Spinning

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Metal spinning is a term used to describe the forming of metal into seamless, axisymmetric shapes by a combination of rotational motion and force (Ref 1–4). Metal spinning typically involves the forming of axisymmetric components over a rotating mandrel using rigid tools or rollers. There are three types of metal-spinning techniques that are practiced: manual (conventional) spinning (Ref 1, 2), power spinning (Ref 4–11), and tube spinning (Ref 7, 8). The first two of these techniques are described in this article. Tube-spinning technology is described in the articles “Flow Forming” and “Roll Forming of Axially Symmetric Components” in Metalworking: Bulk Forming, Vol 14A of ASM Handbook, 2005.

Figure 1 shows examples of products from metal spinning. The range of components includes:

- Bases, baskets, basins, and bowls
- Bottoms for tanks, hoppers, and kettles
- Canopies, caps, and canisters
- Housings for blowers, fans, filters, and flywheels
- Ladies, nozzles, orifices, and tank outlets
- Pails, pans, and pontoons
- Cones, covers, and cups
- Cylinders and drums
- Funnels and horns
- Domes, hemispheres, and shells
- Rings, spun tubing, and seamless shapes
- Vents, venturis, and fan wheels

The equipment for metal spinning is based on lathe technology, with appropriate modifications for the components that are being formed. Typically, sheet preforms are employed to allow relatively low forming stresses. Metal spinning can be used to cost-effectively produce single or a small number of parts out of expensive materials, such as platinum, or large quantities of components of low-cost materials, such as aluminum reflectors. In this article, the term preform is used to describe the component both before and during metal spinning; other terms that are sometimes used include workpiece and starting blank.

In manual spinning, a circular blank of a flat sheet, or preform, is pressed against a rotating mandrel using a rigid tool (Ref 1, 2). The tool is moved either manually or hydraulically over the mandrel to form the component, as shown in Fig. 2. The forming operation can be performed using several passes.

Manual metal spinning is typically performed at room temperature. However, elevated-temperature metal spinning is performed for components with thick sections or for alloys with low ductility. Typical shapes that can be formed using manual metal spinning are shown in Fig. 3 and 4; these shapes are difficult to form economically using other techniques. Manual spinning is only economical for low-volume production. Manual metal spinning is

![Fig. 1 Various components produced by metal spinning. Courtesy of Leifeld USA Metal Spinning, Inc.](image1)

![Fig. 2 Schematic diagram of the manual metal-spinning process, showing the deformation of a metal disk over a mandrel to form a cone](image2)

![Fig. 3 Typical components that can be produced by manual metal spinning. Conical, cylindrical, and dome shapes are shown. Some product examples include bells, tank ends, funnels, caps, aluminum kitchen utensils, and light reflectors.](image3)
extensively used for prototypes or for production runs of less than ~1000 pieces, because of the low tooling costs. Larger volumes can usually be produced at lower cost by power spinning or press forming.

Power spinning of metals and alloys is also known as shear spinning (Ref 4–11), because this forming method employs high shear forces. There are two large-volume applications of power spinning: metal cone spinning and metal tube spinning. Power spinning can also be employed to produce hemispheres, provided a preform of the appropriate design is employed. In cone spinning, a flat blank or metal sheet is deformed over a mandrel at high speed. Almost all ductile metals can be shaped using power spinning (provided they have a minimum ductility corresponding to an elongation to ~2%). Some of the alloys used to make components by metal spinning include:

- 300- and 400-series stainless steels
- Precipitation-hardening stainless steels (17-4PH, 17-7PH)
- Iron-nickel superalloys (A-286)
- Nickel-base superalloys such as Hastelloys (X, C, B, S) and Inconels (600, 625, 718, X-750), N-155, Nimonic 263, and Waspaloy
- Cobalt-base alloys (Haynes 188, Haynes 230)
- Other nonferrous alloys such as aluminum, brass, copper, and platinum

A wide range of shapes can be produced with relatively simple tooling. Power spinning can be used to form large conical parts (up to 3 m, or 10 ft, in diameter) to close tolerances (<±0.5 mm, or 0.020 in.); there is little scrap material, and the forming operation can be completed quickly. The high material utilization is highly desirable, because the preforms for power spinning can be expensive, particularly for aerospace components.

Products that can be produced by metal spinning range from small hardware items made in large quantities (such as metal tumblers and automotive components) to household articles to large components for aerospace applications in low-volume production. Some examples of metal components that are spun include trophies, kettles, kettle drums, cymbals, tank ends, centrifuge parts, pressure bottles, ventilus, radar reflectors, parabolic dishes, wheel discs, and wheel rims.

The use of elevated metal temperatures is sometimes required during metal spinning to reduce the flow stress and increase the ductility of the component, particularly if the machine capacity is insufficient for cold forming the component or if the alloy ductility is too low. Although power spinning can be performed with only one roller, two rollers are generally preferred to balance the radial forces acting on the mandrel and the bearings within the lathe. Power spinning involves large plastic strains and relatively high strain rates, and as a result, significant heat can be generated during forming; the heat is generally dissipated using a coolant/lubricant during power spinning.

The surface finish of spun components is usually of sufficient quality that no additional machining is required after spinning. The surface finish of spun components is typically approximately 1.5 μm (0.06 mil), although finishes as smooth as 0.5 μm (0.02 mil) have been produced by power spinning. Preforms are generally used for cone spinning when the included angle of the component is less than 35° or when the percentage of wall reduction is high, as is described in more detail subsequently. The preforms are typically cold formed in a die, although hot forging or machining, or a combination of both, can also be used.

In this article, manual spinning is described first, and power spinning is described second. For each of these techniques, the process technology, equipment, and tooling is described.

Manual Spinning of Metallic Components

General Description. Manual metal spinning is practiced by pressing a tool against a circular metal preform that is rotated using a lathe-type spinning machine. The tool typically has a work face that is rounded and hardened. Some of the traditional tools are given curious names that describe their shape, such as “sheep’s nose” and “duck’s bill.” The first manual spinning machine was developed in the 1930s. Manual metal spinning involves no significant thinning of the work metal; it is essentially a shaping technique. Metal spinning can be performed with or without a forming mandrel. The sheet preform is usually deformed over a mandrel of a predetermined shape, but simple shapes can be spun without a mandrel. Various mechanical devices and/or levers are typically used to increase the force that can be applied to the preform. Most ductile metals and alloys can be formed using metal spinning. Manual metal spinning is generally performed without heating the workpiece; the preform can also be preheated to increase ductility and/or reduce the flow stress and thereby allow thicker sections to be formed.

Manual metal spinning is used to form cups, cones, flanges, rolled rims, and double-curved surfaces of revolution (such as bells). Typical shapes that can be formed by manual metal spinning are shown in Fig. 3 and 4; these shapes include components such as light reflectors, tank ends, covers, housings, shields, and components for musical instruments. The maximum practical component diameter is often limited by the size of the available equipment. The upper limit of component thickness increases as preform ductility increases or as flow stress decreases. For example, the manual spinning of aluminum as thick as ~6 mm (0.24 in.) is possible. The practical maximum thickness of low-carbon steel that can be deformed by spinning without mechanical assistance is ~3 mm (0.12 in.).

Manual metal spinning has several advantages and several disadvantages over alternate processes such as press forming or forging (Ref 1, 2). There are three advantages of manual metal spinning. First, the tooling costs and investment in capital equipment are relatively small (typically, at least an order of magnitude less than a typical forging press that can effect the same operation). Second, the setup time is shorter than for forging. Third, the design changes in the workpiece can be made at relatively low cost. However, there are several disadvantages of manual metal spinning. First, highly skilled operators are required, because the uniformity of the formed part depends to a large degree on the skill of the operator. Second, manual metal spinning is usually significantly slower than press forming. Third, the deformation loads available are much lower in manual metal spinning than in press forming. Manual metal spinning and power spinning are generally in competition with pressing and deep drawing.

Equipment for Manual Spinning—Lathes and Tooling. A simple tool and sheet preform setup for manual metal spinning is shown in Fig. 5(a). The forming mandrel is mounted on the headstock of a lathe. The circular preform is clamped to the mandrel by the follower. Pressure is applied at the tailstock by means of an anti-friction center and suitable pressure to form the component. The tool rest and pedestal permit the support pin (tulcrum) to be moved to various positions. Metal spinning is performed by manually applying the friction-type spinning tool as the preform is rotated. Figure 5(b) shows a more complex setup for manual metal spinning. In this arrangement, the spinning rollers are mounted in the fork sections of long levers, and the tool support has a series of holes to adjust the tool position. The roller is manipulated by moving two scissorlike handles around the preform/workpiece.

Horizontal metal-spinning lathes that can spin preforms with diameters in the range of ~6 mm to 1.8 m (0.24 in. to 5.9 ft) have been built. For large-diameter parts that may be formed at high speeds, special pit lathes (per the safety requirements that permit the spinning of blanks as large as ~5 m (16 ft) in diameter have been built. Standard lathes can also be fitted with special tooling for making ovular parts. Tooling costs are generally low for manual spinning. However, manual spinning is generally
performed using multiple passes, and tool life can be low. Hydraulic lathes were introduced after about 1945 for forming components with either a thicker section or higher-strength alloys. A reliable spinning machine must possess a significant mass in order to ensure stability; the mass provides vibration-free operation when producing components to tight and repeatable tolerances at high speed. The high speeds associated with metal-spinning processes require considerations for all safety aspects of the process.

Mandrel technology plays a very important role in metal spinning. The mandrels are also sometimes referred to as form blocks or spin blocks for manual spinning. The mandrels can be made of seasoned hard-maple wood or metals or combinations of the two. Most hardwood mandrels are constructed by gluing strips of 25 to 50 mm (1.0 to 2.0 in.) thick maple into the main block to create a cross-laminated structure to increase strength. Such mandrels are stronger and more durable than mandrels machined from a solid block. Some wooden mandrels are reinforced with steel at the ends and at small radii, to ensure maintenance of radii in the final part. Minimum inside radii of 1.6 mm (0.06 in.) are possible using mandrels of appropriate construction; corners with radii of smaller than 1.6 mm (0.06 in.) are not desirable. Corners with radii of greater than 3 mm (0.12 in.) are preferred where possible.

Other mandrel materials include steel, cast iron, aluminum, magnesium, and plastic-coated wood. When it is necessary to produce parts to close tolerance, the mandrels are typically made entirely of steel and cast iron. Cored castings of steel or cast iron are preferred in order to reduce the rotating weight. Mandrels must be statically balanced, and, when used at high speed, the mandrels should also be dynamically balanced. Simple metal-spinning tools can be made by forging carbon or low-alloy tool steels to the desired shape and hardening the working surfaces to a hardness of ~60 HRC. The rollers also need to be polished when surface finish of the final part is important. Typically, the rollers are made of hardened tool steel or aluminum bronze.

Process Technology for Manual Spinning. Manual metal spinning is extensively used for prototypes or for production runs of less than ~1000 pieces, because of the low tooling costs. Larger volumes can usually be produced at lower cost by power spinning or press forming. For large-quantity production, power spinning can generally be conducted at lower cost than manual metal spinning. For example, a stainless-steel cover for a food-processing machine is the same as that of the starting blank. When metal spinning is performed in accordance with the sine law, as is described in more detail in the section “Mechanics of Cone Spinning” in this article.

The rotational speeds that are best suited to manual metal spinning depend mainly on work metal composition and thickness. For example, a given blank of stainless steel can be spun at a surface speed of 60 m/min (200 surface feet per minute, or sfm). Under otherwise identical conditions, changing to an aluminum blank will permit speeds of 120 to 180 m/min (400 to 600 sfm). Selection of optimal speed depends largely on operator skill. In many metal-spinning operations, speed is changed (usually increased) during the operation by means of a variable-speed drive on the headstock. The dimensional tolerances that can be achieved by manual spinning increase as the diameter of the component decreases. For components up to 300 mm (12 in.) in diameter, tolerances of ±0.20 mm (0.008 in.) can be achieved. For larger-diameter components, the tolerances are worse. For example, parts ~4 m (13 ft) in diameter can only be produced to tolerances of approximately ±1.0 mm (0.04 in.), but this is machine dependent.

Lubricants generally need to be used in all metal-spinning operations, regardless of the preform composition or shape or the type of metal-spinning tools that are used. Lubricants are typically required both before and during forming. The need for lubrication during spinning depends on the tenacity of the lubricant used and on the rotational speed of the preform. The lubricant must continue to adhere to the rotating preform during spinning. Ordinary cup grease is often used. It can be heated to reduce its viscosity, for ease of application. Other lubricants used for metal spinning include soaps, waxes and tallows, and pigmented drawing compounds; in the selection of the most suitable lubricant, the ease of removal of the lubricant after forming has to be considered.

Power Spinning

General Description. Power spinning of metals and alloys is also known as shear spinning, because in this method metal is deformed using high shear forces (up to 3.5 MN, or 800,000 lbf). There are two broad applications of power spinning: metal cone spinning and metal tube spinning. In cone spinning, the deformation of the metal from the flat blank is performed in accordance with the sine law, as is described subsequently. Almost all ductile metals can be shaped using power spinning (provided they have a minimum ductility of ~2%). Products range from small hardware items made in large quantities (metal tumblers, for example) to large components for aerospace applications in low-volume production. A classic low-production-volume example of power spinning involved the Concorde engine compressor shaft (Ref 4), which was formed by a combination of forging and spinning, because this was more efficient than forging alone.

Metal blanks as large as 6 m (20 ft) in diameter have been successfully formed using power spinning. Conical and curvilinear shapes are most commonly produced from flat (pre-formed) blanks by power spinning. Plate stock up to 25 mm (1.0 in.) thick can be power spun at room temperature. Blanks as thick as 140 mm (5.5 in.) have been successfully spun at elevated temperature.

Mechanics of Cone Spinning. The most common application of power spinning is for conical shapes. In this variant, the metal is volumetrically displaced in the axial direction. The metal deformation occurs in accordance with the sine law, which relates the wall thickness of the starting blank, \( t_1 \), and the wall thickness of the finished workpiece, \( t_2 \), as \( t_2 \) as \( t_2 = t_1 \alpha \) (sine), where \( \alpha \) is half the apex angle of the cone (assuming uniform wall thickness in the conical section). The diameter of the finished component is the same as that of the starting blank. When metal spinning is performed in accordance with the so-called sine law (Ref 1, 2, 4), the thickness of the component in the axial direction is the same as the thickness of the starting blank.
(Fig. 6). The arrangement shown in Fig. 6 is for cone spinning using a single pass.

When spinning metal cones to small single conical angles (<35° included angle), it is generally easier to use multiple spinning passes with different cone angles for each pass, as illustrated in Fig. 7; typically, the component is annealed or stress relieved between passes. The practice of multiple passes with intermediate anneals permits a high total reduction while maintaining a practical reduction limit of 50 to 75% between process anneals. The reduction between successive annealing operations is determined by the maximum deformation limit for the metal being spun, as described subsequently.

Deformation limits are shown for a range of alloys in Table 1; the deformation limit is obtained by multiplying the thickness of the starting preform, \( t_1 \), by the maximum reduction factor and then dividing the result by \( t_2 \) to attain the sine half-angle requirement for the conical mandrel. In power spinning of small-angle cones (as shown in Fig. 7), even when multiple-pass spinning is used, the original blank diameter is retained, and the exact volume of material is used in the final part. At any diameter of either preform or the completed workpiece, the axial thickness equals the thickness of the original blank. For example, if a flat plate has a diameter of 190 mm (7.5 in.) and a thickness of 12.5 mm (0.5 in.), the spun preform has the same 12.5 mm (0.5 in.) axial thickness, but the wall thickness is only 6.25 mm (0.25 in.) \( t_2 \) in Fig. 7, thus satisfying the sine law. Similarly, the final workpiece has an axial thickness of 12.5 mm (0.5 in.), but in accordance with the sine law, it has a wall thickness of only 3.1 mm \( (0.125 \text{ in.}) \) \( t_3 \) in Fig. 7.

Deviations from the sine law that can occur are usually expressed in terms of overreduction or underreduction. In overreduction, the final thickness of the workpiece is less than that indicated by the sine law; in underreduction, the thickness is greater. In overreduction, the flange on the cone will lean forward; in underreduction, the flange on the cone will lean backward. If a thin blank is spun with severe underreduction, the flange can also wrinkle.

**Machines for Power Spinning—Lathes and Tooling.** Power spinning is generally performed using special-purpose machines. The significant components of a power-spinning machine are shown schematically in Fig. 8.

Although Fig. 8 illustrates power spinning of a conical shape, similar machines can be used for power spinning of tubes. Figure 9 shows a horizontal lathe for spinning large-diameter cone and dish-shaped components, and Fig. 10 is a photograph of some remarkably large-diameter (~2 m, or 6.5 ft) cone- and dish-shaped components that were produced by metal spinning. Spinning machines can also be configured to

Table 1 Maximum preform thickness reductions (approximate), or deformation limits for single-pass power spinning of a range of metals and alloys

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum reduction for a cone, %</th>
<th>Maximum reduction for a hemisphere, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum alloys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>2024</td>
<td>50</td>
<td>...</td>
</tr>
<tr>
<td>3000</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>5086</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>5286</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>6061</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>7075</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>Beryllium</td>
<td>35</td>
<td>...</td>
</tr>
<tr>
<td>Copper</td>
<td>75</td>
<td>...</td>
</tr>
<tr>
<td>Nickel alloys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waspaloy</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>René 41</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>Stainless steels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>321</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>347</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>410</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>17-7PH</td>
<td>65</td>
<td>45</td>
</tr>
<tr>
<td>A-286</td>
<td>70</td>
<td>55</td>
</tr>
<tr>
<td>Titanium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercially pure titanium</td>
<td>45</td>
<td>...</td>
</tr>
<tr>
<td>Ti-6Al-4V</td>
<td>55</td>
<td>...</td>
</tr>
<tr>
<td>Ti-6Al-13V-11Cr</td>
<td>30</td>
<td>...</td>
</tr>
<tr>
<td>Ti-6Al-6V-2.5Sn</td>
<td>50</td>
<td>...</td>
</tr>
<tr>
<td>Tungsten</td>
<td>45</td>
<td>...</td>
</tr>
</tbody>
</table>

![Fig. 6](image1) Typical arrangement for power spinning a cone in a single operation. The mandrel diameter is 188 mm (7.5 in.), \( t_1 \) is the thickness of the preform, and \( t_2 \) is the wall thickness of the final conical component. The included angle of the cone is \( \alpha \). For the case of power spinning, the diameter of the final component is the same as the starting sheet preform. Dimensions given in inches.

![Fig. 7](image2) Typical arrangement for power spinning a cone in two stages. The two-step approach is used for small included cone angles (35° in this figure). Dimensions given in inches.

![Fig. 8](image3) Schematic diagrams of a vertical arrangement employed for power spinning of large-diameter cones. The diagram shows the preform, clamping cylinder, and the positioning cylinders that are used to control the axial, radial, and angular positions of the roller and for the forming scheme used to generate the cone.

![Fig. 9](image4) Photograph of a horizontal lathe, workpiece, and mandrel arrangement for spinning large-diameter (~2 m, or 6.5 ft) cone- and dish-shaped components. Courtesy of Leifeld USA Metal Spinning, Inc.
accommodate several different rollers with quick switchovers.

Machines for power spinning are generally specified by the diameter and length of the largest component that can be spun and the maximum load that can be applied to the work. Metal-spinning machines can be vertical or horizontal. Machines used for spinning large-diameter and large-mass preforms, such as 1.8 m (6 ft) or more in diameter, are usually vertical because they are better suited to handling large components. A broad range of power-spinning machines has been built. The capacity of spinning machines ranges from 455 mm (18 in.) diameter and 380 mm (15 in.) length (maximum component dimensions) to machines capable of spinning workpieces as large as 6 m (20 ft) in diameter and 6 m (20 ft) long. The load on the work can be as great as 3.5 MN (800,000 lbf).

Figure 11 shows an automated metal-spinning machine that can be configured for forming cone-shaped components. The lathe, roller, mandrel, and controls work station can be seen.

Machines for power spinning can be automated in a variety of ways. Contemporary metal-spinning machines use template guides that control the shape and accuracy of the workpiece. Most modern machines used for production spinning are at least semiautomatic; that is, they are loaded and unloaded by the operator, but the entire spinning cycle is controlled automatically. Machines can also be equipped with automatic loading and unloading devices for high-volume production. The most recent machines employ computer numerically controlled (CNC)-based techniques, with both playback and CNC controls. In playback mode, the first component is run in manual mode by the operator, typically with joystick control; the program that has been acquired can be modified and optimized for high-speed production.

During power spinning, the tooling is subjected to more severe service conditions than during manual spinning, and as a result, design and manufacture of the tooling must be performed in a more rigorous manner. The tooling that is used for both the rollers and the mandrels is described in the following paragraphs. A typical mandrel profile for cone spinning is shown in Fig. 12. The flange diameter, dimension A, and the diameter of the nose of the cone, dimension B, and angle α can be adjusted as required. The usual practice is to have an integral flange to permit the mandrel to be bolted to the headstock. The radius R can vary from a minimum of 0.8 mm (0.03 in.) to a round nose. Mandrel wear or failure can be a problem in the power spinning of cones. The mandrels used for production spinning of cones must be hard in order to resist wear, and they must have a high fatigue strength in order to resist the fatigue loading due to the normal eccentric loading during power spinning. Failure is typically caused by spallation of regions from the surface.

The materials used for the mandrels for cone spinning are selected primarily on the basis of the desired mandrel life. The most commonly used materials are cast irons and tool steels; the actual mandrel material selection depends on the part design, part material, and desired life. For example, gray cast iron can be used for the low-volume (10 to 100 pieces) spinning of soft metals, and alloy cast iron for spinning 100 to 250 pieces; the mandrels can be hardened in areas of high wear. For high-production volumes (250 to 750 pieces), 4150 or 52100 steel hardened to approximately 60 HRC can be used. Tool steels such as O6, A2, D2, or D4 hardened to 60 HRC or slightly higher are more suitable for high-volume production. The surface finish of the mandrels should be at least 1.5 μm (0.006 mil). The mandrel dimensions should be machined so that they are within ±0.025 mm (0.0010 in.) of being concentric with each other.

Three types of rollers are used in power spinning; these are shown in Fig. 13. The roller...
designs shown in Fig. 13 typically have outside diameters in the range 305 to 510 mm (12 to 20 in.), depending on the type and size of the spinning machine and the part to be formed. Roller widths are usually 50 to 75 mm (2 to 3 in.). The design of the roller employed depends principally on the shape of the component that is to be formed. The full-radius roller design shown in Fig. 13(a) (two axes of symmetry) is generally used to produce curvilinear shapes, and the designs with radii of curvature shown in Fig. 13(b) and (c) are preferred for the spinning of cones. The design of the rollers, and the alloy used for the rollers, play a critical role in ensuring efficient power spinning.

The roller angle \( \alpha \) shown in Fig. 13(b) and (c) is adjusted to suit the geometry of the component that is being spun (the included angle of the cone has a significant effect on selection of roller design). This roller angle is selected to provide clearance such that the work metal does not contact the faces of the roller where the metal is being deformed (surfaces A and B, shown in Fig. 13(c)). The radius \( R \) should not be less than the final wall thickness.

The roller design illustrated in Fig. 13(b) has been widely used for cone spinning. A typical arrangement for cone spinning, using two opposed rollers, is shown in Fig. 14.

When two rollers are used to spin a part from flat plate, the rollers are positioned at equivalent/symmetric conditions with respect to the preform. However, when metal spinning is performed from a preform, a lead roller is often used, and it is set ahead of the other by 1.5 to 3 mm (0.06 to 0.12 in.). The angle between the axis of rotation of the rollers and the surface of rotation of the workpiece (angle \( \beta \) in Fig. 14) is typically \(-10^\circ\). The angle between the axis of rotation of the roller and the peripheral face of the roller (angle \( \gamma \) in Fig. 14) can be adjusted for different shapes, and it is also often adjusted during the forming operation; this angle is shown in Fig. 14 as approximately \(30^\circ\).

Rollers for power spinning are typically made from tool steel or tungsten carbide. A variety of tool steels have been employed, including W2, O6, D2, and D4. The roller material is selected on the basis of the number of parts that are to be formed. D2 and D4 tool steels are preferred for high-production quantities (they should be hardened to 60 to 65 HRC). Tungsten carbide is only used for specialized applications when the high cost can be justified. The rollers should be polished to a maximum surface roughness of 0.25 \(\mu m\) (0.001 mil).

**Process Technology for Power Spinning.**

An important factor in power spinning is the deformation limit, or so-called spinnability, of the metal; the spinnability is the smallest section thickness (or the maximum reduction in thickness) to which a component can be formed by metal spinning without failure of the component. A simple test has been established (Ref 1, 4, 6–8) to determine deformation limit (or spinnability) of a metal, as shown in Fig. 15.

![Fig. 14 Schematic diagram showing the relative position of the preform and two forming rollers used for spinning a cone. One roller can be positioned to follow the second roller, if appropriate for the forming scheme that is being employed.](image1)

The deformation limit, or spinnability, test is performed by spinning a circular blank over an ellipsoidal mandrel, and spinning is performed so that the outside diameter of the final component is the same as the initial blank. Because the thickness is eventually reduced to zero for the ellipsoidal mandrel, all metals will eventually fail at some thickness, \( t_f \). The deformation-limit data on a range of materials with different tensile strengths and different formabilities are shown in Fig. 16 and Table 1 (Ref 1, 4).

The deformation limit is defined as:

\[
\text{Maximum thickness reduction} = \frac{t_0 - t_f}{t_0} \times 100\%
\]

The maximum reduction is plotted against the tensile reduction in area of the material in Fig. 16. It can be seen that if the metal possesses a tensile reduction in area of 50% or greater, the metal can be reduced by power spinning to a thickness of up to 80% in one pass for spinning a cone. The maximum reduction that can be employed to form a hemisphere is less than can be employed for forming a cone. Also, any increase in the material tensile ductility (as described by the reduction in area) above 50% reduction in area does not increase formability or spinnability. For materials with low ductility, if the ductility can be increased by increasing temperature, then the formability can be improved. Process parameters, such as the feed rate and the rotational speed, have a less significant effect on the spinnability.

The best quality for most components is achieved when spinning at high speeds. The minimum surface speed considered to be
practical for metal spinning is approximately 120 m/min (400 sfm), and this is only used for spinning small-diameter workpieces. Surface speeds of 300 to 600 m/min (1000 to 2000 sfm) are typically used; this speed range is suitable for a range of metal compositions, preform shapes, and process conditions (such as reduction per pass, roller design, roller position, and forming temperature).

Most cone-spinning operations are performed at linear feed rates of 0.25 to 2 mm/rev (0.010 to 0.08 in./rev); for typical spinning machines, this equates to linear feed rates in the range 38 to 380 mm/min (1.5 to 15 in./min) (feed rates are usually measured in millimeters per minute). Most machines used in cone spinning are equipped with devices that continuously change the rate of feed with the diameter on which the rollers are working.

The feed rate controls the workpiece finish and the material properties and the fit of the workpiece to the mandrel. With all other factors constant, a decrease in the feed rate will improve surface finish. An increase in feed rate will make the workpiece fit tighter on the mandrel, and the finish of the workpiece will become coarser. The use of preforms can influence surface finish and is common in cone spinning when the included angle of the cone is less than 35° or when the percentage of wall reduction is high. Preforms are usually prepared by cold forming in a die, although hot forging or machining or a combination of both can be used.

The surface finish of a spun component is usually of sufficient quality that no additional machining is required after spinning. The surface finish of spun components can typically be approximately 1.5 μm (0.06 mil), although surface finishes as smooth as 0.5 μm (0.02 mil) have been produced by power spinning, when using appropriate tooling and surface finish of the tooling.

A lubricant is almost always used during power spinning. The fluid used serves as both a lubricant and a coolant. A water-based coolant, such as an emulsion of soluble oil in water, is most commonly used, and in large quantities because of the large amount of heat generated. When spinning aluminum, stainless steel, or titanium, the workpieces or mandrels or both are sometimes coated with the lubricant before spinning. An increase in the forming temperature can lead to a reduction in the flow stress and an increase in the ductility of the preform; this is sometimes required if the load capacity of the spinning machine is not sufficient for cold forming the preform or if the room-temperature ductility of the work metal is too low. When operating at elevated temperatures, great diligence must be exercised in the selection and use of an appropriate lubricant.

**Power Spinning of Hemispheres.** Spinning of hemispheres is more complicated than spinning of cones. However, in order to spin hemispheres, preforms of specially designed geometries can be used to adjust the percentage of reduction as a function of radial position, as is described in the following section. This approach has enabled power spinning to be applied to the forming of hemispheres, ellipses, ogives, and almost any curvilinear surface of revolution. However, the design of the preform for curvilinear shapes is more complicated than that for conical shapes. For the case of spinning of conical shapes, it is possible to determine an axial thickness that corresponds to the thickness of the blank (Fig. 6, 7). However, the same relationship does not exist for a curvilinear surface; this problem is illustrated in Fig. 17. In the path from the pole to the equator of a hemisphere, the axial thickness of the metal on a hemisphere changes from stock thickness at the pole to infinity (the inverse of sin 0°) at the equator (the wall thickness, in the normal direction, goes to zero). The blank thickness must therefore be back-tapered to compensate for the change in thickness that takes place during spinning of hemispheres. Figure 17 shows a preform for a ~1.5 m (5 ft) diameter hemisphere; the machined taper started at 3.8 mm (0.15 in.) in thickness in the center of the preform and ended at a thickness of 7.5 mm (0.30 in.) in thickness at the circle where the 30° ‘radial’ line of the sphere was projected to the blank. At the corresponding 45° line, the blank thickness was 5.4 mm (0.21 in.), and the final part thickness was 0.71 times the original thickness. For the region of the hemisphere below the 30° line, the reduction of the preform was greater than permissible for spinning aluminum alloy 6061 (according to the previous description), and the forming operation was performed as if spinning a cylinder; the preform for this region had a flange with a thickness proportional to the designed percentage of reduction.

As an example, a suitable preform for spinning a hemisphere was designed by first finding in Table 1 the maximum allowable reduction for the material that was used in order to obtain the maximum part thickness associated with the deformation limit and minimum angle of the cone. A beginning stock thickness was selected that, with the maximum allowable reduction, gave the thickness desired in the final hemisphere shape. The ratio of finished stock thickness to original stock thickness was then taken as the sine of an angle, which was the angle of the surface at the latitude at which forming was started. Beyond this point, the reduction required to make the hemisphere was greater than is permissible for the 6061 aluminum alloy. At 45° from the pole, final part thickness was 0.71 times the original thickness. Forming started at the circle corresponding to the latitude associated with the forming limit (the point where the maximum permissible reduction has taken place). In a cross-sectional view, the circles resulting from the aforementioned approach become points, and the thickness of the stock at these points can be determined. The correct roller locus can be programmed with state-of-the-art CNC-based techniques.

The following example describes forming a 1.5 m (5 ft) diameter hemisphere by power spinning. Large hemispheres (Fig. 17) have been power spun from a solution-treated aluminum alloy 6061 using the following calculations. From Table 1 it was determined that a 50% reduction could be used with this alloy. Preliminary calculations for the thickness of the starting preform indicated a thickness of 7.6 mm (0.30 in.) was required (preform thickness = final wall thickness/maximum reduction = 3.8 mm/2).

In calculating the blank thickness profile for various points on the sphere, it was found that at the pole, or 90° point, the thickness had to be reduced to 3.8 mm (0.15 in.) and that a linear reduction was required out to a point directly above the 30° tangency on the hemisphere, where the thickness of the starting blank had to be 7.6 mm (0.30 in.). Beyond this point, a flange was incorporated; the preform thickness was increased in the region by 30% to allow for this flange, and the initial blank thickness was established at 9.9 mm (0.39 in.). Final spinning was accomplished in one pass of the rollers.

The type of procedure described in the previous example has also been successfully used to form both hemispheres and ellipses with diameters in the range of 150 mm to 1.8 m (6 in. to 6 ft). Hemispheres from the following alloys have also been formed: 17-7PH and type 410 stainless steels, alloy steels such as 4130 and 4140, and from aluminum alloys 5086, 2014, 2024, and 6061.

**Effects of Power Spinning on Component Properties.** Power spinning is a severe cold working operation, and it therefore can have a very significant effect on the mechanical properties of the component. Typically, well-defined flow patterns are generated in the grain structure by power spinning. In many applications, the increase in strength caused by spinning is highly desirable, because it eliminates the need for subsequent heat treating. In those applications where the change in mechanical properties is not desired, the component must be annealed after
metal spinning. The effect of power spinning on mechanical properties, such as fatigue performance and creep resistance, is similar to that of other cold working operations.

**Conclusions**

This article has described two forming techniques, manual spinning and power spinning, for forming seamless metal components. The equipment for both of these two spinning techniques is based on lathe technology, with appropriate modifications for the components that are being formed. A wide range of components can be produced using these two metal-spinning techniques with relatively simple tooling. Metal spinning is very competitive with other forming processes, such as pressing and deep drawing; it is a highly flexible forming technique.

Metal spinning can be operated economically to produce complicated parts for single applications, low-volume production, and mass production. Manual-metal-spinning and power-spinning processes are very flexible and lend themselves to broad automation. Machine design changes, innovations in control systems, and process developments have led to improvements in all aspects of metal-spinning technology since the 1980s. Manual spinning is generally suitable for low-volume production of components.

This article has described process technology, equipment, and tooling for both manual spinning and power spinning. Power spinning can be used to form large parts (up to 6 m, or 20 ft, in diameter); there is little scrap material, and the forming operation can be completed quickly. A wide range of shapes can be produced with relatively simple tooling. Power spinning is particularly suited to cones and hemispheres. Other components that can be produced by metal spinning range from small hardware items made in large quantities (such as metal tumblers and automotive components) to large components for high-performance aerospace applications in low-volume production (such as rocket engine casings and missile nose cones).

Other examples of metal components that are spun include trophies, kettles, kettle drums, cymbals, tank ends, centrifuge parts, pressure bottles, venturis, radar reflectors, parabolic dishes, wheel discs, and wheel rims. For these types of complex geometries, manual-metal-spinning and power-spinning techniques are generally preferred over pressing and deep drawing; the advantages of spinning include flexible production, relatively low tooling costs, and short setup times.

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