press frame deforms symmetrically with respect to the vertical axis of the press. Similar, values of the effective stress are identical in the press columns. This result is expecting since model of load with no eccentric force is used in the simulation. Maximum effective stresses (about 180MPa) occur at regions where the press columns connect the press body as within the rest of column’s volume they do not exceed 120MPa. Effective stresses in the press body (press bed and upper traverse) are significantly lower and it almost acts as rigid body. The values of both axial and radial displacements of the press frame are given in Fig.5.

For nominal press force of 6.3 MN, maximum displacement of upper part of the press (traverse) is +0.3148 mm (positive way of z-axis) as press bed moves down for -0.0107 mm (negative way of z-axis). This means that the total change of the vertical (axial) distance between upper and lower part of the press is 0.3255 mm. Simulation shown that except elongation also bending of press columns occurs. Results of this is loss of parallelism and reduction of distance between the press columns. According to the simulation the maximum of bending amplitude is 0.16 mm, i.e. distance between left and right column is less for 0.32 mm. If compare the results of numerical simulations with experimental data it is evident that they are in good agreement (Fig.5 and Fig.6). Experimental values for both axial and radial displacements of the press frame are slightly higher with the maximum difference less then 10% for load of 2000 kN. It may comes from the measurement inaccuracy of due to lack of the FE model.

Elastic deformations of the press-tool system obtained by the experiment are given in Fig.7 (axial direction). In this case, measuring devise was in contact to the press table (movable part of the press – see middle photo in Fig.3).
As it can bee seen from Fig.7, elastic deformation of the press-tool system are much higher compared the press frame (Fig.5) since elastic deformation of the tool and the drive system are taken into account in this case. At very beginning of press loading deformations of this system are nonlinear as a result of clearance in the driving system and contact gap between both press and tool members.

If elastic deformation of the press-tool system (\(\Delta l_{p+t}\)) are known then elastic deformation of the press (press frame + drive system), can be obtained from the next expression:

\[
\Delta l_p = \Delta l_{p+t} - \Delta l_t
\]

Due to simple configuration of the tool used in experiment, its elastic deformation can be calculated analytically. Using model of axially loaded bar, the change in length of the tool elements (flat cylindrical plates with constant cross section) is obtained from:

\[
\Delta l_t = \sum \frac{Fl}{AE} = 2 \frac{Fl}{AE}
\]

where:
- \(F\) – active force
- \(l\) – length of the plate
- \(A\) – cross-section of the plate
- \(E\) – modulus of elasticity

Elastic deformation of the press as a result of solving Eqs. 2 and 3 is also given in Fig.7. It can be seen that this deformation is almost four times higher then elastic deflection of the press frame (Fig.5), and reaches values of 0.452 mm for load of 2000 kN. This indicates that for the analyzed press condition and design of the drive system have dominant influence on the press elasticity in axial direction and consequently effect variation (errors) of workpiece dimension in direction of forming force.

Entering necessary data in Eq.1, following values for stiffness are obtained:

- Press-tool system: \(C_{p+t} = 3890\ kN/mm\)
- Press \(C_p = 5763\ kN/mm\)
- Tool \(C_t = 12097\ kN/mm\)
- Press frame \(C_{pf} = 16129\ kN/mm\)

5. Conclusion

Data about elastic characteristic of press and press-tool system are essential for proper design of forming process. In this paper two deferent approaches were employed for investigation of the press elasticity. The first one is based on FE analyses using ABAQUS software package. The aim was to develop simple but reliable FE model of press frame load. Accuracy of the FE model is checked experimentally. Displacement of relevant points of the press assembly is measured using transducers with high resolutions and obtained values fully confirmed results of the numerical simulation. Therefore, developed FE model can be utilized for quick estimation of the press elastic deflection under different load. It enables shortening of the time for forming process design and prevention of workpiece dimensional errors.

Literature