Characterizing the Elastic Behaviour of a Press Table through Topology Optimization

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Abstract. Sheet metal forming in the car industry is a highly competitive area. The use of
digital techniques and numerical methods are therefore of high interest for reduced costs and
lead times. One method for reducing the try-out phase is virtual rework of die surfaces. The
virtual rework is based on Finite Element (FE) simulations and can reduce and support manual
rework. The elastic behaviour of dies and presses must be represented in a reliable way in FE-
models to be able to perform virtual rework. CAD-models exists for nearly all dies today, but
not for press lines. A full geometrical representation of presses will also yield very large FE-
models. This paper will discuss and demonstrate a strategy for measuring and characterizing a
press table for inclusion in FE-models. The measurements of the elastic press deformations is
carried out with force transducers and an ARAMIS 3D optical measurement system. The press
table is then inverse modelled by topology optimization using the recorded results as boundary
conditions. Finally, the press table is coupled with a FE-model of a die to demonstrate its
influence on the deformations. This indicates the importance of having a reliable representation
of the press deformations during virtual rework.

1. Introduction
The modern automotive stamping industry is highly competitive and is therefore continuously
increasing its usage of numerical simulation software. These software are used to achieve reliable
stamping processes, support running production, and for achieving a shorter lead time for stamping
dies and car projects.

One numerical method which isn’t used on a wide industrial scale yet is virtual rework of forming
surfaces in stamping dies, see Lingbeek [1]. This rework is performed by numerical algorithms and
based on Finite Element (FE) simulations of the stamping die and the forming of the sheet. Virtual
rework has the potential to support and reduce the expensive and time consuming process of manual
rework during the try-out phase of stamping dies. Rework of forming surfaces is done to compensate
against elastic deformations of dies and presses, and to reach a desired pressure distribution between
the sheet and the forming surfaces.

While performing virtual rework it is often challenging to accurately predict the elastic behavior of
the stamping presses. The stamping die is often easier to represent since a reliable CAD-model almost
always exists. This paper suggests a method to inverse model the elastic behavior of a press table
through topology optimization. The goal of the optimization is to replicate deformations of a loaded
press table recorded with a 3D camera measurement system. The method will yield a press table that is deflecting and deforming. This is another strategy compared to previous work which often includes deflections, and sometimes but not always deformations [2–4]. This strategy will also enable a characterization of the press even when there is no available information about the structure below the table and above the ram(s).

2. Method
A double action press is loaded in three different ways, the deformations of the press are measured with a 3D camera measurement system together with the magnitude of the load. The recorded deformations are then used as constraints in a topology optimization which aim to replicate the elastic behaviour of the press table. This chapter describes the methods in detail.

2.1. Press deformation measurements
The measured press is a Danly double action press at Volvo Cars stamping plant in Olofström, Sweden. The press table is 144x96 inches. The maximum force of the inner slide is 1000 US tons and 600 US tons for the outer slide. The press can be seen in figure 1.

The measurement system is a GOM ARAMIS 5M [5] with 8mm Schneider-lenses and a distance between the cameras of 1220 mm. The frequency of the cameras is set to 15 Hz with a shutter speed of 35.818 ms. The actual ARAMIS system can be seen in figure 2.

A blankholder plate is mounted in the press and the force acting on the press table is applied by the outer ram. The force is transferred between the outer ram and the table through the blankholder plate and four steel pillars. The steel pillars are placed in two different formations which are visualized in figures 3 and 4. Force transducers on each pillar record the forces acting on each pillar. References that are tracked by the ARAMIS system are placed on the ram, the table, the steel pillars, the force transducers and the blankholder plate.

During the measurements the ram is stopped for a few seconds in its lowest position to achieve a stable static measurement of forces and deformations with as little dynamic effects as possible. It is the deformations in this position that is compared with the unloaded press table.
2.2. inverse modelling of press deformations by topology optimization

The recorded deformations from the ARAMIS measurements are used as constraints when the press table is inverse modelled. The deformation and initial position of each measured point is extracted in the software ARAMIS Professional 2016 and exported as a text file. Since the measurements aren’t covering the entire table the deformations are extrapolated across the entire table with least square fitting and a second order polynomial in MATLAB R2011b [6]. All points are assumed to be positioned on a horizontal plane before the table is deformed. Three measured load cases are selected for the inverse modelling of the table, they are selected so that all the positions of the pillars are included in the simulations. The three load cases are presented in subsection 3.1.

An Optistruct FE-model for topology optimization are created in Hypermesh [7], depicted in figure 5. The red part has the same size as the real press table of the Danly press. Underneath the table there is a blue design volume. The bottom part of the model is locked in all directions. Steel pillars are placed on top of the press table in all measured positions. The numbering of the positions and the forces can also be seen in figure 5.
The goal of the topology optimization is to minimize the volume of the blue design volume. A large reduction will result in very large deformations in the z-direction. Without any constraints on the deformations the volume will be reduced to zero and the deformations of the table will go towards infinity. However, if the measured deformations are used as constraints the volume will be decreased until the deformations match the set constraints. The more measured load cases that are included into the topology optimization the closer the table will mimic the behavior of the real press table. The constraints in the model are set with a tolerance of ±10 percent of the total measured deformation in each point due to noise and vibrations in the measured values. Otherwise it will be hard for the optimization routine to find a feasible solution. In future work the tolerance should be based on estimations of noise, error and dynamic effects in the ARAMIS measurement.

2.3. Structural analysis of a stamping die
A structural model of a matrix from a stamping die is solved in Optistruct, when it is loaded with a blankholder pressure extracted from a sheet metal forming (SMF) simulation. The die is placed both on a rigid surface and the optimized press table. This will visualize the influence of the press deformation on a stamping die and also give an indication of how much virtual rework of the die surfaces that are needed. The aim of virtual rework is normally that the die surfaces shall move into their nominal position from the original construction when the die is loaded [8].

3. Results
This chapter describes the results from the press measurements, the inverse modelling of the press table by topology optimization, and the structural simulation of a stamping die.

3.1. Press measurements
An example of measured deformations visualized with vectors in ARAMIS Professional 2016 is depicted in figure 6. As can be seen there are not points covering the entire press table. This is one of the reasons for why the deformations were extrapolated across the entire table. Another reason is that the least square fitting is smoothing the deformations, this is desired since there will always be some noise in measured data.

The measured forces from the three load cases (LC), LC1-LC3, selected for the topology optimization is presented in table 1. The deformations in z-direction extrapolated across the entire table based on the ARAMIS measurements can be seen in figure 8, 10 and 12.

![Figure 6. Deformations represented with vectors in ARAMIS](image)
Table 1. Applied loads in LC1-LC3 (metric tonnes)

|     | F1   | F2   | F3   | F4   | F5   | F6   | F7   | F8   |
|-----|------|------|------|------|------|------|------|------|
| LC1 | 52.93| -    | 45.61| -    | 57.39| -    | 42.98| -    |
| LC2 | -    | -    | -    | 77.62| -    | -    | -    | 82.99|
| LC3 | -    | 75.76| -    | -    | -    | 75.38| -    | -    |

3.2. Inverse modelling of press deformations by topology optimization
The optimized design volume is depicted in figure 7, the solids in the figure is shown with some transparency for a better visualization of the final geometry. When the optimized model is loaded with the forces in LC1-LC3 the resulting deformation in z-direction are seen in figure 9, 10, and 11.

![Figure 7. Optimized design volume](image)

![Figure 8. ARAMIS/MATLAB LC1](image)

![Figure 9. Optistruct LC1](image)

![Figure 10. ARAMIS/MATLAB LC2](image)

![Figure 11. Optistruct LC2](image)
3.3. Structural analysis of a stamping die

The deformations in z-direction for the matrix on a rigid press table is visualized in figure 14, if the matrix is placed on the inverse modelled table the deformations will increase to what is seen in figure 15. If the deformations in figure 15 are magnified it can clearly be seen that the matrix is both deflecting and deforming in many different ways, see figure 16. A comparison of the die surfaces in a best fit position can be seen in figure 17.

Figure 14. Deformation on rigid press table. Note that the colour range is different from figure 16.

Figure 15. Deformation on topology optimized press table. Note that the colour range is different from figure 15.

Figure 16. Magnified deformations for the matrix on the topology optimized press table.
Figure 17. Comparison of the deformed surfaces on a rigid press table and on the topology optimized table. The surfaces are compared in a Best fit position.

4. Discussion & Conclusion
The suggested method for inverse modelling of a press table through topology optimization is accurate for the three presented load cases. A good approximation of the die deformations should therefore be reached when a blankholder pressure from a SMF simulation is applied to a matrix positioned on the table. A major benefit of this method is that both deflection and deformations are included and inverse modelled in a single topology optimization step.

However, for a full characterization of the press table more load positions should be included. Since the steel pillars were placed around the edges of the table in these measurements it is uncertain if the deformations will be reliable when the punch is applying pressure to the middle of the matrix and the table. A good idea would probably be to use the load positions in this paper together with the suggested positions in [3] for an even better estimation of the entire table. The inverse modeling will never yield a better result than what is fed into the topology optimization, more and better data will give a more accurate final result.

To be able to accurately rework the die in a virtual try-out environment the inner and outer ram needs to be inverse modelled as well. It is only when the entire system with all the die and press parts are loaded together that the calculated deformations will resemble the deformations of the real die.

One potential problem is also that the measurement did not cover the entire press table. This gives uncertainties about the deformations outside the actual measured area. The distance between the cameras can be increased which will enable the system to measure a larger area. However, for larger press tables it will probably not be sufficient with one ARAMIS system measuring from one position. Several measurements will have to be made in different positions. The measurements will then have to be stitched together, or the number of load cases in the topology optimization needs to be increased.

Another problem in a stamping plant that this method can support and visualize is that the same stamping die can produce different geometrical output in different press lines. One factor, probably major, influencing this is the elastic behavior of the press itself. This can be visualized and analyzed through the methods presented in this paper.

5. Future Work
The next step in this research will be to characterize the outer ram of the press as well. When that step is completed it will be possible to perform a virtual rework of the forming surfaces of the blankholder and the matrix.
To be able to virtually rework the punch, additional measurements and optimizations with loads on the inner ram, and simulations with the punch, will be needed. An investigation into which deformations the virtual rework should compensate for is also needed, the larger deformations in figure 16 or something more similar to the smaller deformations in figure 17.

An assumption made in this research was that all the points on the press table are initially situated on a horizontal plane. A method to include the real initial geometry and position of the upper surface of the table should be applied in future work. Otherwise it is a potential error source that can influence the virtual rework.

A method to verify the calculated deformations of the stamping die is also needed. This can be achieved by placing references on the outer parts of the die itself and filming it with an ARAMIS system [9]. These deformations should match the simulated ones.

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