# Integrated piezoelectric actuators in deep drawing tools to reduce the try-out

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**Abstract.** Tool making is a very time consuming and expensive operation because many iteration loops are used to manually adjust tool components during the try-out process. That means that trying out deep drawing tools is 30% of the total costs. This is the reason why an active deep drawing tool was developed at the Fraunhofer Institute for Machine Tools and Forming Technology IWU in cooperation with Audi and Volkswagen to reduce the costs and production rates. The main difference between the active and conventional deep drawing tools is using piezoelectric actuators to control the forming process. The active tool idea, which is the main subject of this research, will be presented as well as the findings of experiments with the custom-built deep drawing tool. This experimental tool was designed according to production requirements and has been equipped with piezoelectric actuators that allow active pressure distribution on the sheet metal flange. The disposed piezoelectric elements are similar to those being used in piezo injector systems for modern diesel engines. In order to achieve the required force, the actuators are combined in a cluster that is embedded in the die of the deep drawing tool. One main objective of this work, i.e. reducing the time-consuming try-out-period, has been achieved with the experimental tool which means that the actuators were used to set static pressure distribution between the blankholder and die. We will present the findings of our analysis and the advantages of the active system over a conventional deep drawing tool. In addition to the ability of changing the static pressure distribution, the piezoelectric actuator can also be used to generate a dynamic pressure distribution during the forming process. As a result the active tool has the potential to expand the forming constraints to make it possible to manage forming restrictions caused by light weight materials in future.

**Keywords:** Deep drawing tools; try-out; sheet metal forming; piezoelectric actuator.
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## THE INITIAL SITUATION

When forming intricate deep-drawing pieces such as can be found in the production of car body parts, plastic deformation in the flange zone creates a complicated workpiece flow. That means that there are higher tangential compressive strains in the corner zones of the deep-drawing flange than in the adjacent straight or slightly curved zones of the deep-drawing piece. This results in an uneven distribution of sheet thickness where the sheet metal thickens in the corner zone of the deep-drawing flange, as Figure 1 illustrates /1/.

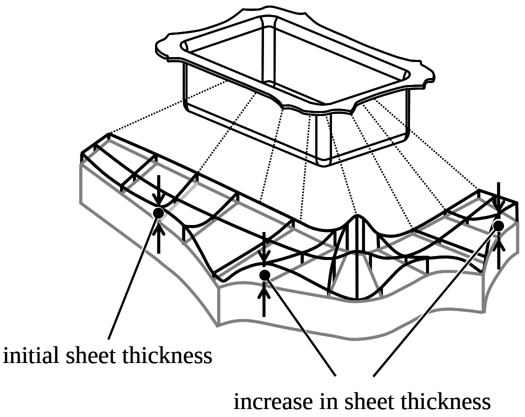

**FIGURE 1.** Distribution of sheet thickness in the deep-drawing flange according to STRACKERJAHN /1/

The workpiece flow in the corner zones has to be relieved or braked in the straight or slightly curved zones of the deep-drawing piece to avoid deep-drawing wrinkles in the form of cracks in the corners or wrinkles in the side zones. Correcting variables are known in the form of pressure distributions on the blankholder, drawbeads /2, 3, 4/, blankholder distances /5/ or tribological systems. Furthermore, the correcting variables listed above have to be well aligned to the forming process to create forming tools with reliable processes. This is aligned in time- and cost-intensive iterative loops in the form of manual activities in tool working of tool building. Actuator correcting variables in tool incorporation are not known in contrast to manual adjustment of the correcting variables, although they are desired.

## ACTIVE DIE

A correcting variable that can be adjusted in the process for the active pressure distribution in the flange zone was developed in the studies presented here in the form of an active die and the active die shown in Figure 2 was tested on an experimental geometry presented by Waltl /6/. Waltl’s experimental geometry /6/ reflects the challenges that the automobile industry presents today in terms of forming technology and has both corners zones that are critical in terms of deep-drawing technology and side zones critical in terms of wrinkles similar to the rectangular cup.

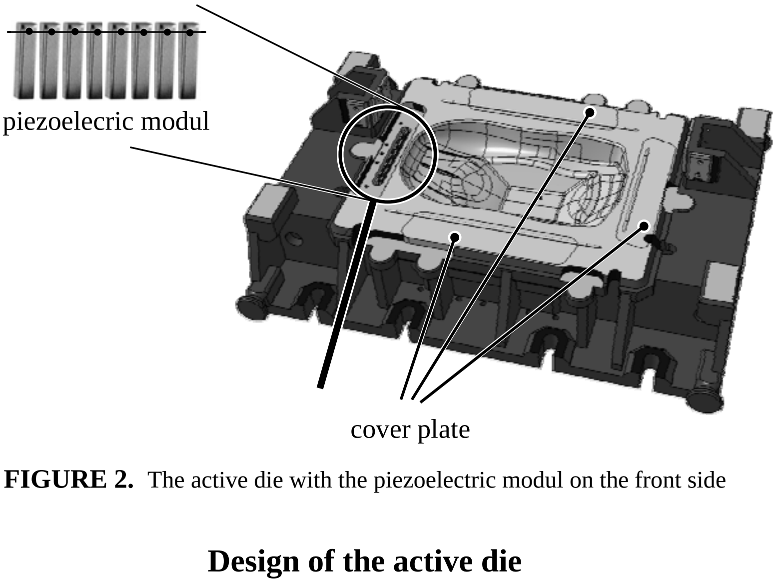

**FIGURE 2.** The active die with the piezoelectric modul on the front side

### Design of the active die

The active adjustable zones are placed in the straight side zones of the deep-drawing flange with the active die in accordance with the requirements of /2, 3, 4/ as an analogy to the rectangular cup and the active zones are triggered by piezoelectric actuators. These piezoelectric actuators were arranged in modular design in comparison to the work of Neugebauer /7, 8/ because the modular design make large-scale pressure patterns possible in the side zones. Using the piezoelectric modules in the flange zone of the active bottom die enables us to actively shift the surface pressure in the flange zone. The side zones can be impinged with locally higher surface pressure as per the requirements of /2, 3, 4/ by activating the piezoelectric actuator. Maximizing the surface pressure in the side zones reduces the surface pressure if the blankholder force remains the same in the corner zones which guarantees a higher level of material in the corner zones.

The active die is substantially different in its structure to already known segmented /9,10/ or elastic solutions /7,8,11,12/. The deep drawing tool is only formed on the active surface with a defined elasticity due to the high level of binding rigidity in the form of a cast rib below the piezoelectric actuators so that using piezoelectric actuators can generate locally convex forming on the active surface within 10 milliseconds. The convex forming of the active surface distributes the surface pressure in the flange zone as described above which has an impact on the forming process. The piezoelectric actuators are arranged in a rectangular pocket that is sealed with an elastically made cover plate that is connected to the die with bolted connections all around.

The four piezoelectric modules arranged in the side zones of the active bottom die below the active surface of the cover plate are regularly used in injection systems of modern diesel motors.

## RESULTS

Not only a coupled FEM simulation, but also an experimental test was carried out with the active bottom die to test the functioning of the active bottom die.

### Results of the coupled FEM simulation

A coupled FEM simulation (Figure 3) was set up in LS DYNA for virtually safeguarding the functioning of the active die. This study focused on checking the previously described homogenous pressure pattern characteristic and the impact this has on the process by using the active die. In comparison to conventional forming simulations, the tool elements of the blankholder and die were set up as volume bodies with elastic properties in the FEM simulation carried out. The serial arrangement of the tool elements to the piezoelectric actuator is the reason for the additional effort since the actuator generates the parameters of force and path depending upon the surrounding rigidity. The piezoelectric actuators were mapped in the form of volume elements including the corresponding blocking forces functioning in the direction of polarization so this is a complete mechanical description of the actuator. Furthermore, the punch (that does not have any impact on the piezoelectric actuator) was mapped in the simulation as a rigid body.

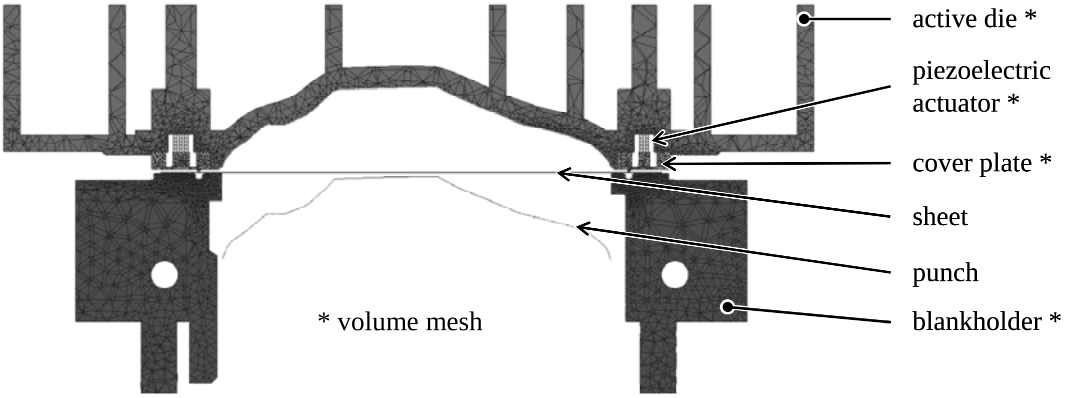

**FIGURE 3.** Model of the coupled FEM simulation

The findings of this simulation of pressure distribution were juxtaposed with one another with the active and inactive actuators in Figure 4 to reduce the effort of calculating and this illustrates the fact that activating the piezoelectric actuator changes the pressure distribution in the flange zone.

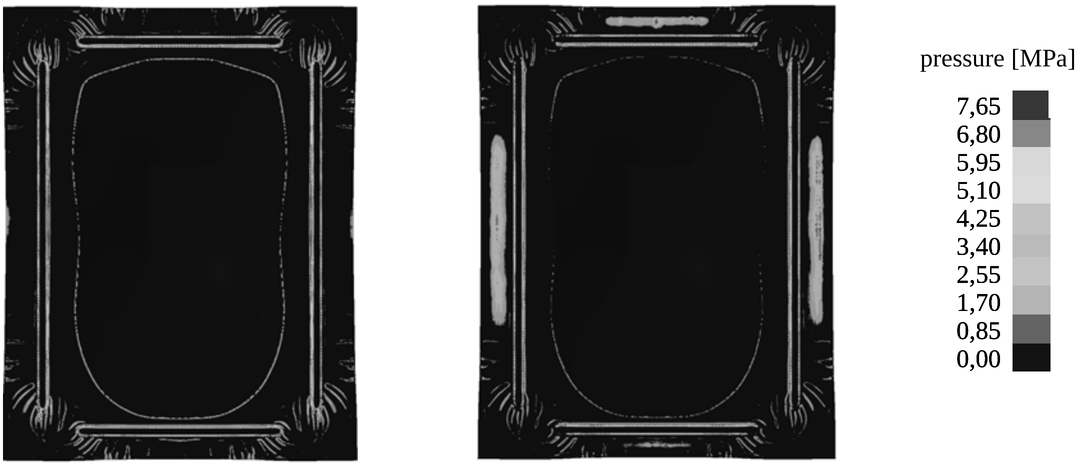

**FIGURE 4.** The pressure distribution according to the FEM simulation (inactive actuators on the left-hand side and active actuators on the right-hand side)

The piezoelectric modules made it possible to set up homogenous pressure patterns in the active zones that blocked the workpiece flow in the side zones. This produced lower pressures in the corner zones due to pressure distribution that caused higher workpiece flow in the corner zones. In turn, this generated a positive impact on the process. The system of the active die was built up and started up based upon the positive results of the simulation and we will present the results of start-up below.

## Experimental studies with the active die

The active die was started up in two steps using an experimental geometry of Waltl /6/ that was not worked in. The fact that the experimental tool was not worked in had the purpose of illustrating the potential of reducing tool start-up. First of all, we created spot-grind impressions in the on and off operating states at the point in time of closing the blankholder. In the second step, we carried out a forming test in the on and off operating states. Each of these specific tests was repeated several times on a hydraulic drawing press in a stochastic sequence.

### *Comparison with a Spot-Grind Impression*

Figure 5 shows a comparison of the spot-grind patterns of the on and off operating states in a partial cutout. The white rectangle in the figure marks where the active zones are while the bright points represent a frictional connection between the sheet metal and tool.

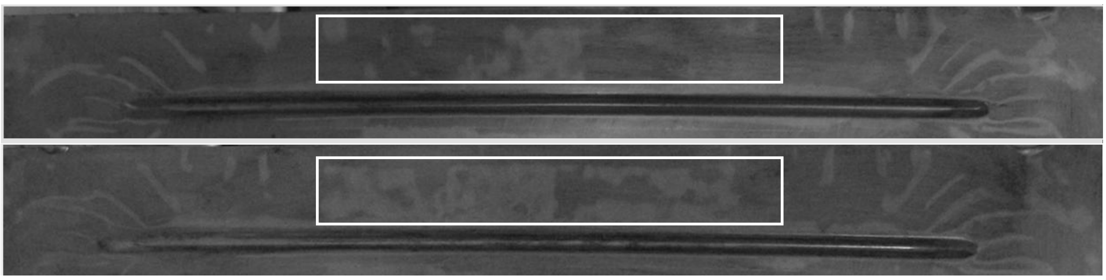

**FIGURE 5.** A comparison of spot-grind patterns with inactive (top) and active (lower) actuators

Figure 5 indicates that the pressure pattern in the on operating state (Figure  below) was improved in the active zone so that the pressure pattern in the on operating state is much more homogenous than the off operating state (Figure  above).

### *Comparison with a Forming Test*

The forming tests were carried out with the force of the blankholders, the friction and the sheet metal material remaining the same.

### *The findings of the forming tests*

Figure 6 compares the means of the change in the course of the flanges with the on and off operating states in a partial cutout. The broken line indicates the on operating state while the full line indicates the off operating state. When we compare these two operating states, we can recognize contrary effects in the change in the course of the flanges because the workpiece flow in the side zones is blocked much more in the on operating state than in the off operating state. Furthermore, we can identify contrary effects in the corner zones because we can see greater workpiece flow in the on operating state than in the off operating state.

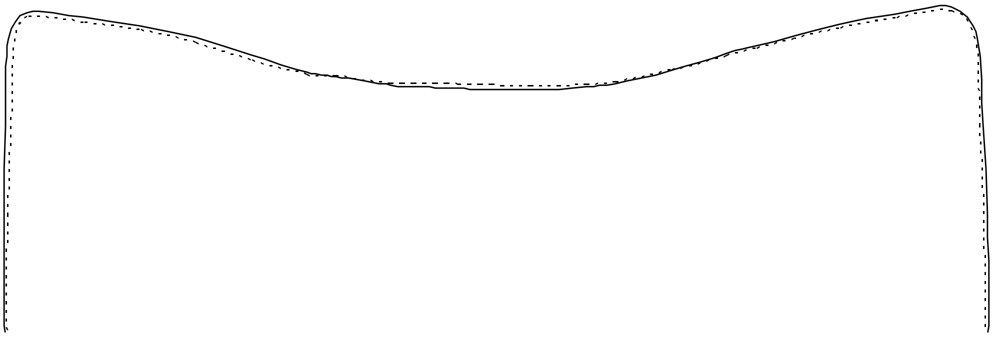

**FIGURE 6.** The change in the course of the flanges as a comparison between the activated actuator (the broken line) and the deactivated actuator (full line)

The higher pressure patterns in the side zones in the on operating state shifted the pressure from the corner zone to the side zone which means that surface pressing was reduced in the corner zone of the deep-drawing flange and the workpiece flow was maximized due to a shift in pressure. This is the reason why deep-drawing pieces were produced with differing component part qualities due to the differing workpiece flow in the on and off operating states. For instance, the off operating state continually caused cracks (Figure 7, left) and contractions in the deep-drawing piece corners and there were no deep-drawing faults in the on operating state (Figure 7, right).

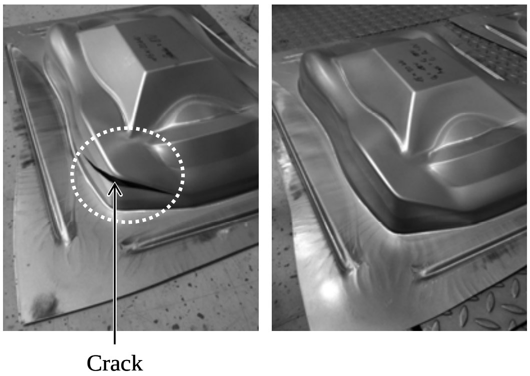

**FIGURE 7.** Results of the forming test between the deactivated actuator (left) and the activated actuator (right)

# SUMMARY AND OUTLOOK

Our studies indicated that using piezoelectric actuators in the forming tool has made it possible to specifically change the pressure patterns in the flange zone and therefore the flange diminution. In the example of experimental geometry, this creates differences in the component part quality. A partially active operating state was mapped with the active die in prior tests by adjusting the actuator outside of the forming process which maps the operating state of the present tool incorporation that the tool mechanic carries out in the form of purely manual work. In spite of non-machined effective areas, it was possible to create a major portion in the on operating state where the potential can be designated for the active die for reducing tool start-up. Using piezoelectric actuators makes it possible to actively impact the forming process (i.e., during the forming process). This spells out potentially adding materials that cannot be formed currently to the limits to the process such as difficult-to-process lightweight materials. This is one of the projects on the agenda of further studies to use the active die to make a contribution to expanding the limits of forming.

# THANKS

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