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ИССЛЕДОВАНИЕ ПНЕВМОМЕХАНИЧЕСКОГО ВЫСОКОСКОРОСНОГО ПРОЦЕССА

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THE INVESTIGATION OF A PNEUMOMECHANICAL HIGH SPEED FORMING PROCESS

In the area of metal forming technology, the pneumomechanical high-speed-forming process is a promising approach for manufacturing of thin walled workpieces made of high strength materials. This process uses a pneumatic accelerated plunger that dives into a working media filled pressure chamber for the generation of a short pressure pulse. This pulse can be influenced, on the one hand, by evacuating the acceleration tube and as a consequence higher plunger energy and on the other hand by varying process parameters such as working media characteristics as e.g. density, oxygen content and type as well as the plunger geometry. The influence of these parameters on the process is subject of intense research work at the Chair of Forming and Machining Technology (LUF) at University of Paderborn. Recent results show that pneumomechanical and electrohydraulic forming allows for manufacturing of complex geometrical details in aluminum alloys that cannot be produced by conventional stamping processes. Due to the high homogeneity of the pressure distribution in the pressure chamber, it is possible to achieve high quality workpieces with low dimensional deviations. This paper presents the results of basic research conducted on pneumomechanical high-speed-forming as well as a comparison with electrohydraulic forming.
Keywords: Pneumomechanical forming, Electrohydraulic forming, High speed hydroforming

INTRODUCTION

High-speed-forming processes provide a high potential for efficient manufacturing of products containing complex geometries. As the forming speed is quite high in comparison to conventional stamping technologies, the materials show improved formability and therefore exceed conventional forming limits significantly. Anyway, current pneumomechanical high speed forming setups suffer from a high degree of kinetic energy loss due to friction and air resistance in the accelerating pipe, which reduces the technology's efficiency. Hence, the target of research conducted at the LUF at the University of Paderborn focuses on the improvement of efficiency in high speed forming processes.

The technology of high speed forming has been known since the 19th century already. Intensive research work in this technological field was performed in the United States, Germany and the Soviet Union, in particular, starting in 1955 [1, 2]. Several working principles, including the use of explosives and electrohydraulic or pneumomechanical pressurization, are used in both research work and industrial practice.

The first known prototype machine based on the pneumomechanical operating principle, with an accelerated plunger diving into the pressure chamber filled with the working media in order to generate a short pressure pulse, was developed by Tomigana and Takamatsu in 1964 [3]. The plunger is accelerated by compressed air inside a pipe. An initial investigation showed that pressures up to 900 MPa and energies of 26 kJ in the working media were possible. Typical process times are just a few milliseconds. A further development of this method was presented by Kosing and Skews in [4]. 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 properties of the blank, including the blank thickness [5]. So far, the pneumomechanical method has only been used for the production of small tube and sheet metal parts.

The electrohydraulic method is another interesting technology for manufacturing parts with complex geometries from high strength materials. The further development of electrohydraulic forming (EHF) 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 electrohydraulic setups. So far, EHF technology has been successfully used for deep drawing, calibration, expansion and joining processes, for example [1, 2]. Electrohydraulic forming, 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. [6]. One major advantage of the electrohydraulic method is the possibility of repeating the discharge process in order to achieve greater deformation [7, 8, 9]. Recent results published in Eguia et al [10], for example, 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 [11, 12, 15]. Current research work being performed in the USA is focused on the extension of the existing forming limits. The use of EHF for manufacturing automotive sheet metal parts has thus been examined by Golovashchenko [13]. Both Golovashchenko and [10, 12] use 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 [9, 12].

MOTIVATION

The aim of the investigations being conducted at the LUF is to increase the level of effectiveness and to make high speed forming processes more efficient for the industrial manufacture of complex parts. This will then permit a higher deformation and hence more complex or sharper geometries using lower energies. One key aim of the technological research being conducted at the LUF is also a detailed analysis of the influence and interaction of the process parameters with the pressure level and pressure distribution during pneumomechanical high speed forming, plus 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, working media type and plunger geometry on the pressure level and the pressure distribution.

EXPERIMENTAL SETUP UND MEASURING PROCEDURE

A pneumomechanical and an electrohydraulic setup were used for the experimental investigations and for achieving the desired comparison between EHF and PMF. Apart from an electrohydraulic setup, use was made of a special pneumomechanical setup, in particular.

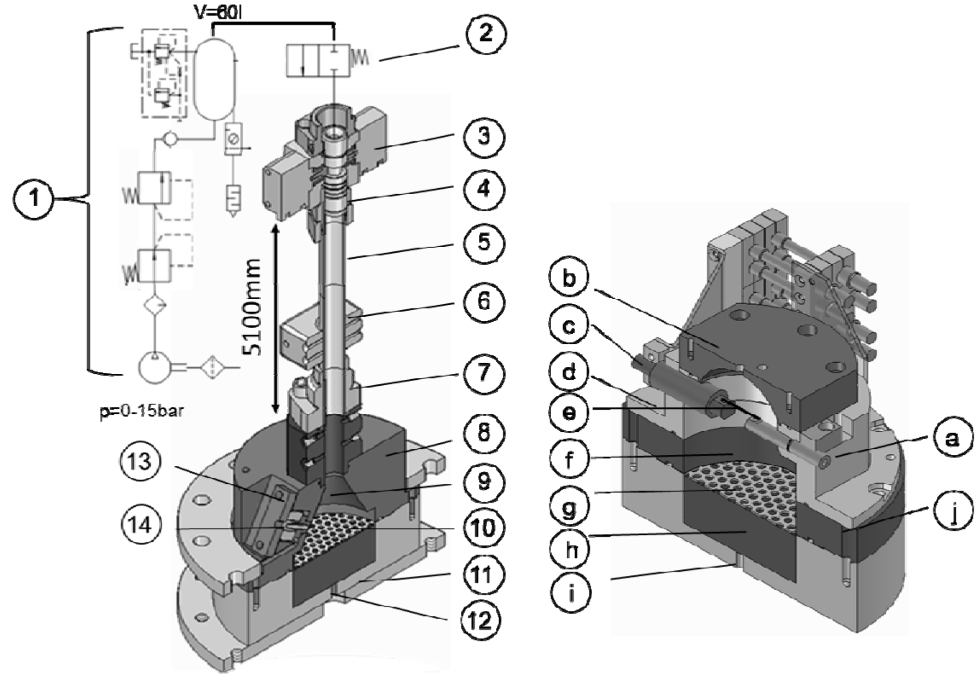

Fig. 1. Pneumomechanical setup: 1–pressure generation unit; 2–lever valve; 3-release mechanism; 4–plunger; 5–acceleration tube; 6–light barrier; 7-SAE flange; 8-pressure chamber; 9–working medium; 10-membrane pressure gauge (die); 11-lower tooling adaptor; 12–vacuum connection; 13–sensor adapter; 14–pressure 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

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 a compressed gas. The accelerated plunger dives into the water-filled cavity of the pressure chamber and thus generates the short pressure pulses of up to 600 bar, which can be used for the deformation of sheet metal and tube. 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 tool were performed using a high-frequency ICP pressure sensor (109C11) from PCB, New York, USA.

Spark gap setup The investigations into 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 [11]). 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.

Determination of the process parameters. In order to determine the pressure distribution and pressure level, use was made of a phenomenological method. With the help of this setup, it proved possible to determine the main process parameters. This method is also known as the multi-point-membrane method and is used in other research institutions [10]. A perforated plate with a height of 2 mm was thus used, with the workpiece being formed in this. The pressure distribution was defined by the measurement of the workpiece height as a function of the radial position of the measured points on the sheet (Fig. 2). The dent height is a (local) indicator of the acting pressure [10, 11]. The measurement of the dent height was performed with a coordinate measuring machine (Contura G2) from Zeiss.

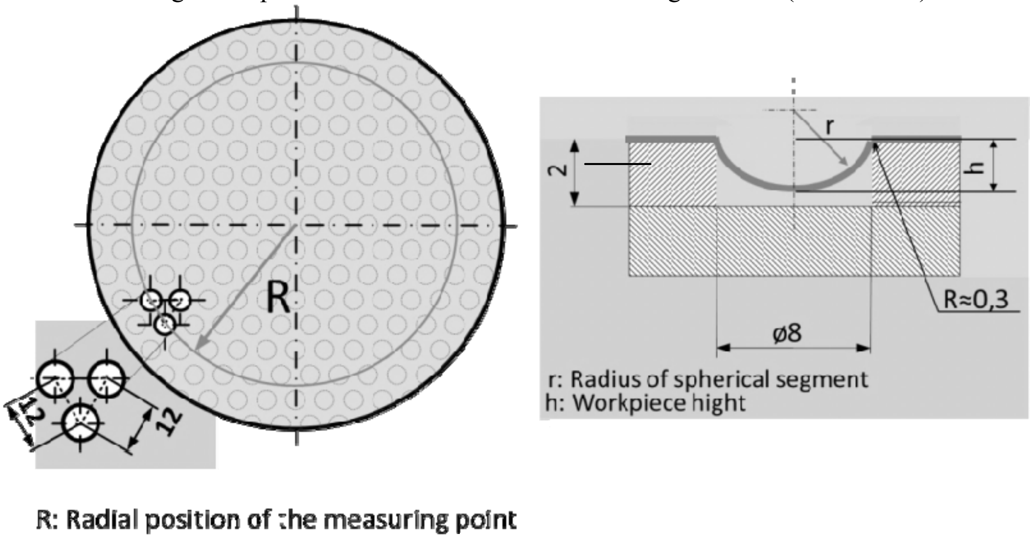

Fig. 2. Determination of the pressure distribution on the basis of the workpiece height

RESULTS AND DISCUSSION

Influence of working-media density. The previously performed research work at the LUF related to the influence of working-media density showed that the forming result of the pneumomechanical forming process can be effectively influenced by varying the working media density. It was proven that an increase, respectively a decrease, of 20% in the working media density leads to 10% higher, respectively 4% lower, sheet forming than can be achieved with pure water. It can also be seen that the variation of the density has no influence on the uniformity of the pressure distribution in the radial direction on the part surface. Typical pressure distributions from three tests in three different types of working media are shown in Fig. 3. The experimental investigation was conducted on blanks in aluminum (AA 5754) with an initial thickness of 0.5 mm.

Influence of working-media type. Due to the fact that the working media has to be accelerated during the deformation process, it is obvious that the working media type will have an influence on the course and result of the pneumomechanical forming process. The experimental investigations have shown that, by using non-Newtonian fluids (water with starch, borax slime), 4% higher or 5% lower sheet metal forming is possible, as a function of the consistency of the working media. In conducting experimental investigations into pneumomechanical forming with pure water, it was found that a pneumatically accelerated plunger often leads to problems with splashing water, which means it is impossible to run through several shocks without refilling the working media. The advantage of the non-Newtonian fluids is that no splash at all results during the immersion of the diving plunger, and hence the filling level can be maintained more or less constant, and several pressurization cycles can be run through without refilling the working media. Another advantage is that, due to the rapid increase in the viscosity of the fluid, the filling level in the pressure chamber can be reduced to 30% compared to water. This increases the efficiency and hence the pressure level. It also permits the use of simple and small tool geometries. A disadvantage of forming in non-Newtonian fluids is the difficult handling of the fluid and the limited handling time. The processing time runs for approximately 3 minutes after the working media has been poured in. After that time, the working media loses its consistency and changes its properties. The use of suspensions with a longer handling time and the combination of different working media is the subject of our current investigations.

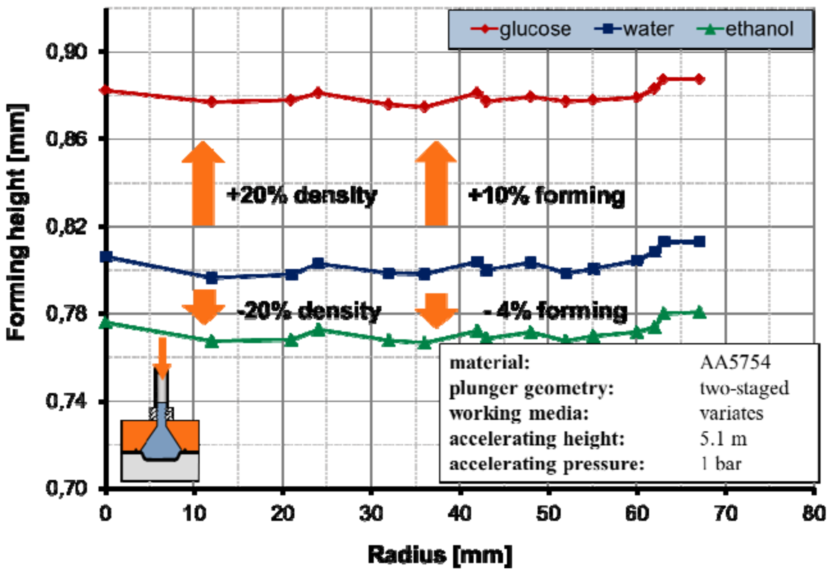

Fig. 3. Influence of the working media density on the forming height

Influence of oxygen content and plunger geometry. Based on the results of previous investigations e.g of the EHF, that the oxygen content has a decisive influence on the forming results, the further investigations of the pneumomechanical high speed forming were focused not only on the obvious key parameters, such as accelerating pressure and length, but also on the variation of the oxygen content and the plunger geometry. Experimental investigations have shown that varying the plunger geometries (Fig. 4) over a dulled, rounded and staged form and reducing the oxygen content in the working media from 7.6 to 1.2 mg O_2/l has only a minor influence on the pressure distribution and pressure level. It was proven that the rounded and staged geometries gave rise to higher impact velocities (+7%), but the forming height remains the same.

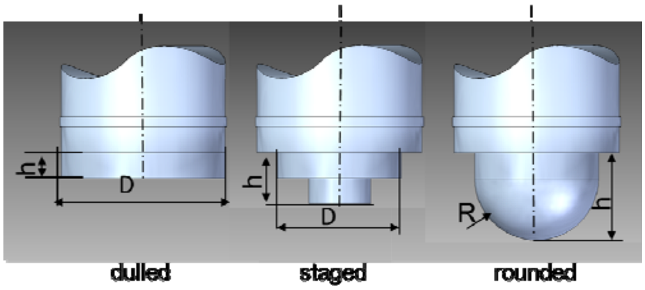

Fig. 4. Different plunger top pieces

Comparison of two high speed forming process. To permit a better characterization of the two high speed forming processes, a qualitative comparison was performed covering, on the one hand, the attainable planar pressure distribution and, on the other hand, the manufacture of a complex, V-shaped part geometry. The experimental results have shown that the pressure distribution in the working area of the electrohydraulic setup was not as uniform as the distribution that can be achieved in the pneumomechanical setup. The higher pressure zones are obviously reached in the center, or just below the ignition wire, and also in the outer region of the workpiece (see Fig. 5).

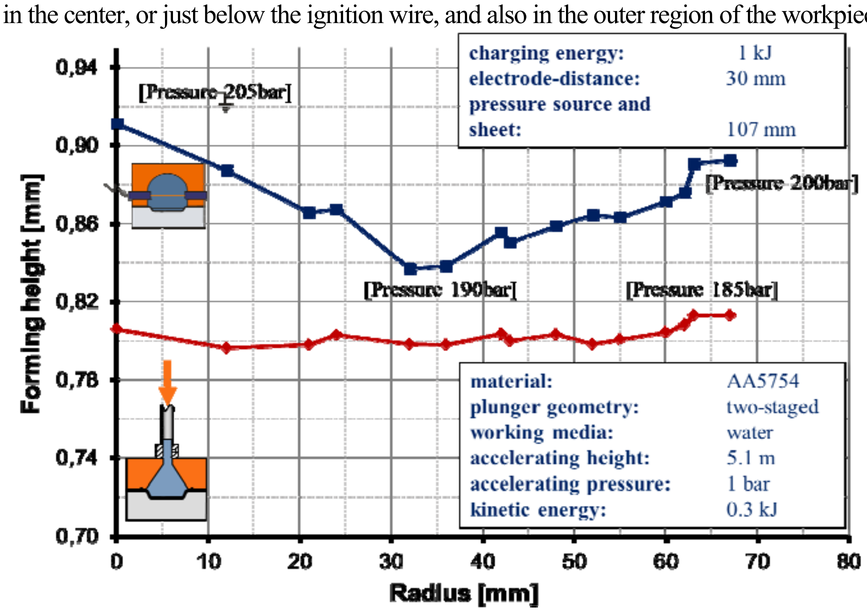

Fig. 5. Distribution of the forming height above the sheet in electrohydraulic und pneumomechanical forming

The scatter of the forming height during repeatedly-performed forming operations was 2% for the pneumomechanical forming process and 4.5% for electrohydraulic forming. We consider that this fairly high uniformity is perhaps due to the geometry employed for the pressure chamber and the position of the spark gap inside. Reducing these deviations by optimizing the pressure chamber geometry and the spark gap arrangement is the subject of current research work that is looking into the further influence of process parameters and the development of improved process strategies.

The research into the manufacture of complex part geometries has shown that it is possible to efficiently produce sharply contoured components with help of the two high-speed processes. Using the pneumomechanical setup, bottom radii (r_B=0.2) smaller than the blank thickness (0.5mm) can be achieved. Bottom radii like this cannot be produced by conventional sheet metal forming operations, nor do these operations have the potential to achieve this. The experiments with the pneumomechanical setup showed that, in addition to quite a uniform pressure distribution, good or slightly better repeatability is possible, and the scatter or deviation in the bottom radii over the groove length is pleasantly low (Fig. 6). The geometric deviation over the entire length of approx. 105 mm is less than 80µm. 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 and a higher geometrical deviation over the entire length (see Fig 6). 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.

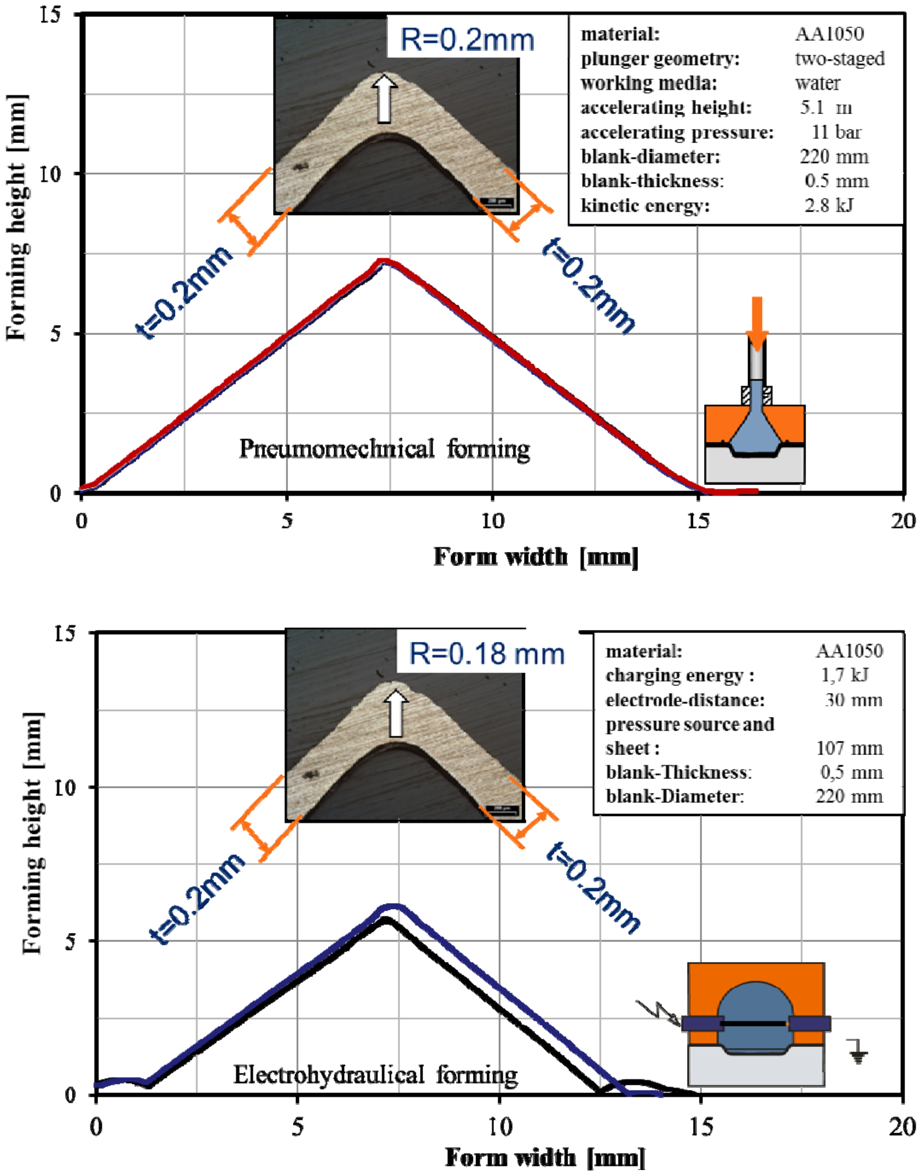

Fig. 6. Manufacturing a sharply countered geometry with the pneumomechanical and electrohydraulic setup

CONCLUSION

1. This paper presents the results of a comparison carried out of electrohydraulic and pneumomechanical forming based on extensive research work, showing that is possible to realize sharp edged ($r<S_0$) workpiece geometries that cannot be produced by conventional processes.
2. The experiments have shown that pneumomechanical and electrohydraulical high speed forming processes hold good potential for the realization of complex geometries by optimally exploiting the formability of the material used.
3. These results show that the variation of the working media density and working media type can effectively increase the pressure effect during the forming process, for example.
4. Furthermore, it was proven that plunger geometries and oxygen content have only a minor influence on the pressure distribution and level.

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, like deep drawing.

Аннотация. *В статье рассматриваются различия обработки листового металла в разных плотностях и видах рабочей среды. В работе было исследовано влияние изменения содержания кислорода в рабочей среде и различных геометрий плунжера на деформацию листового металла. Опытным путем была установлена возможность изготовления сложных геометрических деталей из алюминиевых сплавов с помощью пневмомеханической и електрогидравлической штамповки, обычными способами не производимые. Благодаря точной равномерности распределения давления в радиальном направлении, достигается незначительное геометрическое отклонение заданной формы заготовки. В данной работе представлены результаты фундаментальных исследований пневмомеханической штамповки в сравнение с электрогидравлической формовкой. Результаты исследований были использованы для достижения соответствующих процессов и разработки инструментов для пневмо- механическогой высокоскоростной штамповки.*
Ключевые слова: пневмомеханическая штамповка, електрогидравлическая штамповка

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