UNDERSTANDING SHEET HYDROFORMING

Dive into high-quality part formation using different hydroforming methods

A Whitepaper by Beckwood Press Company
Contributors: Tyler Chu, Christie Williams, & Amina Kopic-Osmanovic

Sheet hydroforming is an essential process for low-volume, high-mix part production commonly seen in the aerospace, electronics, and medical industries. With advantages such as inexpensive tooling, forming accuracy, intuitive controls and programming, it is the method of choice for end-users and job shops alike. But what exactly goes into forming parts correctly with a hydroform press? How do you design for good tooling and blanks? Which materials do you use? How do you protect the flexible diaphragm?

This whitepaper explores the answers to these commonly asked questions about the sheet hydroforming process and offers guidance into successful part formation.

What is Sheet Hydroforming?

Sheet Hydroforming is a method to form metal, plastic, and composite parts using a diaphragm pressurized with fluid and a single, un-mated tool. When the cycle is initiated, the diaphragm envelopes the male tool or female die cavity, applying even pressure on every square inch of the working area. The result is a net-shaped part that requires little or no secondary finishing.

Forces are always perpendicular to the surface in sheet hydroforming, meaning the forces occur in all directions. The ability to push on multiple faces of the part gives crisp geometries not achievable on traditional hydraulic presses.

Developed in the 1950's as an alternative to metal spinning and traditional forming, early sheet hydroforming presses revolutionized low-volume, high-mix production facilities. However, the secret to making quality parts rested with the operator who manually adjusted the levers and knobs (pressure and punch position) for optimal performance.

Today's modern sheet hydroforming presses are sophisticated, yet simple machines that use a digital HMI to precisely control a myriad of cycle parameters including pressure, dwell, and draw depth/speed (in deep draw presses). They negate the need for skilled workers and allow any operator to use the machine quickly and easily.

Flexible Diaphragm / Bladder

The hydroforming process uses a flexible diaphragm, or bladder, to act as a universal die half which forms over a solid tool. Diaphragms are made from an elastic material, typically urethane or rubber. This eliminates the need for conventional mated tooling. The diaphragm acts as a barrier, separating the part from the fluid, which results in a cleaner forming process and less potential for fluid contamination. It also provides predictable sequencing through the forming process, ensuring consistent pressure is maintained.

Triform 25-10-12 Deep Draw

Triform 2448-10 Fluid Cell

Triform 68-10 Fluid Cell

Types of Sheet Hydroforming

The two sheet hydroforming processes are fluid cell and deep draw. Choosing the best hydroforming process depends on a number of requirements including tooling and blank design, but the part geometry and shape will be the deciding factor.

Fluid Cell Sheet Hydroforming

Fluid cell sheet hydroforming is a forming process in which the tooling is stationary and the chamber around the tool is pressurized to form the parts. The fluid cell process is typically used to form multiple shallow geometric parts with contours, bends, beads, or flanges in a single cycle. The blanks will typically be designed as a net shape. The main components are a pressure chamber, forming area, diaphragm, and fluid media (hydraulic oil or similar).

Round Machines

During a cycle on a round (circular) fluid cell sheet hydroforming machine, the operator loads a blank onto a stationary tool resting on the flat forming area. The pressure chamber is closed by raising the forming area or lowering the chamber as the diaphragm is pressurized. Pressure varies from 500 PSI - 20,000 PSI depending on the geometry and thickness of the material. Harder durometer wear pads are often used during these cycles to reduce the chance of wrinkling.

Advantages/Disadvantages

The main advantage to the round fluid cell press is simplicity. It will form quality shallow parts or parts with open corners quickly and easily. The disadvantage is the difficulty to draw parts because there is little control of the material flow in fluid cell presses. In some instances, simple draws can be achieved using a hold-back ring which allows operators to apply pressure to the outside edge of the blank, thus controlling the material flow. Since the forming area is circular, this usually means longer parts are not feasible on a round machine but will work on a tray machine. Parts with diameters up to 68" can be formed, but depending on the part geometry, it may be limited to 30" or less.

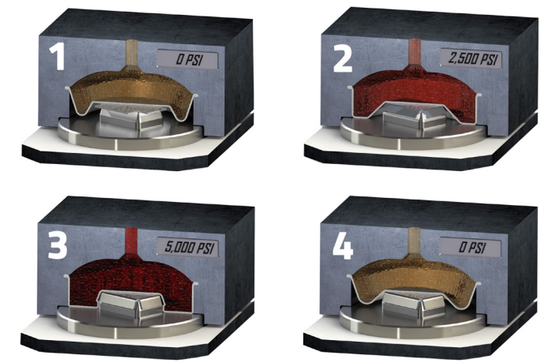


Figure 1: Fluid cell sheet hydroforming process in 4 steps

Tray-Style Machines

A tray style fluid cell sheet hydroforming press has a shuttle with a "tray-shaped" concave forming area. Depending on the output requirements, these presses can have a single shuttle or dual shuttles for continuous production. The forming trays typically have a urethane or rubber perimeter with an angled face to reduce wear on the diaphragm. The tray is shuttled into the cylindrical frame where the pressure is applied to the entire tray.

Due to the geometry of the tray style shuttles, the wear pad is mechanically locked into the cartridge when shuttled in and more durable. The cartridge consists of the diaphragm, wear pad, and mechanisms necessary to stabilize them. This containment is necessary because excessive elongation

Figure 2: Round style machine with a 24" circular forming area to form multiple parts in a single cycle

Figure 3: Tray style machine with shuttle used for elongated part formation

or bladder extrusion will cause the diaphragm to rupture. The trays also contain filler plates which cause the diaphragm to only stretch to the necessary depth to form the part, ensuring a long bladder life.

Advantages/Disadvantages

The main advantage of a tray-style machine is the ability to form elongated parts up to 120" long, often in batches. One disadvantage is size limitations depending on the part geometry and material being formed. While there is a containment system for the pressurized diaphragm, sometimes packing the trays with extra rubber padding is necessary, which can result in longer loading times between cycles.

Deep Draw Sheet Hydroforming

The Deep Draw Hydroforming process is used to form spherical parts with closed corners and other complex geometries. In deep draw sheet hydroforming, there is a blank holder or a draw ring which lays flat on the forming area. The draw ring is a plate with a hole cut in the center. A blank is placed on top of the hole of the draw ring. The punch tool is mounted inside the lower chamber, which extends through the draw ring and pushes against the diaphragm to form the material around the punch.

Figure 4: Deep draw sheet hydroforming process in 4 steps

Draw Ring

The draw ring is a hardened material which provides more resistance against the sliding of the blank. Draw rings are usually customized for each punch tool because the clearances between each are critical to proper finished part dimensions. The force of the punch cylinder is a variable of punch size and bladder pressure. As punch area increases the counteracting punch cylinder force also increases.

Material Flow

To be successful at deep draw sheet hydroforming, it is important to understand how to control the flow of the material being formed. This includes controlling the punch position, bladder pressure, and dwell time.

Material flow will make or break your deep draw hydroformed parts.

Your part will dictate the pressure (PSI) needed for your hydroforming process. When you increase the PSI or the area, you increase the force that's holding down the blank. Too quick of a flow rate results in wrinkling as tension is not maintained and the material rushes into one area. Too slow of a flow rate causes excessive tension in the blank, resulting in tears. Success is dependent on achieving optimal hold down force that allows for material to form over the punch and around the punch.

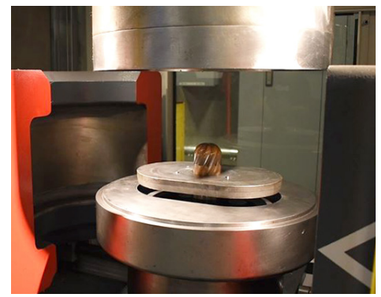


Figure 5: A draw ring (flat metal piece) & a punch (rounded textured piece)

In addition, lubrication can drastically affect the material flow rate in the draw process. Ideally lubrication should last through the entire draw but not gather on the flange or body of the part. If there is too much lubrication, it will build up and not allow the material to lay down flat on the ring. If there is too little lubrication, it can cause stretching and tearing of the part.

Considerations when choosing a lubricant:

- Must have high pressure lubricating properties.
- Must be easily removed from metal after forming.
- Must have good anti-corrosion properties.
- Must have high resistance against sticking to different parts involved.
- Must consider any secondary post forming operations for the part

Blank Design

Blank design is another critical component of successful material flow in deep draw hydroforming. The starting blank-size-to-punch-diameter ratio must be taken into consideration, which depends on material type and thickness. The larger that ratio, the less starting pressure can be applied because it greatly increases blank hold down and the risk of thinning/tearing.

In some cases, a draw-redraw may be required for taller parts with smaller diameters. The smaller the ratio, the less chance for tearing but the chance of running out of material increases or wrinkling occurs if the material rushes inward too quickly. A predesigned blank shape can help control the flow rate of the material towards the punch to draw more evenly and minimize the risk for wrinkles or tears.

Figure 6: A draw formed engine part for the aerospace industry

Advantages/Disadvantages

The main advantage of deep draw sheet hydroforming is it has more capacity to form a range of deeper parts compared to regular draw machines. The smooth, deep geometries can only be formed on a deep draw hydroforming machine, allowing for strict material flow control resulting in quality parts with no wrinkles. Deep drawn parts can range from 1" to 42" diameters with heights up to 12" tall, but material flow control guides the part limitations.

Another advantage of deep draw sheet hydroforming machines is the ability to convert them into fluid cell machines by simply changing out the draw ring to one that is solid. From there, operators can run the machine in fluid cell mode and make near-net-shaped parts with ease.

On Beckwood deep draw sheet hydroforming machines, a proprietary In-Sight feature allows the operator to open the press mid-cycle to perform a visual inspection, at which time they can proceed or modifying the recipe. This feature greatly expedites R&D when developing new part recipes.

On larger deep draw sheet hydroforming presses, tool changes can be a disadvantage to some users. Due to the size and weight of some deep draw tools overhead cranes or forklifts may be needed to assist loading of the tool. To combat this, OEMs can incorporate a t-table which allows for staging of the next tool to take place concurrently with a forming cycle. This feature can reduce die changeover time by up to 50%.

Sheet Hydroforming Tooling

The perfect part lies in the tooling design. To ensure for the utmost accurate and quality part, the tool must be correctly designed. Utilizing a simulation software is ideal for blank and tool development prior to manufacturing. Trial and error can be easily carried out with the software, resulting in cost and time efficiency.

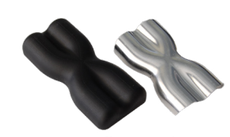
What Can Tooling Be Made From?

Sheet hydroforming tooling can be made from a variety of materials, in turn reducing costs. Material selection is based on required diaphragm elongation, heat, and part geometry. While many materials can work in hydroforming applications, selecting the proper material extends bladder life and uptime.

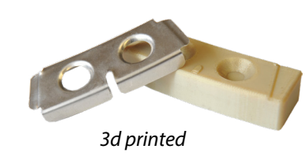
Steel

Tooling can be made from:

- Aluminum
- Steel
- Epoxies
- Wood
- 3d printed substrates
- Composites



Composite



3d printed

Fluid Cell Tooling Specifications

Fluid cell tooling consists of a single tool (male or female) that matches the geometry of the desired part shape. It is generally a best practice to keep the tooling height as low as possible, ~0.5" taller than final part height, with rounded corners and large radii where possible. Fluid cell tooling typically has a method to locate the blank, such as locating pins. When forming shrink or compression flanges, a blankholder tool may be required to form the part without wrinkling.

Deep Draw Tooling Specifications

Deep draw tooling consists of a male punch and a draw ring. The punch matches the inner diameter of the desired part. A draw ring is a steel plate with a hole in the center that matches the outer diameter of the punch. A general rule of thumb for draw ring hole size is half material thickness per side. For example, when forming .080" thick material, the draw ring hole would be the punch's outer diameter plus .080".

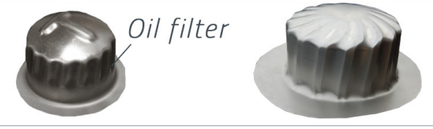
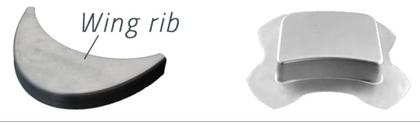
Material Springback

Different materials have a different elastic recovery. This causes some materials to spring away from the tool—springback. Assuming the material is forced into complete contact with the tool during the hydroforming process, the springback is governed by the material characteristics and not by the forming pressure. Springback can be compensated in the tool design by undercutting a certain percentage, so that the resulting spring of the part will be correct. Material spring can also occur in the transition region between the bend radius and tool. Utilizing minimum bend radii, rather than a generous bend radii, will minimize springback.

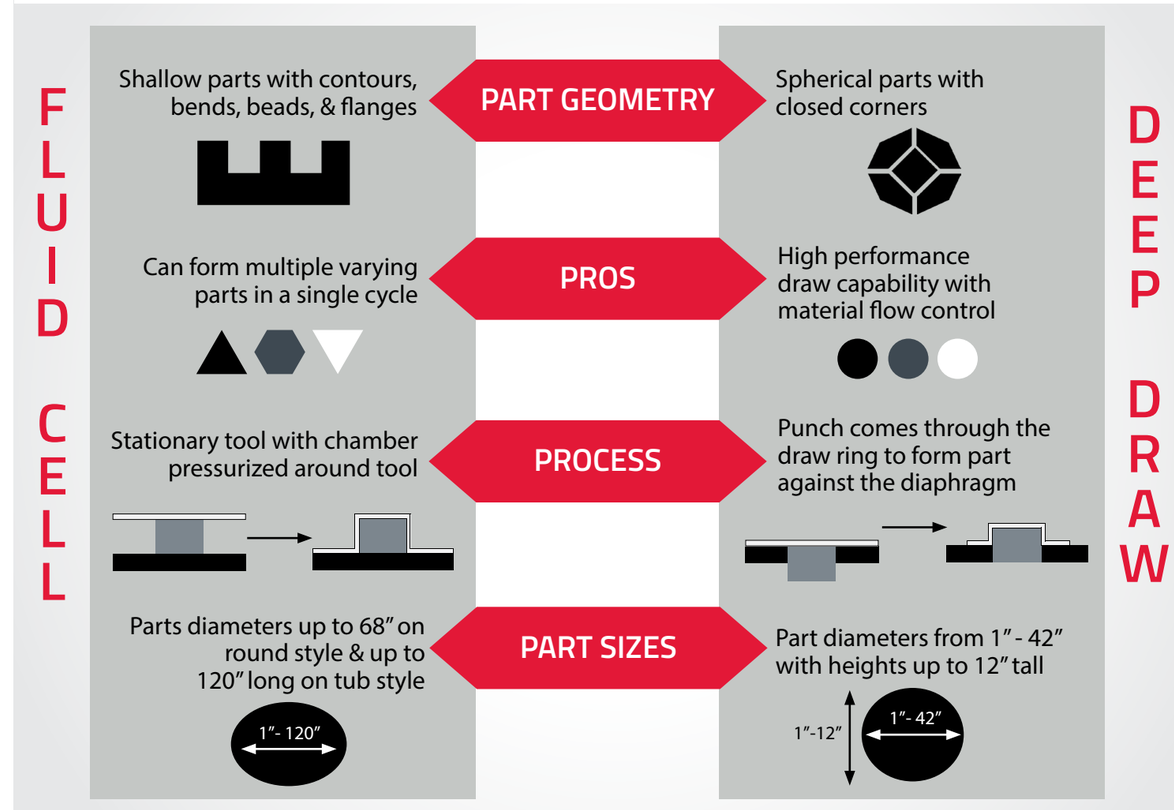
Draw Ring Radius & Surface Finishes

The draw ring radius affects part quality if the material moves into the center hole or draw ring hole. When possible, it is best to keep the radius large (~.250") to allow the material to flow. This will be dependent on a number of factors such as part geometry, material thickness, etc. If the radius is too tight or too rough, it can cause the material flow to lock over the edge and restrict the flow, causing a tear in the part or shock lines on the interior of the part. Capping tools are commonly used to set a tight radius on a part. These can be placed on a semi formed part with the use of the 'In-Sight' feature to set a radius on a two-step part or the flange radius.

EXAMPLES OF SHEET HYDROFORMED PARTS

Fluid Cell	Deep Draw
	
	
	
	

SHEET HYDROFORMING COMPARISON



Draw ring surface finishes depends on the part being formed and the speed at which you form. In some cases, a draw ring surface finish will be cut in a lathe, leaving lines resembling circular record grooves which give more grip and tension. This can prevent material flowing, which both has advantages and disadvantages based on the part. Having bad grooves can cause the material to chase the grooves and result in a bad part. In most circumstances, a good, polished surface for the draw ring is used.
Another surface finish option is using a draw bead. A draw bead is a groove cut into the ring surface that will slow the material flow until it passes through the bead. This is commonly used to eliminate wrinkles on severe compression geometries such as the corners of a square part. Simple cross-cut scratches to the ring can also be used as a draw restriction in place of a draw bead.

Conclusion

Sheet hydroforming offers many benefits over traditional forming processes, but understanding your part requirements and how to correctly form parts on a machine is crucial. Your part geometry primarily dictates which hydroforming process will be required. Typically, hydroforming is an optimal solution for any operation with a low-volume, high mix production rate of 70,000 parts a year or less, of any single part. Parts with complex geometries or operations where tool changes need to occur quickly and frequently are also ideal for this method.

While many options exist for sourcing hydroforming equipment, you should partner with an OEM who intimately understands the processes, limitations, and variables to ensure successful part formation.

About Beckwood Press Company
Beckwood is a global manufacturer of hydraulic and servo-electric presses, automation systems, and turnkey aerospace forming equipment. Since 1976, Beckwood's commitment to manufacturing in the United States has resulted in machines that are safe, reliable, and easy to maintain and support. Headquartered in St. Louis, MO - USA, Beckwood's mission is to deliver better solutions that enable manufacturers to succeed.

Beckwood Press Company
2086 Fenton Logistics Blvd.
St. Louis, MO 63026 - USA
636-343-4100
800-737-0111
sales@beckwoodpress.com
www.beckwood.com