Physical methods for increasing press accuracy

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Abstract. This paper is focused on the design and use of less conventional and unconventional physical methods for achieving higher press accuracy. The methods are applied to three presses, and their contribution and possibilities for using them in practice are evaluated. The limitations, benefits, and options of their use are defined for each method. The generalized outputs are also applicable for other machines.

1. Introduction

Demands placed on the accuracy of products continue to grow as new innovations are made to products. This trend is present through all sectors of the machine industry, and manufacturers of production machines have to take this into account. Nowadays, advanced computation methods make it possible to design machines less over-sized than they used to be.

This paper deals with the proposal and evaluation of methods for achieving the required accuracy parameters of presses. In particular, these are less conventional ‘physical’ methods, which are not often applied in this field. The field of presses is very wide and there are many press manufacturers for various forming operations. All the presses we selected are from the automotive manufacturing sector which has its own specific requirements.

The first section, concerning a 30 kN press, deals with basic methods for influencing the accuracy and stiffness of the press frame. In the second part, with the 1000 kN press, the design possibilities and influence of the applied elements on the stiffness and the resulting accuracy of the press are analyzed. The last part, with the 4000 kN press, deals with the thermal influence on the machine frame and the possibilities of eliminating it, together with other advanced methods of analysis and methods for eliminating frame deformations.

2. Introduction to physical design methods for achieving higher press accuracy

2.1 Stiffness method.

A basic method used for achieving stiffness by adding material, changing the geometry, choosing a different material type or changing the bearings.

2.2 Thermal method.

This method works with the thermal influence of the machine frame.

Passive - The operational properties and working accuracy are altered by the effect of heat conduction or convection to other parts of the press.

Active - The frame or a part of the machine is intentionally heated (or cooled) to achieve higher accuracy.

2.3 Predicted deformation.

Calculation of the bending curve of a machine component and subsequent adjustment to achieve higher accuracy (used especially for the rolling cylinders of roller presses).

2.4 Using a force member.

First option is that the force member is used to actively control undesired static displacements of the press frame. The source of the force can be: a hydraulic cylinder, a linear drive, a mechanism, etc. In second option force member is used to actively control the kinematic accuracy (movement accuracy) of the working part of the press.

3. Analysis of 30 kN Press

This is a single-purpose mounting press for pressing a ring on a hub. This type of press is used in the automotive industry on automated assembly lines. The computation was performed in Inventor's FEM solver, which is customized for basically qualified designers and does not
require great computational experience. Simple geometric sub-optimization was performed, in which the effect of the geometry parameters of the press frame on the resulting precision was examined. The contribution of each parameter to the weight increase of the frame was evaluated.

3.1 Computation results

The first version of the press frame (figure 1 and figure 2) appeared to be too pliable and did not meet the stiffness criterion. The basic material properties used for computation can be found in [1,2].

3.2 Evaluation of the results of geometric sub-optimization

Total increase of weight 53kg while total reduction of displacement is 270% of the required value - less than 0.02mm. From the sub-optimization it is clear that even a seemingly minor modification to the geometry can have a significant effect on the resulting accuracy of the press.

3.3 Active control of frame deformation

For active regulation of deformations of this frame, the force-generating element was placed on the rear plate of the press to compensate the deformation in the x-axis. In addition to improving the "a" value, the slope angle "γ" is also regulated (The "a" and "γ" are identified in figure 2). For example, a hydraulic cylinder or other source of controllable force can be used as a force-generating element.

The computation is set to a ≈0 mm. Because the regulator acts on a smaller arm, the force to compensate the deformations needs to be 60,000 N. The x-axis displacement is shown in figure 2. The results show that the accuracy of the press can be increased markedly. This method of adjusting the press with the addition of regulation can also be used for devices already in operation and higher accuracy will be achieved.

4. Analysis of 1000 kN press

This type of press is used in the production of interior and acoustic parts for private and commercial vehicles. The basic design is shown in figure 3. In practice, several press concepts are used with different components of the guide-ways, different placements of the pressing cylinders and different types of frame construction. The selected variants (see Table 1) are solved using FEM and are assessed according to the stiffness of the clamping plates of the press.

4.1 Analysis of the 1000 kN press

Computations were made for the design variants of the press described in Table 1. The focus is mainly on the comparison of the variants of the guide-ways and the arrangement of the pressing cylinders and the subsequent evaluation of the achieved accuracy and influence on the accuracy. The frame of the press is adjusted for variants 3 and 4.

Table 1. Analysed variants of the press

| Variant | Table guide-ways | Number and position of cylinders of the upper table | Number and position of cylinders of the lower table | Frame of the press |
|---------|------------------|-----------------------------------------------|-----------------------------------------------|------------------|
| Variant 1 | Ball linear guide | 4 cylinders – over mould | 4 cylinders – corners of the table | Basic design, see figure 3 |
| Variant 2 | Ball linear guide | 2 cylinders – over mould | 4 cylinders – corners of the table | Basic design, see figure 3 |
| Variant 3 | Ball linear guide | 4 cylinders – corners of the table | 4 cylinders – corners of the table | Without the middle upper traverse |
| Variant 4 | Guiding rods | 4 cylinders – over mould | 4 cylinders – under mould | Lower traverse from sheets |
| Variant 5 | Outer half prism | 4 cylinders – over mould | 4 cylinders – corners of the table | Basic design, see figure 3 |
| Variant 6 | Inner half prism | 4 cylinders – over mould | 4 cylinders – corners of the table | Basic design, see figure 3 |
| Variant 7 | Without | 4 cylinders – over mould | 4 cylinders – corners of the table | Basic design, see figure 3 |
The aim of this section is to make a comprehensive evaluation of the design options for this type of press in terms of the components used, the design options of the frame of the press, the spacing and the number of press cylinders, etc.

4.2 Results
Figure 4 shows the displacements of variants 2, 3 and 4 of the press. These results show different deformations of the tables and the frames of the presses, influenced by different design variants. Table 2 and Table 3 contain an evaluation of the variants of the guide-ways and arrangement of the hydraulic cylinders with respect to the achieved flatness and the theoretical shift of the mould due to lateral force.

4.3 Evaluation
The placement of the press cylinders further from the projection of the tool results in a higher bending moment and greater deflection. The difference between the two and four pressing cylinders over the mould is low. Two or four press cylinders placed in the projection of the mould are the best options in terms of accuracy. From the point of view of the computations of the guide-ways, the best results are the linear guidance and the inner half prism. The results for guide-ways cannot be applied generally because the rigidity of each frame of the press is different and the strain is also different. This results in a different character of deformations which may have a direct influence on the guide elements.

Figure 4. Examples of results: displacement of the variants 2, 3, 4 [mm]

| Table 2. Evaluation of variants of table guide-ways |
|-----------------------------------------------|
| Lower table | Upper table | Theoretical shift of moulds due to force [mm] |
| Flatness (Centric load) [mm] | Flatness (Lateral force) [mm] | Flatness (Centric load) [mm] | Flatness (Lateral force) [mm] | |
| No guide-ways | 1.19 | Not rated | 0.46 | Not rated | Not rated |
| Outer half prism | 1.18 | 1.21 | 0.46 | 0.58 | 0.72 |
| Inner half prism | 1.14 | 1.21 | 0.46 | 0.62 | 0.36 |
| Guide-ways | 1.14 | 1.23 | 0.44 | 0.61 | 0.29 |
| Guiding rods | 0.39 | 0.70 | 0.43 | 0.83 | 0.84 |

| Table 3. Evaluation of arrangement variants of cylinders |
|-----------------------------------------------|
| Placement and number of pressing cylinders | Lower table flatness | Upper table flatness | Theoretical shift of moulds due to force [mm] |
| | (Centric load) [mm] | (Lateral force) [mm] | (Centric load) [mm] | (Lateral force) [mm] | |
| 4 cylinders in corners of the lower table + 4 cylinders over mould | 1.14 | 1.23 | 0.44 | 0.61 | 0.29 |
| 4 cylinders in corners of the lower table + 2 cylinder over mould | 1.14 | 1.23 | 0.46 | 0.60 | 0.29 |
| 4 cylinders in corners of the lower table + 4 cylinders in corners of the upper table | 1.18 | 1.26 | 0.57 | 1.05 | 0.31 |
| 4 + 4 cylinders over and under mould | 0.39 | 0.70 | 0.43 | 0.83 | 0.84 |

5. Analysis of 4000 kN press
The analysis was performed on a hydraulic press used for the production of acoustic and interior car parts, as in the case of the previous press. However, the technology is different. The parts are composed from layers which are inserted into a heated mold in the press where they reach their final shape under a defined pressure, or rather by defined compression. The tools of this press are tempered by heat conduction from the clamping plates of the press. The clamping plates have holes for the heating elements. Because it was not possible to measure the thermal fields in this case, the setting of the computation was done according to a similar computation for a curing press which was checked by a thermal camera [3], [4], [5], [6]. Other material properties and values for setting the computation were found in [7], [8], [9].
5.1 Results of the analysis
The greatest thermal influence on the frame is noticeable on the ram and the table of the press. To illustrate this, two scales are used where the scale on the right is limited by 45 °C, which is the maximum value measured on the press frame. The main purpose of this analysis was to determine the values of flatness of the press frame (ram and table) and the clamping plates mounted on them. The values of flatness for the first three analyses are shown in figure 5. The evaluation of these values is described in the next section.

5.2 Evaluation of analysis and description of methods for increasing accuracy
The table of the press is deformed under the pressing load many times more than the ram, which is caused by the lower stiffness of the table. The graph in figure 5b shows a certain ‘straightening’ of the table due to the temperature difference on the upper and lower surfaces of the part, which causes opposite deformation to that caused by the pressing force. This phenomenon occurs in the same way for the ram, but the deformation due to the static load is very small, and the opposite deformation due to temperature difference is predominant, and the resulting deformation is greater. Based on these findings, it is possible to propose methods for designing the frame of the press with higher accuracy:

- Design the table and the ram of the press to be very stiff, thus making deformation from static load very low. It is also necessary for the heat transfer to the frame to be very low so it does not cause thermal deformation, which can be dealt with by thicker insulation, or additional cooling.
- Another option is to design the table (or ram) of the press with such rigidity that deformation from the static load will be partially eliminated by the temperature deflection.
- In some cases, it is not possible for a variety of reasons (dimensions, technology, etc.) to produce a frame as rigid as required. For example, the upper surface of the table may be produced with a reverse ‘shape’ according to the expected main bending curve.

5.3 Analysis of possible methods to increase accuracy of a model of the table
A modified table model was designed to illustrate possible approaches to the design. For this model, the geometry was determined. Due to the centric load of the table, it was possible to create a model using only 1/4 of the table.

5.4 Overview of analysis.

5.4.1 Computation 1
The table of the press is loaded with a force of 4000 kN. The table is not thermally influenced.

5.4.2 Computation 2
The table of the press is loaded with a force of 4000 kN. A temperature difference of 12 °C between the upper and the lower surface of the table is set. The temperature difference is idealized and determined by an iterative method.

5.4.3 Computation 3
The table of the press is loaded with a force of 4000 kN. The frame of the press is not thermally influenced. The geometry of the table is modified according to the bending curve from the first computation (according to the main bending axis).

The results are shown in Table 4. The values show that very good results can be obtained using the temperature method (computation 2) and the method with the shaped surface (computation 3). All solutions are further affected by manufacturing and installation inaccuracies.

Table 4. Flatness of examined surface

|                  | Computation 1 | Computation 2 | Computation 3 |
|------------------|--------------|--------------|--------------|
| Flatness [mm]    | 0.343        | 0.151        | 0.037        |
6. Conclusion

Requirements on accuracy are growing with the development of new products. The increased accuracy of a product also raises demands on the accuracy of the production machine, and this is dealt with in this paper.

A geometric sub-optimization of the frame was carried out on a 30 kN press and its procedure was described in detail. This procedure is suitable for a design engineer/development engineer who has access to basic types of FEM solvers, usually implemented in ‘cheap’ CAD systems. Active regulation of deformations of the press from pressing forces was also designed for this press. In the section dealing with the 1000 kN press, selected machine parts and concepts of the machine based on the created morphological matrix are evaluated. The individual machine parts and concepts of the machine are assessed mainly in terms of their impact on achievable accuracy. In the next part, computations of the 4000 kN press were made, where the thermal influences on the machine and the possibilities and methods of its solution were evaluated. The possibilities of the proposed methods for achieving higher accuracy were further presented on a simplified model of the table.

These methods can be used to achieve higher accuracy, and their possibilities and limitations are also presented. The proposed methods and procedures should help machine manufacturers to achieve the required machine parameters. The aim of using these methodologies is to ensure sufficient machine accuracy/stiffness at the lowest possible cost. Because these outputs are relatively generally utilizable, the results and algorithms are not limited only to hydraulic presses, but it is possible to use these methodologies for a number of similar production machines.

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