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FluidForming – Hydroforming reinvented

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Abstract. The FluidForming technology represents an alternative sheet metal forming approach as compared to the traditional, bladder based hydroforming, metal spinning, and sheet metal stamping processes. The machine construction allows for much higher forming pressures of up to 400 MPa/60,000 psi. The technology also enables material flow into the dies, thus, providing more material in potentially critical areas. Modular die construction allows for very cost effective solutions including plastic dies, 3D printed dies, die nesting, and split dies. This approach, in-turn, allows undercuts in the parts and generates scratch- and mostly distortion-free parts from pre-painted, pre-patterned, and pre-polished materials like AL, SS, CU, TI or any of the new high performance alloys. As a result, the technology enables a new product development approach that can focus on optimization and/or Time-to-Market while maintaining or lowering the overall Cost-to-Market. In fact, the development cycle can be accelerated to be less than a week from the CAD design to the production of highly accurate, repeatable metal parts that may not even be manufacturable with other technologies.

1. Introduction

Hydroforming as a sheet metal forming process was first patented and used in the 1950s by Fred Leutheuser, Jr. and John A. Fox [1] although other inventors should be credited in the area of tube hydroforming: in 1934, J. Squires [2] was awarded a patent for propeller blade forming and, in 1941, A. Odenwald [3] was awarded a patent for high pressure tube forming. Multiple variations of hydroforming exist today and are typically operating with forming pressure in the range of 70 MPa to 100 MPa (10,000 psi to 15,000 psi). In general, we can differentiate between tube hydroforming and sheet metal hydroforming. Forming of sheet metal is traditionally achieved by pressurizing a flexible bladder which in turn expands against the sheet metal that is being formed. A mechanical containment structure ensures that the liquid pressure forms the sheet metal into or over a single mould or die with the desired shaping of the metal. Tube hydroforming requires two moulds but no bladder as the forming fluid is pressurized into the tube which in turn, deforms the tube into the dies.

The FluidForming Technology is a reinvention of the hydroforming process in that the machine design allows for much higher forming pressures without the need for a containment bladder. In the

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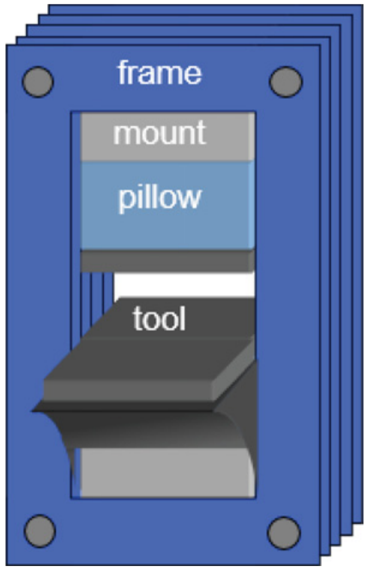

Figure 1. Basic construction of the FormBalancer® Hydroforming Machine.

following article, the technology will be explained in the context of its profound implications on part quality and repeatability as well as the product development cycle, product optimization, and the resulting Time-to-Market and Cost-to-Market opportunities.

2. Machine technology

The design of the machine creates a floating tool structure ("pressure pillow") both for the upper and lower die mounting fixtures. This design inherently allows for plane-parallel, self-alignment of the tools and, consequently, provides a good, level seal surface with evenly distributed sealing forces. This is also the reason why the containment bladder can be eliminated and much higher forming pressures can be achieved.

In order to seal the sheet metal and prevent leakage of the high pressure fluid, typically, protective film (like laser film or scratch prevention film) is utilized. The seal performance can be enhanced with a simple O-ring application or a more complex metal seal design for special cases.

2.1 Machine design

Figure 1 shows the basic construction of the machine. The frame contains the forming forces with the die mounting fixtures connected to the "pressure pillow" and results in a very compact and lightweight construction.

3. Tooling advantages

The metal forming approach through pressurized liquid and the force containing frame allow for a modular and/or nested die design since no instantaneous stamping forces are introduced into the frame or structure of the machine or into the foundation of the supporting floor. Figure 2 shows options of modularization of the tooling. The ability to modularize or nest also allows for die inserts in order to

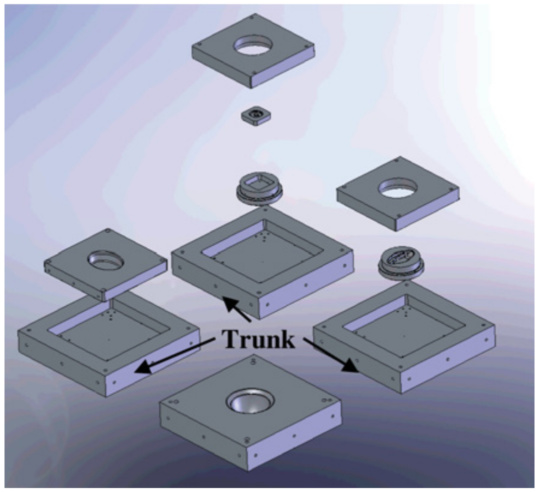

Figure 2. Illustration of the nested, modular die structure.

form typically non-formable undercuts or to differentiate otherwise identical parts through features, logos and/or patterns.

The result of such approach is the ability to contain and minimize cost for individual parts or a family of parts as well as for entire development or performance optimization programs. Tool lead times are also positively affected: only one tool has to be manufactured and that tool has to be only slightly larger and deeper than the part to be formed as it is placed within the nested die structure.

Another advantage of the tooling approach is the ability to move away from steel tools as long as the die size is small enough to fit into an outer, five-sided frame (trunk) which is the typical approach even for steel tools. With that criteria fulfilled, tools can be made from easily machinable hard plastic, engineered wood, composites or any other hard material with low compressibility. This includes tools created by 3-D printing or other additive manufacturing methods that can generate hard, low compressible tools like selective laser sintering.

4. Part design

The aforementioned machine attributes translate into a cost-effective approach to creating sheet metal parts. With the high pressures that can be generated, another fundamental area of advantages with respect to accuracy, repeatability and overall part quality is realized. These advantages allow for new levels of part design with respect to aesthetics, functionality, complexity, and performance.

4.1 Warping, accuracy, repeatability & quality

Due to the fact that one surface of the sheet metal is essentially subjected to a “flexible”, “self-adjusting” tool surface (namely water), the sheet metal will – given the right pressure – be forced into the tool and onto the tool surface. The resulting part will have little to no distance to the tool surface, thus, resulting in highly accurate parts.

Figure 3 shows a satellite dish of 1000 mm in diameter. Product accuracy requirements of ± 0.5 mm anywhere on the surface are achieved with a single step forming process despite spring-back and material thickness variations of up to ± 0.12 mm.

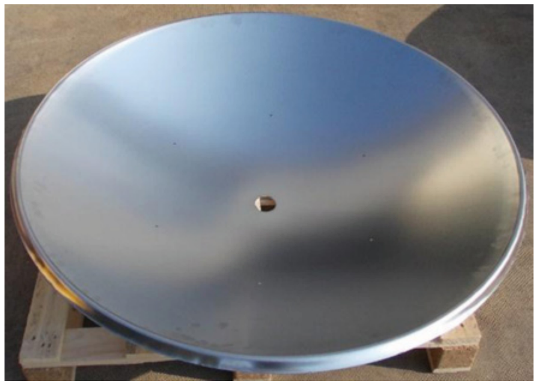

Figure 3. Hydroformed reflector dish.

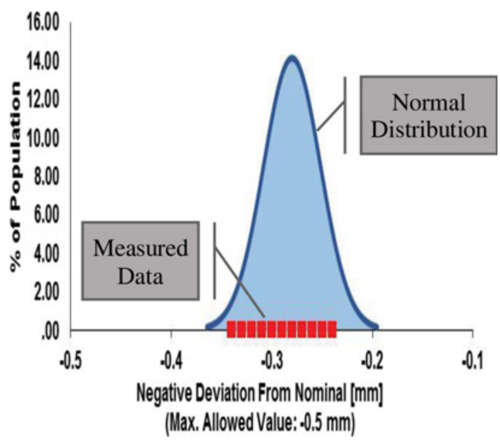

Figure 4. Normal distribution and measurements for the maximum negative deviation from the design surface plane.

Besides the accuracy of the process, it is highly repeatable. Figure 4 and Fig. 5 show production accuracy and repeatability information for the part in Fig. 3 verified through a scanning measurement process.

The individual data points refer to respective maximum negative and positive distance deviation from the design CAD model of the part. Each point refers to a different physical part and the part location is not defined on the part.

Part-to-Part variation of the surface dimensions are due to multiple causes, two of which are:

- spring-back of the metal
  - typically minimal, spring-back can be compensated by appropriately deepening or changing the tool surface, if necessary
- wall thickness variation of the sheet metal
  - may be significant depending on performance requirements and which surface is critical for the application, the tool side or the water side;
  - example: in the above case, the supplied 2 mm thick AL varies by up to ± 0.12 mm.

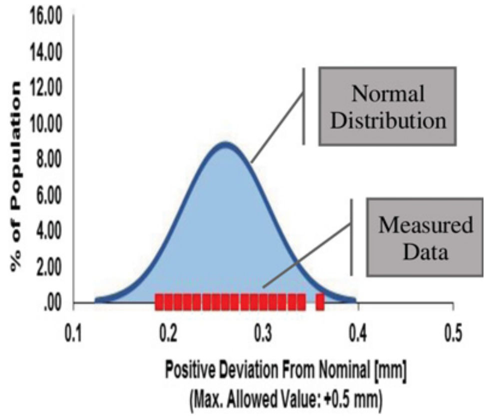

Figure 5. Normal distribution and measurements for the maximum positive deviation from the design surface plane.

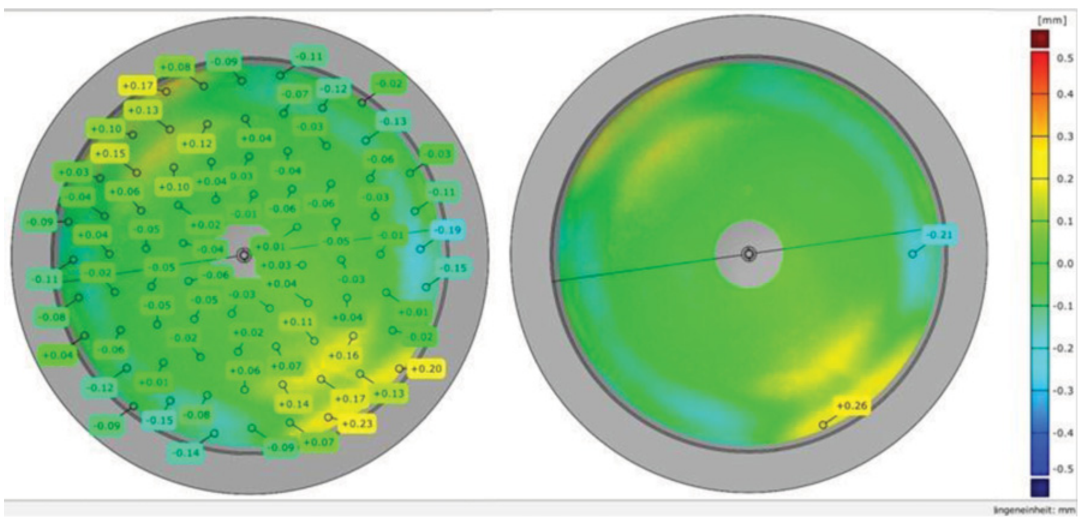

Figure 6. Typical measurement results for equidistant and min / max analysis.

In Fig. 6, a typical measurement result is shown for the deviation of the actual part surface dimension from the CAD design surface dimension.

Part spring-back and warping results for parts manufactured with this process are an order of magnitude better / lower than typically found with an equivalent die stamping part. As a result, this process often allows for minimized downstream operations like fixturing and clamping, i.e., it can deliver significant cost reductions. In special cases that require highest degrees of accuracy, an intermediate or additional annealing step with a subsequent hydroforming step in the same die will yield even better results.

4.2 Design opportunities

Considering the above machine design and resulting capabilities, it is easy to understand that the process not only

- allows for improvements in existing designs,
- opens up previously cost prohibitive designs to being formed in metal rather than as plastic injection moulded parts, but
- also creates exiting new opportunities in the medical, fuel cell, heat exchanger, aerospace and many other areas.

4.3 Material choice and opportunity

The “flexible”, “self-adjusting” tool surface of the water side opens other interesting opportunities: material choice and material thickness. As long as the material properties allow the forming of the part, the same tool can form the part from any metal or alloy. This is especially true when considering stress relief and annealing steps in between multiple hydroforming steps (all with the same tool).

The other variable that can be readily modified is the material thickness. As long as the sealing forces are sufficient to form the material thickness then the same tool can be used to form parts of different thicknesses.

For example, optimizing the material thickness for minimum weight and maximum fuel efficiency is easily accomplished and can be done during the original development process or as a design iteration later on in the product life.

5. Product development cycle and time-to-market

Having described the basic machine function and the resulting cost effective tooling approach, as well as the benefits in quality, accuracy, and repeatability, the FluidForming process and it’s Formbalancer® machine execution provide a unique opportunity for product design and cost effective, fast product development cycles. With today’s CAD capabilities, with FEA simulation technologies allowing accurate part forming predictions, and with additive manufacturing of hard tools, it is possible to proceed from a design idea to a tooled solution to a mass manufactured part in less than a week. Depending on the length of the test requirements, a test-and-iterate product development cycle can be executed within a month. All of that can be accomplished at a fraction of the cost of typical die stamping solutions for the same part.

References

[1] F.W. Leuthesser, Jr., J.A. Fox, *US Patent 2,713,314* (1955)
[2] J. Squires, *US Patent 1,943,560* (1934)
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