Understanding the influence of servo-press kinematics on a sheet metal forming process using a simulation-based approach

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Abstract. The capabilities offered by the servo-presses are not fully exploited by the sheet metal forming companies due to the lack of knowledge of their influence on the forming processes. Indeed, the control of the beneficial effects and the full use of servo-press features, such as the programmable kinematics, are increasingly becoming concerns for the companies having acquired that type of press. In this context, the finite element simulation is undoubtedly an approach to evaluate the potential gains generated by those presses and to validate the servo-press kinematics. This study is an attempt to gain insight into the impact of servo-press kinematics on a sheet metal forming feasibility. The forming experiments presented in this study have been carried out by CETIM for a X2CrNi18-09 stainless steel. The numerical simulation has been performed with AutoForm software that enables the user to rapidly and accurately design and simulate the sheet metal forming processes, including stamping operations. All parameters influencing the stamping operation in a servo-press can be considered. They include, for example, press kinematics, sheet temperature variation during the forming process and of course material mechanical properties. The hardening curves of the studied stainless steel at different strain rates and different temperatures have been taken into account. The simulation has been carried out for two servo-press kinematics: sinusoidal and soft-touch. The feasibility criterion, i.e. the part drawing depth, has been defined to match the experimental results. The numerical simulation with AutoForm made it possible to highlight the thermal effects, in particular, the maximum temperatures reached during the drawing operation. The simulation results analysis allowed the user to optimize the motion curve of the press in order to have a minimum cycle time while respecting the lowest possible temperature the sheet might reach during a drawing operation. Thanks to this study, the sheet metal forming companies will therefore benefit from this technology to develop and optimize the servo-presses usage.

1. Introduction

Thanks to the use of servo-presses, with their programmable kinematics and – for specific configurations – a blank holder force control feature, it is now possible to consider significant progress in sheet metal forming in terms of formability \cite{1}, control and monitoring of the forming process \cite{2} as well as tool improvement during production \cite{3}. The increasing use of servo-presses amongst sheet metal forming companies can be explained by these potential gains which, given the higher cost of these machines, need to be accurately assessed. Depending on the type of part to be produced (sheet metal material, drawing depth, etc.), the improvements sought (prevention of fractures, reduction of springback, etc.) and in the absence of experiments, finding answers remains a difficult task. Therefore, it is important to be able to assess these gains using predictive tools, such as deep drawing simulation.
In this context, the study presented here aims to explain the gains provided by the kinematic sequences of servo presses for a stainless steel material, based on a numerical simulation of the drawing process.

2. Experimental data, reference point for the simulation
The experimental data used as reference for simulation relate to the drawing of an austenitic stainless steel bump shape using two press kinematic sequences. The experimental results of these tests are presented in [4]. The blank, part and drawing tool characteristics are provided in Table 1.

**Table 1. Data of the reference experimental drawing process.**

| Description | Characteristics |
|-------------|-----------------|
| Blank / Part | - Blank: Circular, dia.: 300 mm  
- Material: Stainless steel X2CrNi18-10 (type 304), thickness 1 mm  
- Drawing depth reached upon fracture: 23.3 mm and 25.4 mm depending on the kinematic sequences (cf. Table 2). |
| Tool        | - Punch: dia. 50 mm, hemispherical end with radius \( r_p = 25 \) mm  
- Die: inside dia.: 56 mm; die radius \( r_d = 10 \) mm  
- Blank holder force varying from 3,600 daN to 4,000 daN  
- Tool / sheet lubrication with neat oil. |

The two kinematic sequences taken into account for simulation are described in Table 2. The “Sinusoidal mode” kinematic sequence results in a maximum drawing depth before fracture of 23.29 mm, while the “Soft mode” kinematic sequence results in a maximum drawing depth of 25.04 mm, showing that the “Soft mode” kinematic sequence can help reach higher drawing depth [4]. Aside from the press kinematics, the sheet temperature variations during the drawing process and the material mechanical properties are parameters that can influence the forming operation in a servo-press. The X2CrNi18-09 stainless steel material used in the experimental tests was characterised by means of tensile tests carried out at different strain rates and temperatures to properly study these effects in simulation. Table 3 presents the main results obtained.
Table 2. Press kinematics used in the experimental tests.

| Type            | Diagram | Description                                                                                                                                 |
|-----------------|---------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Sinusoidal mode | ![Diagram](image1.png) | This sequence represents the movement of a conventional mechanical press. This is our reference for comparing the different simulation results. The velocity of the ram at the beginning of the drawing process (first contact with the sheet metal) is 140 mm/s. |
| Soft mode       | ![Diagram](image2.png) | The kinematic sequence of the press ram follows 3 steps with different velocities:  
- velocity $S_1 = 14.4$ mm/s, until 8 mm from the bottom dead center (BDC),  
- velocity $S_2 = 2.4$ mm/s, until 2 mm from the BDC,  
- velocity $S_3 = 0.6$ mm/s, until BDC. |

During our tests, the X2CrNi18-09 stainless steel appeared to be highly susceptible to the temperature and almost not to the strain rate: the relationship between temperature and the work hardening of the material will be taken into account in the following forming simulations of the part.
Table 3. Results of the tensile tests on the X2CrNi18-09 stainless steel used for this study.

| Title                                      | Tensile diagram | Analysis                                                                 |
|--------------------------------------------|-----------------|--------------------------------------------------------------------------|
| Strain rate influence (at room temperature) | Strain          | No major influence of the strain rate, within the characterized variation range, at room temperature or at a higher temperature. |
| Strain rates:                              |                 |                                                                          |
| 0.1 s\(^{-1}\)                             |                 |                                                                          |
| 0.01 s\(^{-1}\)                            |                 |                                                                          |
| 0.001 s\(^{-1}\)                           |                 |                                                                          |
| Temperature influence (strain rate of 0.01s\(^{-1}\)) | Strain          | Major influence of temperature on the yield stress.                       |
| Temperatures:                               |                 |                                                                          |
| 20°C                                       |                 |                                                                          |
| 50°C                                       |                 |                                                                          |
| 100°C                                      |                 |                                                                          |
| 150°C                                      |                 |                                                                          |

3. Simulation of the drawing processes

Numerical simulation helped us understand why the “Soft mode” kinematic sequence could reach higher drawing depths. We simulated the experimental process thanks to the AutoForm software and used its thermosolver to consider the temperature effects accurately. This solver enables the accurate prediction of the temperature increase within the sheet due to the combined effects of plastic work and friction, and of the cooling of the sheet during contact with the tools or with the ambient air.

The material description used for simulation has been adapted to include the influence of temperature as seen in Table 3 (Figure 1).

We created the kinematic curves input for both press kinematics used for the two simulations (“Sinusoidal mode” and “Soft mode” kinematic sequences), identical to the curves used in the real experiment. They are are shown on Table 4.
Figure 1. Temperature dependent hardening curves as input in the AutoForm simulation depending the temperature

Table 4. Press kinematics used in simulation.

| Type          | Diagram                                                                 |
|---------------|-------------------------------------------------------------------------|
| Sinusoidal mode | ![Diagram of Sinusoidal mode](image)                                      |
| Temperature   | 20 °C, 50 °C, 100 °C, 150 °C                                             |

| Type          | Diagram                                                                 |
|---------------|-------------------------------------------------------------------------|
| Soft mode     | ![Diagram of Soft mode](image)                                          |
To compare both processes, we first analyzed the thinning reached on a specific point of the sheet at a specific drawing depth for the “Sinusoidal mode” simulation. In the example on the left in Figure 2, we reached a thinning of 29.8% at 2.50 mm of bottom dead center (BDC).

Then the same point was located on the “Soft mode” simulation and we changed the process time viewed to find the same thinning value of 29.8%. In this case, it was reached at 1.30 mm of BDC, so 1.20 mm lower, therefore corresponding to a higher drawing depth than in the “Sinusoidal mode” simulation. This confirmed the experimental result stating that the “Soft mode” enables us to draw the part deeper.

We saw that temperature has an important effect on the mechanical characteristics of the sheet between 20°C and 100°C (cf Table 3). During a classical drawing process, we can expect this range of temperatures within the sheet due to the friction and the plastic strain within the material. If we compare the temperature reached on the same point for both simulations, we can see that the “Sinusoidal mode” simulation reached a sheet temperature of 67.5°C, with a steady increase of that temperature over process time (Figure 3 top). The temperature history for that point in the “Soft mode” simulation is not steadily increasing (Figure 3 bottom), but has a peak at 8 mm of BDC. That peak value is 39.4°C, lower than the temperature reached in the “Sinusoidal mode” simulation, and then decreases as the process velocity also decreases (cf Table 2). The temperature reached for the thinning value of 29.8% is 24.5°C. This soft touch process, offering a slower punch impact and then even smaller values of the drawing velocity, enables the strain work to dissipate more within the sheet, therefore, decreasing the temperature reached during the process and affecting the drawing depth value reached for a given thinning.
Figure 3. Temperature and temperature history within the sheet during both processes up to a thinning of 29.8%.

When we compare the hardening curves of the material depending the temperature, we could easily understand the simulated and experimental behaviour: as the temperature rises, the material softens and thus becomes less resistant. A quicker localisation of the thinning is observed as the material heats up compared to a behaviour at low temperature.

Analyzing the plastic strain rates history for that point of the sheet after both simulations (figure 4) shows us that the “Sinusoidal mode” simulation undergoes plastic strain rates up to almost 3 s⁻¹ whereas the “Soft mode” simulation undergoes much lower values, up to almost 0.4 s⁻¹. It would be interesting in a follow-up study to characterise the material at these higher values of plastic strain rates and simulate their influence if it proves necessary.
4. Conclusion
When we talk about servo-press, we expect the strain rate effects on the material characteristics to be the main factor influencing the forming of said material. The numerical simulation with AutoForm made it possible to highlight the thermal effects, in particular, the maximum temperatures reached during the drawing operation. For the stainless steel in this study, simulation could show that the temperatures reached within the sheet had a very prominent influence on the achievable drawing depth. The soft touch process, enabling a much lower temperature, ensures a deeper drawing. To complete this study, we could further investigate the strain rate effects on the material properties, as simulation showed that the plastic strain rates reached in this study were higher than the available data.

This study shows that simulation allows the user to optimize the motion curve of the press in order to have a minimum cycle time while respecting the lowest possible temperature the sheet might reach during a drawing operation. Thanks to this study, the sheet metal forming companies will therefore be able to confidently develop and optimize their servo-presses usage. Until now, servo-presses were not utilized to their full capacity in a production setting; now, thanks to simulation, an important gap is filled and servo-presses will be exploited to their full potential by the industry.

5. References
[1] Majidi O. and al 2015 Formability of AHSS under an Attach–Detach Forming Mode, *Steel research Int.* 86 N°2, pp98-109
[2] Hyunok Kim and al 2019 Control of the servo-press in stamping considering the variation of the incoming material properties, *International Deep Drawing Research Group 38th*
[3] Murakami T. and al 2015 Influence of blanking distance of materials on increase in blanking vibration using screw drive servo press, *Mechanical Engineering Journal*
[4] Danel A. and al 2016 Influence of servo-press kinematics on the formability of drawing parts, *IDDRG International Conference. Linz, Austria, June 12-15*