Some aspects regarding the use of a pneumomechanical high speed forming process

W. Homberg, E. Djakow, O. Akst

Chair of Manufacturing and Forming Technology (LUF), Paderborn University, Paderborn Germany

Abstract

A promising approach to the production of thin-walled workpieces in high strength materials is the use of a special pneumomechanical high-speed-forming process. This process uses a pneumatically accelerated plunger that dives into a pressure chamber filled with the working media in order to generate a short pressure pulse. Ways in which the pressure pulse can be influenced include e.g. varying the type of working media, the density of the working media, the accelerating pressure distance and the plunger geometry. The influence of these parameters on the process formed the subject of intense technological research at the Chair of Forming and Machining Technology (LUF) at Paderborn University. The results of these investigations were used to achieve an appropriate process and tool design for the pneumomechanical high-speed forming process. It thus proved possible to manufacture complex workpieces and geometrical details from thin-walled, high strength stainless steel or aluminium alloys that cannot be produced by conventional stamping processes. Because of the high uniformity of the pressure distribution in the radial direction, it is possible to achieve just small dimensional or geometrical deviations in respect of the desired shape of the workpiece. The planned paper will present results of the basic research conducted into pneumomechanical high-speed-forming as well as a comparison with electrohydraulic forming.

Keywords

Pneumomechanical Forming, Electro Hydraulic Forming, High Speed Hydroforming

1 Introduction

The technology of high-speed forming has been familiar since the 19th century already. Intensive research related to this technological field has been conducted in the United States, Germany and the Soviet Union, in particular, starting in 1955 [1]. The high speed forming process includes all those manufacturing processes in which the necessary forming energy is released very quickly and then rapidly transferred to the workpiece. The total time taken by a typical high speed forming process ranges from a few microseconds to 1000 microseconds. An important characteristic of a process of this kind is that it will allow very high pressures to be achieved, permitting the manufacture of small, sharp contoured geometrical details. Using the high speed technology it is also possible to achieve very high strain rates during forming, often with beneficial effects on formability. Several working principles, including use of a explosive, electrohydraulic and pneumomechanical compression, are used for pressure pulse generation in both research work and industrial practice [2, 3]. An energy level of up to 250 kJ and pressures of up to 25 GPa are possible [6, 9].

Electrohydraulic forming (EHF), as one key process, is characterized by an electric discharge process using a special electrode arrangement inside a liquid working medium. The electric discharge is used to create a short pressure pulse or shock wave inside a discharge chamber in order to deform the workpiece. Typical process times are a few microseconds [7].

The first experiments with EHF were performed in the 1940s. The further development of electrohydraulic forming began in the 1960s, described among others by Bruno (1968) and Wilson (1964). Scientists in Germany, the USSR, the USA, Japan and other countries have developed a large number of experimental electro-hydraulic setups. So far, EHF technology has been successfully used for deep drawing, calibration, expansion and joining processes, for example. A major advantage of the electrohydraulic method is the possibility of repeating the discharge process in order to achieve greater deformation [10, 11, 12]. Recent results published in Eguia [6] and Homberg [4] inter alia show that the reproducibility of the high voltage underwater discharge can be increased by using an ignition wire. This wire vaporizes during the process and promotes the formation of a plasma channel [6, 9]. Current research work being performed in the USA is focused on extending the forming limits by comparison to conventional forming processes. The use of EHF for manufacturing automotive sheet metal parts has thus been examined by Golovashchenko [8]. He used a special electrohydraulic setup in a two-step method to extend the capability of conventional stamping technology for parts with deep cavities and sharp radii. In the first forming step, a conventional quasi static forming process like deep drawing is used to produce a preform. In the second step, a pressure pulse generated with the help of the underwater discharge process is used to calibrate the desired geometry. Golovashchenko and also [6, 9] are using a multi electrode arrangement to better control the deformation process and enhance the pressurized area. The results of the experiments performed show that the use of the multi chamber forming tool and electrode arrays permits the efficient production of large-scale geometries [8, 12].

Another interesting method for the generation of shock waves is the pneumomechanical method, where a pneumatically accelerated plunger dives into a closed cavity, thereby generating a short pressure pulse. The plunger is accelerated by compressed air inside a pipe. A major advantage of the pneumomechanical method (PMF) is the possibility of generating high pressure pulses with a high reproducibility. The first known prototype machine based on this working principle was developed by Tomigana and Takamatsu in 1964 [5]. An initial investigation showed that pressures up to 900 MPa and energies of 26 kJ in the working media were possible. Furthermore, the research showed that inertia effects supported the locking of the tool, so that only low locking forces are necessary. To manufacture parts with complex and sharp formed geometries it was also useful to employ several strokes or a pressurization cycles. With this setup, it was even possible to manufacture complex parts. Typical process times are just a few milliseconds. A further development of this setup was presented by Kosing and Skews in [13]. Another pneumomechanical setup was used by Frolov for forming and cutting procedures like stretch drawing and cutting. For the cutting procedures, the plunger was used as a stamp, with no working media in the chamber. The cutting result depends on the attainable energies as well as on the blank properties like blank thickness [14]. So far the pneumomechanical method has only been used for the production of small tube and sheet metal parts.

To summarize, it can be said that quite a lot of research has been conducted into the use of EHF and PMF. There has been no adequate comparison of the two processes, however, especially regarding the production of sharp contoured geometrical details.

2 Experimental setup

To realize the desired comparison between EHF and PMF two different experimental setups were used. Apart from an electrohydraulic setup, use was made of a special pneumomechanical setup, in particular.

2.1 Pneumomechanical setup

The experimental setup used at the LUF for the high speed forming of sheet metal parts with the help of a pneumatically accelerated plunger consists of a pressure generation unit, a vertically arranged acceleration tube and the die with the necessary base plates. Inside the tube, a plunger is accelerated by the compressed gas. The accelerated plunger dives into the water-filled cavity of the die and brings about the desired deformation of the sheet metal there. The maximum acceleration pressure is 1.5 MPa, the length of the acceleration tube is 5.1 m, and the diameter used is 38 mm. At the lower end of the tube there is a device for measuring the plunger speed in order to determine the plunger energy. The pressure measurements inside the pressurized areas of the tool were performed using a high-frequency ICP pressure sensor (109C11) from PCB, New York, USA.

2.2 Spark gap setup

The investigations regarding the electrohydraulic forming were performed using a laboratory setup from Poynting GmbH. This consists of a capacitor bank, a switch, a discharge chamber, a forming tool, and an underwater spark gap, which was fitted with an ignition wire for reliable or improved discharge behavior (see also [4]). The power unit consists of two capacitor banks, with a capacity of 14.1 µF (per capacitor) and a maximum charging voltage of 18.5 kV, so that the maximum charging energy of the system was 4.5 kJ. The distance between the pressure sources and the sheet metal was determined by the arrangement of the electrodes in the pressure chamber, with a minimum of 87 mm. The pressure chamber was adjusted adaptively to the existing lower half of the tool in the pneumomechanical experimental setup. In order to achieve a more reproducible spark discharge and to minimize the number of failed attempts, the discharge was initiated by the ignition wire. As the ignition wire was 0.1 mm thick and 10 mm long, stainless steel wire was used.

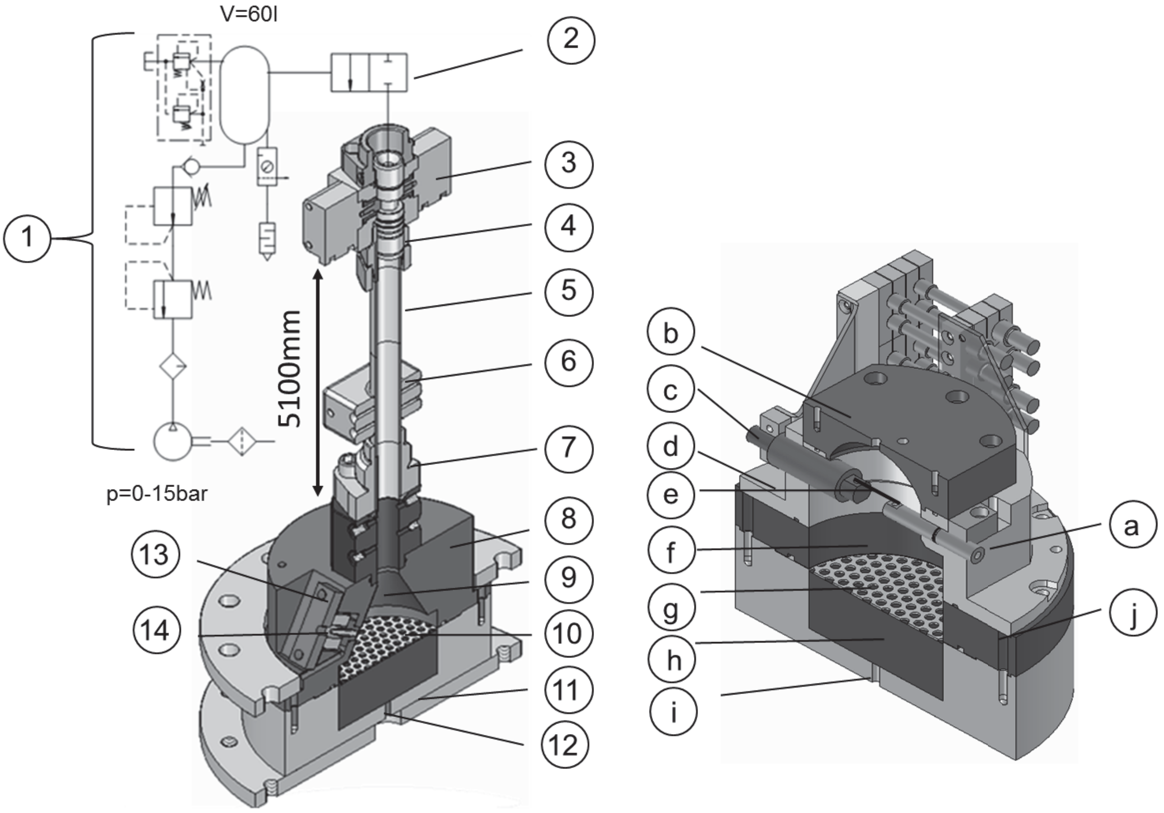


***Fig. 1**: **Pneumomechanical setup:** 1 – pressure generation unit; 2 – lever valve; 3 - release mechanism; 4 – plunger; 5 – acceleration tube; 6 – light barrier; 7- SAE flange; 8 - pressure chamber; 9 – working medium; 10 - membrane pressure gauge (die); 11 - lower tooling adaptor; 12 – vacuum connection; 13 – sensor adapter; 14 – pressure transducer (PCB 109C11 p=0-5500bar). **Spark gap setup (wire configuration):** a – mass electrode; b - discharge chamber adapter; c – insulated electrode; d - discharge chamber; e – wire; f - working medium; g – die; h – die spacer ring; i – vacuum connection; j - spacer ring 40 mm in height*

3 Results and Discussion

One important aim of the technological research conducted at the LUF was a detailed analysis of the influence and interaction of the process parameters with the pressure height and distribution during pneumomechanical high speed forming, and a comparison with electrohydraulic forming. Initially, the pneumomechanical forming process was therefore examined with regard to the influence of parameters such as the working media density, the accelerating distance and the plunger geometry on the pressure height and the pressure distribution. In order to determine the pressure distribution and height, use is made of a phenomenological approach. This approach is based on the determination of the resulting local dent height in a multiply-bulged sheet metal part (Fig. 2). The dent height is a (local) indicator of the acting pressure [4].

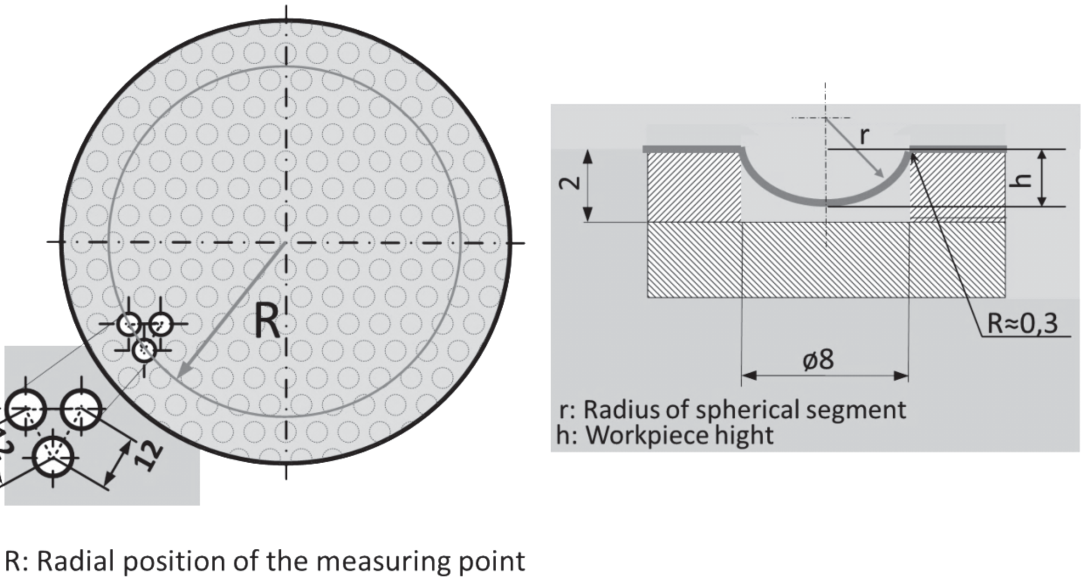


***Fig. 2**: Determination of the pressure distribution on the basis of the workpiece height*

Influence of working-media type and density.

Due to the fact that the working media has to be accelerated during the deformation process, it is obvious that the working media density will have an influence on the course and result of the pneumomechanical forming process. That is why sugar water (density of 1.2 g/cm^3), ethanol (density 0.8 g/cm^3) and water (density 0.99 g/cm^3) were used during an experimental series focusing on the influence of the working media density on the pressure distribution and height.

The pressure distribution setup described in Fig. 2 above was thus used. Typical pressure distributions from three tests in three different working media are shown in Fig. 3. It is obvious that the density of the medium has a decisive influence on the forming results. It can be seen that an increase of 20% in the working media density (sugar water) leads to a 10% higher dent height by comparison with pure water. On the other hand, the use of ethanol coupled with a 20% reduction in the working media density leads to a 4% decrease in the dent height. Furthermore, it can be seen from Fig. 3 that there is quite a uniform pressure distribution in the radial direction on the part surface. Beside this, it was also seen that the higher density of the working medium reduced pressure scatter in the pressure chamber and led to more uniform sheet metal forming.

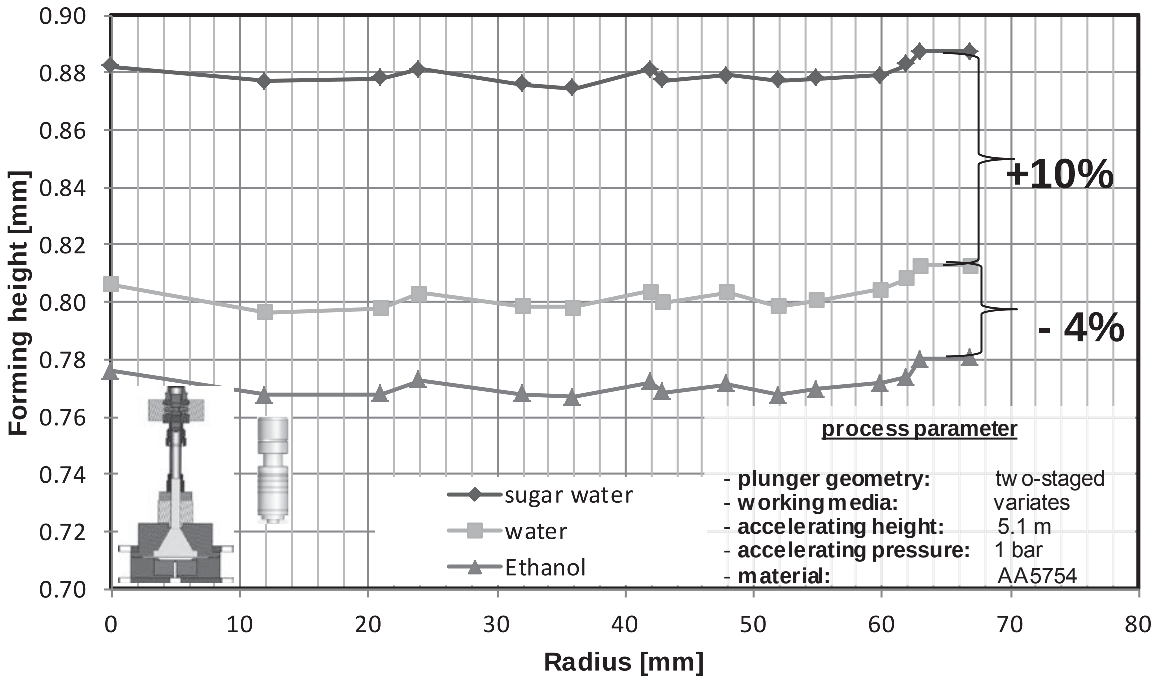


***Fig. 3**: Influence of the working media density on the forming height*

Further investigations into the influence of the parameters of pneumomechanical high-speed forming are focusing not only on the obvious key parameters, such as accelerating pressure and length, but also on the variation of the plunger geometry, for example. A flat, rounded and staged plunger geometry was thus used. The rounded and staged geometries gave rise to higher impact velocities (+7%) but had no influence, or only a minor influence, on the pressure distribution and height.

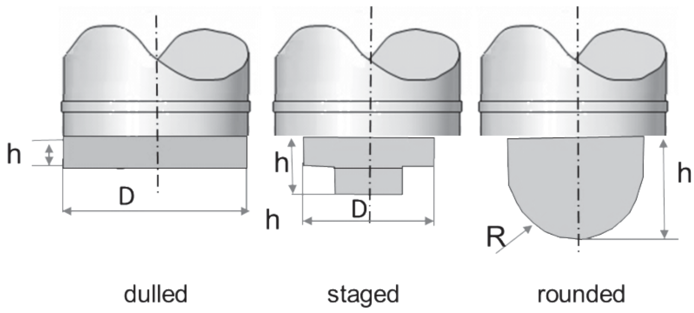


***Fig. 4**: Different plunger top pieces*

Comparison of pneumomechanical and electrohydraulic forming processes.

To permit a better characterization of the two high speed forming processes, a qualitative comparison was performed, focusing first of all on the attainable planar pressure distribution. A phenomenological approach is thus used, based on the determination of the resulting dent height in a multiply-bulged sheet metal part (see also [4]). Analyzing the forming height distribution of the deformed parts, it can be seen that the pressure distribution in the working area of the electrohydraulic setup was not as uniform as that for the pneumomechanical setup. In the electrohydraulic forming process, the highest pressures are obviously reached in the center, or just below the ignition wire, and also in the outer region of the workpiece (see Fig. 5).

This fairly high uniformity is perhaps caused by the geometry employed for the pressure chamber and the position of the spark gap inside. There is potential for unifying the pressure distribution by optimizing the pressure chamber geometry and the spark gap arrangement. Further experiments with the pneumomechanical setup showed that, in addition to quite a uniform pressure distribution, good or slightly better repeatability is possible. The scatter of the forming height during repeatedly-performed forming operations was 2% for the pneumomechanical forming process and 4.5% for electrohydraulic forming. Reducing these deviations is the subject of current research work looking into the further influence of process parameters and developing improved process strategies.

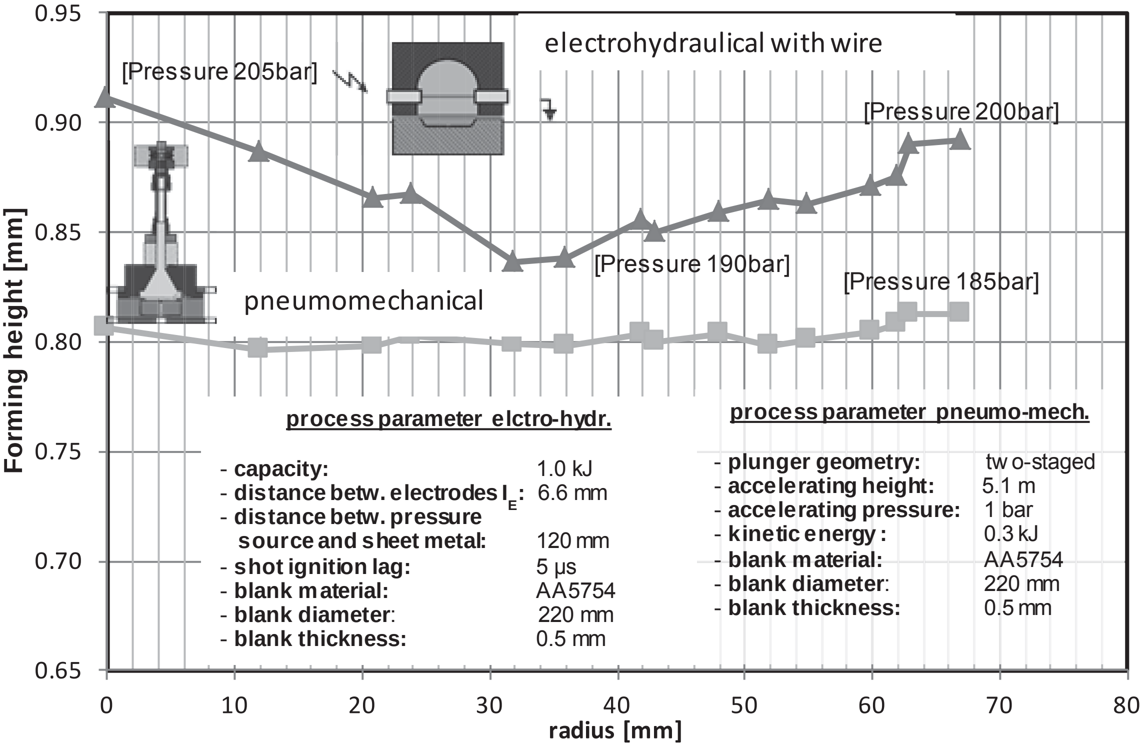
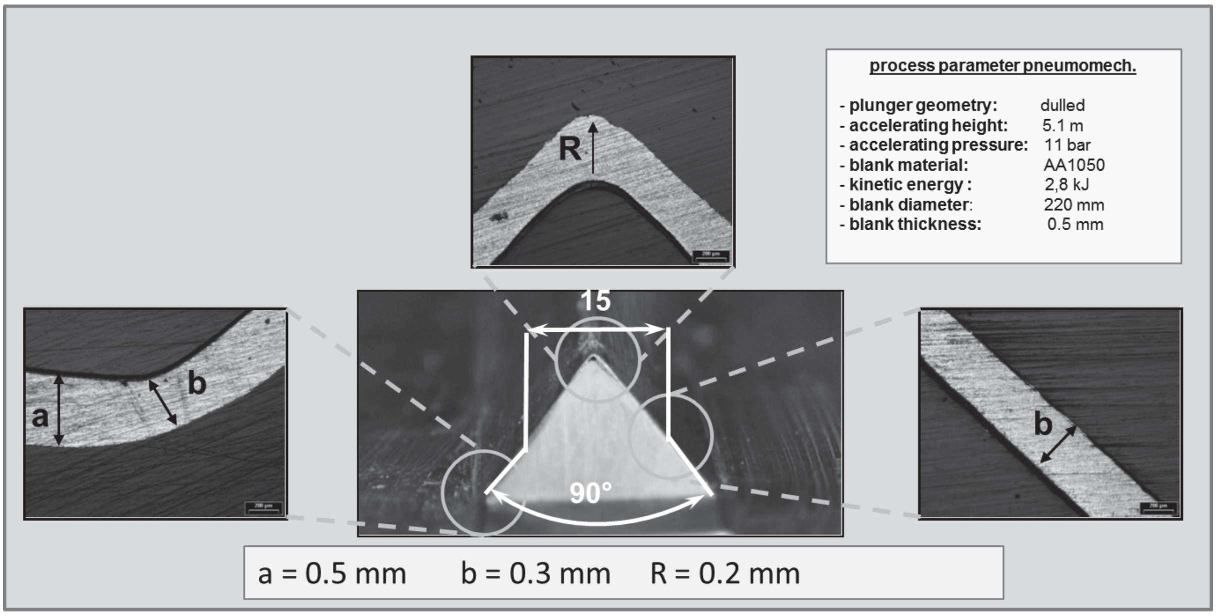


Fig.5: *Distribution of the forming height above the sheet by electrohydraulic und pneumomechanical forming*

Unfortunately, with the pneumomechanical experimental setup employed, it is not possible to perform multiple forming steps or pressurizations in a single operation as is possible with electrohydraulic forming. Also, the handling of the experimental setup is quite time consuming and ought to be covered in further research work at the LUF.

Ongoing research is focusing on the manufacture of a complex, v-shaped part geometry (a groove) with sharp radii using the above-mentioned processes. This work was similarly aimed at comparing the two processes. Use was thus made of blanks in aluminum (AA 1050) with an initial thickness of 0.5 mm. The experiments showed that the production of sharply contoured components with help of the two high-speed processes is possible in an efficient manner. Using the pneumomechanical setup, it was feasible to achieve bottom radii of r_B=0.2 mm (E=2.8 kJ) as can be seen in Fig. 5. The scatter or deviations in the bottom radii over the groove length are pleasantly low, and hence the uniform pressure distribution in the pneumomechanical process produced a geometrical deviation of less than 0.08 mm over the entire length. Bottom radii like this cannot be produced by conventional sheet metal forming operations, nor do these operations have the potential to achieve this.

The electrohydraulic setup made it possible to achieve smaller bottom radii r_B=0.18 mm with a lower charging energy (E=1.5 kJ) but, unfortunately, this was associated with the occurrence of a crack in the corner region between the sheet metal and the flange.



process parameter pneumomech.

- plunger geometry: dulled
- accelerating height: 5.1 m
- accelerating pressure: 11 bar
- blank material: AA1050
- kinetic energy : 2,8 kJ
- blank diameter: 220 mm
- blank thickness: 0.5 mm

a = 0.5 mm b = 0.3 mm R = 0.2 mm

***Fig. 6**: Forming strongly contoured workpieces by the pneumomechanical forming process*

The non-uniform pressure distribution with electrohydraulic forming led to some higher geometrical deviations in the edge and in the forming height over the entire length. Reducing these deviations and further investigating the influence of process parameters on the microstructure is subject of current research work at the LUF.

4 Conclusion

The subject of this present paper is the influence of significant process parameters, such as the working media density, on pressure distribution when using the pneumomechanical and electrohydraulic forming high speed processes. These results showed that varying the working media density, for example, can effectively increase the pressure effect during forming. A comparison of electrohydraulic and pneumomechanical forming, which was also performed on the basis of extensive research work, showed that is possible to achieve sharp edged ($r<S_0$) workpiece geometries with the aid of the two above-mentioned processes which cannot be achieved with the conventional process. These processes thus hold a high potential for producing complex geometries through the optimal use of the formability of the material employed. To conclude, pneumomechanical and electrohydraulic forming processes are a highly innovative and efficient forming technique, which provides an opportunity to expand the forming limits of conventional metal forming processes such as deep drawing.

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