Introduction to Hydroforming

This chapter defines the basic elements of the hydroforming process and, after looking at the history of its development, previews what the future of hydroforming may bring to manufacturing.

THE BASIC PROCESS

Hydroforming is a manufacturing process where fluid pressure is applied to ductile metallic blanks to form desired component shapes. The blanks are either sheet metal or tubular sections. If sheet metal blanks are used, the process is called sheet metal hydroforming, and if tubular-section blanks are used, it is called tube hydroforming. In either of these processes, a hydroforming tool (or die), a hydraulic press, and a fluid-pressure intensification system are required. Figure 1-1 is a schematic of such a system. Tube and sheet metal hydroforming are further divided into various process-related techniques to be discussed later in Chapters 2 and 3.

The typical process cycle includes placing the blank onto the lower tool, closing the die, and applying fluid pressure into the tubular section or to one side of the sheet metal blank. The pressure is sufficient to cause the blank to deform plastically and take the shape of the tool cavity. Holes and slots can be pierced into the hydroformed component while it is still at high pressure.

Tubular hydroformed components exhibit greater strength-to-weight ratios and lower costs compared with conventional stamped and welded assemblies. The tube-hydroforming process has been successfully applied to high-volume production. Low cost, low weight, and improved quality—the "holy grail" of engineers in the automotive industry—is the driving force behind the popularity of the tubular hydroforming process. Figure 1-2 shows a typical tube-hydroformed component in its intermediate manufacturing steps:
Figure 1-1. Hydroforming-system schematic, including hydraulic press with additional hydraulics and pressure intensifier.

Figure 1-2. Tubular-hydroforming example, showing four intermediate steps from cut-to-length blank to finished pierced part. (Courtesy Schuler Hydroforming, Inc.).
cut-to-length tube, CNC bent tube, pre-form, and hydroform with pierced holes.

Sheet metal hydroforming can achieve greater depth of draw, uniform material stretching over panel surfaces, and lower tool costs compared to a conventional stamping draw operation. However, due to higher cycle times and the requirement for very large, high-force presses for larger parts, hydroforming is primarily used today for low-volume batch production. A sheet metal hydroformed component—a car-door outer panel—is shown in Figure 1-3.

The use of fluid pressure for forming goes back to the early 1900s. During the period 1900 to 1950, it was mainly used on rather creative applications in steam boilers, musical instruments, and artificial limbs. Then, from 1950 to 1985, it was primarily used in the plumbing industry to make copper T fittings and branched bicycle-frame joints. During the late 1980s and early 1990s, tubular hydroforming was extensively studied and developed in North

Figure 1-3. Sheet metal hydroformed car-door outer panel. (Courtesy Hydrodynamic Technologies, Inc.)
America primarily by Vari-Form, General Motors Corp., and Hydrodynamic Technologies Inc. At the same time in Germany, comparable work was being done by a number of equipment manufacturers—Schuler, SPS, Anton Bauer, and Hydrap—and several universities: University GH of Paderborn and University of Stuttgart. This competition resulted in significant improvements in hydroforming methods and equipment. All this effort was driven by the need of the automotive industry for mass-efficient, low-cost structures manufactured in high-volume production processes.

In the North-American market, the first high-volume automotive hydroformed part—the Chrysler minivan instrument-panel (IP) beam—was introduced in 1990 by Vari-Form. The first high-volume chassis part, an engine cradle for the Ford Contour® and Mystique®, was introduced in 1994. Since 1994, the use of hydroformed parts has increased significantly on chassis members and exhaust components. General Motors’ decisions to use hydroformed chassis rails for the Chevrolet Corvette® sports car and for the frame rails of the high-volume-production truck range that includes the GMC Sierra® and Chevrolet Silverado®, shown in Figure 1-4, have increased the interest in hydroforming worldwide. The increased popularity of chassis-frame-based sports utility vehicles (SUV) has also had an accelerating effect on the application of the tubular-hydroforming process. Due to various process and assembly restrictions, the use of hydroformed components for the automotive body-in-white (BIW) structure has been limited.

Recent examples of hydroformed parts include:

- auto-body instrument panel beams, radiator enclosures, seat frames, and side roof rails;
- auto-chassis engine cradles, rear-suspension cradles, chassis frames, bumper beams, suspension control arms, and trailing links;
- power-train exhaust manifolds, camshafts, and exhaust cones;
- plumbing fixtures, Figure 1-5;
- copper fittings, Figure 1-6;
- oven-door handles, and
- low-volume batch production of sheet metal automotive and aircraft components.
Figure 1-4. Hydroformed structures in production. (Courtesy General Motors Corp.)

Figure 1-5. Examples of hydroformed plumbing fixtures. (Courtesy hde Solutions GmbH.)
HISTORY OF TUBE HYDROFORMING

The early history of tube hydroforming can be illustrated by a series of United States patents, although during this period, similar inventions also were developed in Europe and Japan.

1900 Through 1980

Applications using fluid pressure to form tubular metal parts can be traced to the early 1900s. A patent, (Park 1903) Figure 1-7, describes an apparatus for forming serpentine hollow bodies used in the construction of steam boilers.

The serpentine-shaped member was made from a tubular blank. A heated straight tube was first placed between the dies and then filled with molten lead and pressurized to expand the tube to the closed die-cavity shape. The basic principle of using fluid pressure as the forming media are identified in this patent. Die closing, fluid sealing, and pressurization are achieved using hydraulically operated mechanisms.

In 1917, a process for improving bent brass tubes used for musical wind instruments was patented (Foster 1917). An illustration
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Figure 1-7. Illustration from Patent 731,124, "Apparatus for Forming Serpentine Hollow Bodies."

from this patent, Figure 1-8, identifies the major elements of the tubular hydroforming process, showing the pre-formed tube of ductile metal placed in the lower tool cavity and the fluid-sealing method. The advantages of the process were defined in the patent as "reduced hand-working and scrap, and improved uniformity of shape and dimensions." Similar techniques are presently used to manufacture plumbing fixtures, as in Figure 1-5.

Another interesting patent, Figure 1-9 (Davies 1932), describes a process for making artificial limbs (arms and legs) from aluminum tubing. The tube is first spin-formed over a mandrel to achieve the required perimeter for the section of the limb. The blank is then pre-formed so it will sit in the tool. The text of this patent explains: "The bent spindle is thereafter expanded to the eccentric shape of the limb, using a pressure of 2000 pounds per square inch satisfactory for that purpose."

A patent from 1940 (Gray 1940), shown in Figure 1-10, describes an apparatus for making wrought-metal T fittings. It details the
Figure 1-8. Illustration from Patent 1,210,619, "Process of Calibrating and Justifying Parts of Wind Musical Instruments."

Figure 1-9. Illustration from Patent 1,884,589, "Method of Making Artificial Limbs."
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Figure 1-10. Illustration from Patent 2,203,868, "Apparatus for Making Wrought-Metal Ts."

axial feeding of the material at lower pressure and then increasing the pressure to a maximum for final forming. This method of pushing material from the ends of the tube makes it possible to make branched components, as shown in Figure 1-6. The same technique is also applied to bulge forming components used in the exhaust systems shown in Figures 2-6 and 2-7.

A 1950 patent (Kearns 1950), shown in Figure 1-11, is for producing hollow-metal aircraft-propeller blades. The variable sections of the blade core are formed by expanding a tubular blank using high fluid pressure. The hydroformed construction method provided increased stiffness with reduced blade weight.

The invention of a method for making camshafts from hollow steel tubing is described in a 1959 patent (Garvin 1959), shown in Figure 1-12. Cam lobes are formed on a shaft sequentially by axially feeding material from the end of the tube.

During the 1960s, various processing techniques using fluid pressure were also developed in Japan by Nippon Bulge Industries
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Figure 1-11. Illustration from Patent 2,652,121 of hydroformed aircraft-propeller blade.

Ltd. (Ogura 1968). Initially, the process was used for bulge-forming small seamless T pieces from copper tube. The liquid bulge-forming process and high-pressure sealing methods were also developed for steel components that were bulge-expanded into multiple branches. Typical applications were bicycle-frame joints.

A 1970 patent (Fuchs 1970), shown in Figure 1-13, describes a method of shaping and forming articles. The method and apparatus covered by this patent illustrates swaging (end-diameter reduction), axial feeding for diameter expansion, piercing of a slot, and in-die end shearing performed by high pressure.

1980 to the Present

In 1986, Standard Tube Canada of Woodstock, Canada, (now a unit of Copperweld), a producer of tubes and tubular products,
Figure 1-12. Illustration from Patent 2,892,254 of process to hydroform tubular camshafts.

Figure 1-13. Process to shape, form, and end trim from Patent 3,487,668.
acquired the first patent in North America for the application of the hydroforming technique to larger frame members (Cudini 1986), shown in Figure 1-14. Standard Tube called the process Vari-Form, and that division of the company became the now well-known company in hydroforming, Vari-Form.

Standard Tube developed these techniques as an extension of their work on tubular products. Typically, components made from tubes using conventional bending and/or die-forming operations have higher springback and lower surface-dimensional control. The use of fluid pressure inside the tube pushes the metal against the die-cavity walls more uniformly and achieves greater surface-dimensional control. The Standard Tube patent limited the section "length-of-line" expansion to 5% or lower. Further improvements to the process, described in patents 4,744,237 (Cudini 1988) and 4,829,803 (Cudini 1989), stress the benefits of pressurizing the blank during the die-closing phase of the forming cycle. The fluid acts as a mandrel and reduces the tendency of material to be pinched in the die and the component shape is formed without

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**Figure 1-14.** Illustration from Patent 4,567,743, showing the intermediate steps in the hydroforming of box-section frame members.
excessive wrinkling during the die-closing stage. This process is referred to by Vari-Form as pressure-sequence hydroforming (PSH).

Three Hydrodynamic Technologies Inc. patents—5,353,618; 5,481,892; and 5,890,387 (Roper and Webb 1994, 1996, 1999)—stress the importance of higher expansions through axial end feeding, hydropiercing of holes, localized cam forming, and in-die hydrobending of large auto-frame members. As shown in Figure 1-15, in-plane bends can be produced in the hydroforming die, thus eliminating the CNC bending operation. Axial feeding of material to date has been applied only to small components, as shown in Figure 1-6. Application of axial feeding to large frames—to expand the structure without appreciable thinning—leads to very efficient structures. This patent also illustrates the use of local cams in the tool. Part features that otherwise would lead to a die-lock condition can be formed using cams driven by hydraulic cylinders.

General Motors patent 5,720,092 (Chi-Mou Ni and Brugge-mann 1998) introduces the idea of using multiple, different diameter and thickness tubes for complete-frame hydroforming in a
single die, as shown in Figure 1-16. A number of simple tubular blanks are welded together to form the required assembly. The tubular blank assembly is then hydroformed in a single tool into the required structural sections.

THE FUTURE OF HYDROFORMING

Considerable effort is being devoted today to applying both the tubular and sheet metal hydroforming processes to auto-body structures. Advanced methods of making tubes, increased understanding of process parameters and materials behavior, and advanced assembly using laser-welding methods are coming together to successfully resolve many existing problems. These successes will yield far greater global benefits. Today's body structure is composed of many more parts and it is being redesigned and retooled every three to five years, compared with chassis
members composed of fewer components and redesigned every seven to 10 years. The body-in-white structure typically accounts for 20-25% of the completed vehicle weight (ULSAB 1995). The use of hydroformed members in this area offers great potential for weight savings while improving structural performance.

The body-in-white structure in Figure 1-17 shows a number of hydroformed members that can be integrated into the unibody structure. This comprehensive study conducted by the Ultra-Light Steel Auto-Body Consortium (ULSAB 1995) concluded that a hydroformed intensive body structure (HIBS) would yield significant advantages—reductions in weight of 11%, part count 15%, and cost 10%—when compared with a similar-size unibody structure of Year-2000 design. Since the completion of this study in 1995, new developments in hydroforming technology indicate that even higher savings are possible. Further developments based on increased knowledge and understanding of the hydroforming process could revolutionize the manufacture of auto-chassis frames and body-in-white structures.

Figure 1-17. Hydroformed members integrated into a unibody structure. (Courtesy AISI)
Ideas described in GM patent 5,720,092 can be used to combine and form a complete body side structure in a single step, as shown in Figure 1-18—including rocker section, front body-hinge pillar, roof rail, center pillar, rear pillar, and rear rail. The upper structure—including the A-pillars, roof rails, and front and rear headers—could be formed as an assembly as shown. A rear-end module with rear rails and cross members is another possible application for single-step hydroforming technology. Considerable weight savings for the vehicle structure is possible with this approach, without compromising structural integrity and safety. Used worldwide, this technology would produce savings that would translate into lower fuel consumption and significant reductions in greenhouse-gas emissions into the environment.
REFERENCES


