Calibration of Aluminum Sheets by High-Speed Hydroforming

M. Hermes[1,*], N. Weiß-Borkowski[2], T. Wieseler[1], V. Holstein[1] , E. Köster[1]

[1] Laboratory for Metal Forming and Joining, University of Applied Science South Westphalia, Germany
[2] Laboratory for Material Technology, University of Applied Science South Westphalia, Germany
*Corresponding author. Email: Hermes.matthias@fh-swf.de

Abstract

A new, robust production system for tubular and sheet-based workpieces is presented. It combines the methodologies of high-speed forming with conventional hydroforming and is based on components and drive technology that can be easy controlled by the use of standard industrial technology. In the article the new system and its function is explained and potentials are shown. Moreover, the focus is on the experimental results of production and calibration of high quality, thin-walled sheet metal and cast components for aircraft and power electronics industry. Thin-walled metal parts are difficult to machine due to their low stiffness and potentially high residual stresses. The paper shows an application example of the new forming device to calibrate these parts by high-speed forming. Moreover, the technological properties of the parts are analysed and an outlook on further work is shown.

Keywords

Hydroforming, Calibrating, High-speed forming

1 Introduction

Hydroforming is an important production technology since many years. Complex thin-walled lightweight components based on sheets and tubes for example for automotive applications can be produced in one process step with high accuracy (Neugebauer, 2007).

For smaller production lots this technology is inefficient because of high machine and tool costs. For smaller parts and very big lots the relatively high process time is a problem.

High-speed forming methods were developed to produce sheet metal or tubular parts. Advantages of the high forming speed are among others the extension of process limits and the production of workpieces with high geometrical complexity and accuracy in one process step (Psyk et Risch, 2012).

Very well-known is the electromagnetic forming process that can be used for forming operations on tubular parts and sheet metal parts (Psyk et al, 2011). Niaraki (2019) shows a combination of electromagnetic forming and high-speed hydroforming that extends process limits of electromagnetic forming. For bigger workpieces, the energy of the electromagnetic devices is not sufficient. High-speed forming technology then is driven by explosive materials or the detonation of gas mixtures (Mynors et al. 2002, Weber et al. 2006). Further investigations use plunger-based mechanical drives for forming (Liangliang et al. 2024).

The problem of all high-speed methods is the difficult control and automation of the process by standard control systems. Moreover, tools and production system components are not robust enough for industrial application and bigger production lots. In addition, licenses are required for the use of explosives and there is a risk of misuse. In the case of electromagnetic forming, the service life of the tool coils and the dangers caused by the high voltages are relevant.

Better control possibilities and many advantages seem to have the plunger-based systems because of the more conventional drive technology. This technology is robust and components can be adjusted by mechanical engineers without special training. The problem of these processes is the limit in the production of complex large-surface parts because of the short pressure pulse. In the state-of-the-art, large surface parts are produced by quasi-static processes like deep drawing or conventional hydroforming. Thus, the combination of the methodologies of high-speed forming with conventional hydroforming is a senseful innovation. An interesting possible approach is the combination of quasi-static high pressure sheet metal hydroforming and pneumo-mechanical high-speed forming on one and the same high-speed forming machine (Djakow et al. 2016).

2 Development of a device for high-speed hydroforming

In previous work (Hermes et Böhmer 2024) an idea for a production device combining the methodologies of high-speed forming with conventional hydroforming to a High-Speed Hydroforming Process (HSHF) is shown. Based on these ideas in a first development step a robust production system that is easy to control by standard industrial components was built up in an earlier project (Hermes et al. 2018). The system can be used as well for highly automated production systems for mass production of smaller tubular and sheet metal parts as for the flexible manufacturing of workpieces with larger dimensions. The device is a hydraulic driven high speed pressure generator that can be mounted directly on the hydroforming tool. The system consists of pressure amplifier driven by an oil-based hydraulic system with a seat valve and an accumulator. A pressure of 230 MPa and a pressure rising of 20 ms was reached. The axial feed mechanism for tube hydroforming was relatively slow, so a dynamic axial feeding in tube hydroforming (THF) was not possible. The device showed a high potential of the method but not sufficient was i.e., the slow speed of the pressure rising, the slow axial feeding for tube hydroforming to reduce thinning and the fragile rubber-based stopper of the pressure amplifier.

The second development step is shown in this paper: The aim is to increase the forming pressure and the forming speed of the system. So, a new device was designed (Figure 1).

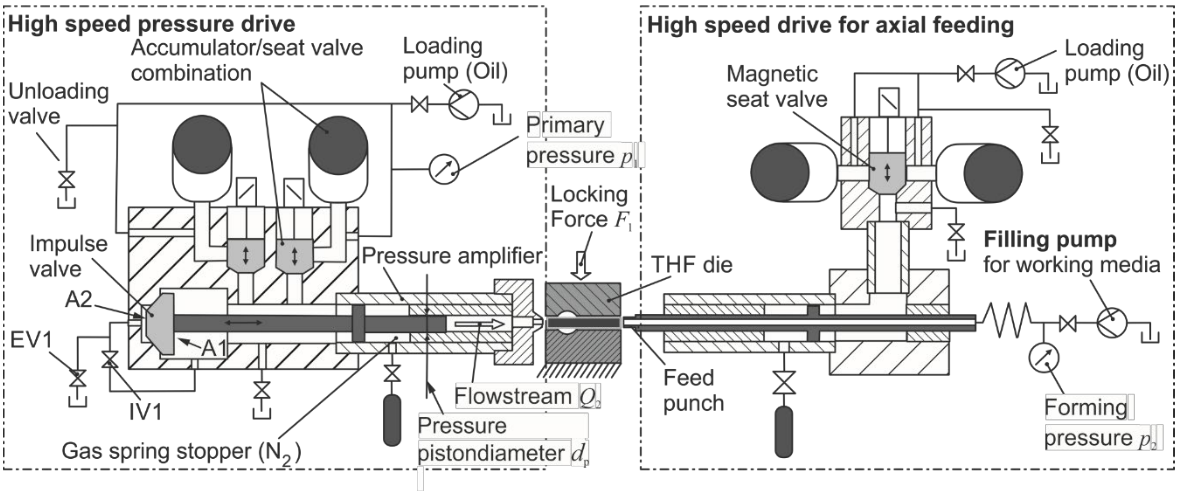

Figure 1: *Actual (second) development step of the high-speed hydroforming system*

The high-speed pressure drive on the left is a pump system driven by four accumulator seat valve combinations to increase the flow rate of the hydraulic loading pump. To reduce losses in speed caused by the poor opening time of the standard seat valves an impulse valve was designed that opens a big cross section at a short time by the opening of a smaller valve that creates pressure equalization. The stopper is realized by a N_2-filled chamber that works as an adjustable gas spring and prevents piston seizing and diesel effects. It is possible to influence the maximum forming pressure by adjusting the primary pressure p_1 on the oil side and moreover by changing the pressure amplifier components by reducing the piston diameter (d_p = Ø 40, 30, 20 mm).

On the right-hand side, the function of the high-speed drive for axial feeding is shown. The punch is driven by an accumulator seat valve system as well. The filling pump for the working media (oil-water emulsion) is filled by a high-pressure pump, so quasi static experiments for comparison are possible.

The function for a tube hydroforming process is as follows: After filling the system and the workpiece with working media, the loading pumps load the pressure accumulator with a defined pressure. The seat valve of the pressure drive can be opened or closed at this step. A controlled signal opens the impulse valve and the seat valve of the axial drive.

Then the tube is axial compressed and radial expanded by the pressure increase of the working media. It is possible to use the impulse valve or the four seat valves to initiate the forming pressure pulse. All valves can be independent activated.

Due to the slow opening time (70 ms) of the standard hydraulic seat valves the impulse valve was developed by the authors. The function of the impulse valve is based on a difference in surface area between the piston ring surface A1 and the effective piston surface in the end position state of the other side A2. If the pressure chamber is pressurized by the open poppet valves, but the A2 side is depressurized by an open relief valve EV1 and a closed initial valve IV1, the impulse valve is ready to start. If EV1 is closed and then IV 1 opened, the pressure equalization results and the piston is accelerated towards the forming side. This results in a very large cross-sectional area for the oil flow and thus a very fast impulse-like initialization of the process.

In Table 1 the technical parameters of the device are listed.

The THF tool and the axial feeding system were not used for the investigations and results that are described in the following chapter because of the focus on sheet plate calibrating.

Table 1: *Technical parameters of the high-speed hydroforming system*

Parameter	Value
Hydraulic oil pressure / primary pressure p_1 (pressure drive and axial feeding)	30 MPa
Forming Pressure p_2 (depend on pressure piston diameter d_p)	d_p = Ø 30 mm → p_2 = 200 MPa d_p = Ø 25 mm → p_2 = 300 MPa d_p = Ø 22 mm → p_2 = 400 MPa
Maximum Flow stream in the forming Chamber Q_2	d_p = Ø 30 mm → Q_2 = 45 dm^3/s
Locking force F_1	1000 kN

Advantages of the presented process and the machine compared to conventional methods with explosive drivers, the possibility of setting the forming pressure and volume precisely via the hydraulic parameters. This means that the required pump volume and forming energy can be precisely adapted to the target component. This results in high precision and energy efficiency.

The sealing of workpieces is a major challenge in order to make the forming pressure usable. The technologies described in this paper are an important topic.

3 Investigation of calibrating sheet metal plates

Focus of the following experiments are the calibrating of sheet plates mate of EN AW 1050. In Figure 2 the experimental set-up is shown.

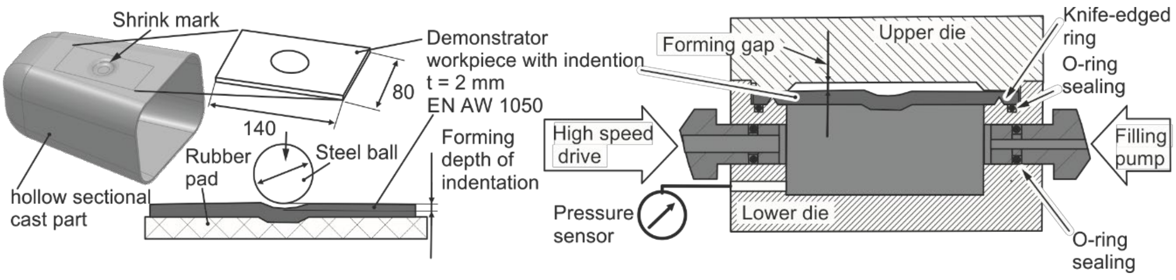

Figure 2: *Experimental setup for forming defined indentations in sheet plates and high-speed die for surface calibrating*

These investigations are based on an industrial request with the focus on calibrating shrink marks on hollow sectional cast parts made of light metal alloys. The idea is to calibrate the surface by an inner pressure shot initiated by the presented high speed hydroforming system. To analyse the problem, demonstrator workpieces with defined dimensions were used. For this, aluminium plates were formed by a steel ball in the surface of the workpiece as a proxy process for the shrink marks of the cast parts.

After that, the workpieces are mounted in the special high-speed die for surface calibration. The die is mounted in the high-speed hydroforming device and is prefilled from the right-hand side the working media with 0.5 MPa. From the left-hand side, the high-speed drive supplies a pressure pulse in the lower die and the sheet plate is pressed on the surface of the upper die. There was a forming gap of 0.5 mm left and the upper die has several venting holes. The sealing is an important challenge that is solved by several different mechanisms. A circumferential knife-edged ring was machined in the lower die to create a metal-metal sealing. Additionally, a circumferential nitril o-ring was used. A pressure sensor was installed in the lower die and the maximum locking force F_l of the device with respect to the dimensions of the workpiece allows a maximum static pressure p_2 of about 90 MPa.

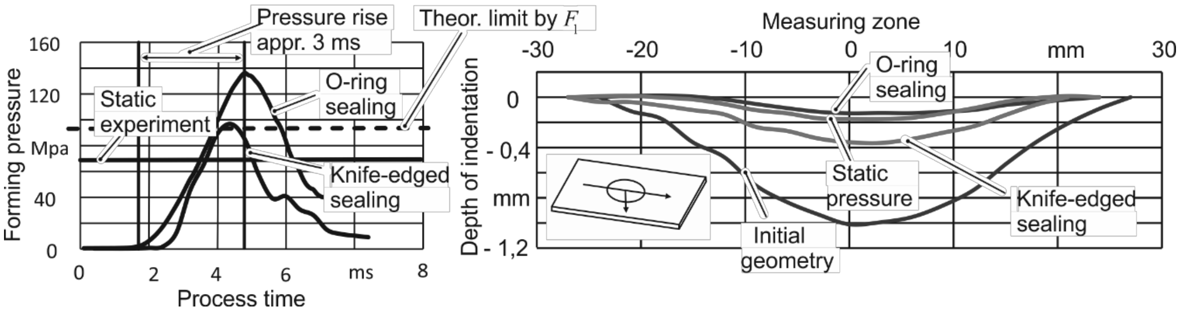

Figure 3: *Pressure profiles and flatness measurement of the calibrated workpieces*

In Figure 3 results of the experimental investigations are shown. On the left-hand side the measured pressure profiles show that the o-ring and additional knife-edged ring sealed experiments reach 140 MPa maximum pressure in 3 ms. Experiments without o-ring reach a maximum pressure of up to 100 MPa. The theoretical possible pressure $p_2 = 200$ MPa of the system with the mounted pressure piston of $d_\text{p} = Ø\ 30$ mm could not be reached in this forming test but the maximum pressure of 90 MPa limit defined by the maximum locking force could of the locking press ($F_\text{l} = 1000$ kN) could be clearly exceeded. The reason for this is on the one hand the pressure loss by seizing of the sealing and on the other hand the inertia effects of the locking system (mass of the upper die and the other moving parts of the locking press). Interesting is the comparison of the results with the static experiment. The pressure was built up by the filling pump of the system, which is able to produce high pressure with a very slow flow rate. The sealing seizing could be detected between 60 and 70 MPa because the positive dynamic effects are not active at low flow rate.

On the right of Figure 3 flatness measurements of the workpieces are shown. The initial geometry formed by the steel ball shows a depth of the indentation of 1.0 mm. After the calibration the best result with the lowest depth less than 0.2 mm was reached by the experiment with the o-ring sealing. The results with the knife-edge ring sealed workpieces lead to results less than 0.4 mm. Although the maximum pressure in the quasi-static reference-experiment is lower, the indentation is in the field of the o-ring results. Furthermore, the roughness and hardness of the quasi-static and dynamic calibration tests are in equal area, meaning these technological properties are unaffected by the dynamic forming load.

4 Conclusion and Outlook

The paper shows, that it is possible to build a hydraulic driven metal hydroforming machine based on mostly standard components that reach high speed and pressure for the forming of tubes and sheets. The presented device produces pressure pulses driven by the combination of hydraulic accumulators and an impulse valve. For tube hydroforming it is possible to feed the tube length into the forming zone by a synchronously working axial high-speed feeding system.

The aim of the presented experimental investigations in this paper is the calibration of workpieces in geometry dimensions and flatness. Sheet metal plates are calibrated by a pressure shot on the surface to reduce the depth of an indentation. The results show an improved flatness by a dynamic driven pressure shot. The sealing of the workpiece in the die resists the dynamic pressure rising better than a slow quasi-static pressure curve. Even the effective locking force of the press is higher than the theoretical because of the influence of mass inertia and the dynamic pressure generated by the very high flow rate of the forming machine. By this effect, leakages of the sealings lead later to a pressure loss.

The quasi-static reference-experiments with lower pressure have nearly the same flatness than the dynamic ones. This has to be analyzed in future. Reasons may be rebound effects that influence the dynamic results. The use of quasi-static pressure is no option for the industrial application of the process because of an inacceptable increasing of the locking force when extrapolating to bigger sized workpieces.

This work shows the beginning of research with the new device. In the field of workpieces geometry and material properties a bigger variety has to be analyzed in future. Theoretical work has to be done to generate basics for process layout and simulation. Dynamic effects, influence on materials behavior and machine stiffness have to be included in the investigations.

Simultaneously the transfer for an industrial application is planned.

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