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Spinning

*By the ASM Committee on Spinning**

SPINNING is a method of forming sheet metal or tubing into seamless hollow cylinders, cones, hemispheres or other circular shapes by a combination of rotation and force. On the basis of techniques used, applications, and results obtainable, the method may be divided into two categories: manual spinning (with or without mechanical assistance to increase the force) and power spinning. This article describes spinning of sheet; spinning of tube is dealt with in the article beginning on page 317.

Manual spinning entails no appreciable thinning of metal. The operation, ordinarily done in a lathe, consists of pressing a tool against a circular metal blank that is rotated by the headstock. The blank is ordinarily forced over a mandrel of pre-established shape, but simple shapes can be spun without a mandrel. By using various mechanical devices for applying force, the range of applications for manual spinning is broadened, because thicker blanks can be spun than by manual force alone.

Power spinning is also known as shear spinning, because in this method metal is intentionally thinned, by shear forces. In power spinning, forces as great as 400 tons are used.

Power spinning is used for two broad fields of application: cone spinning and tube spinning. In cone spinning, the deformation or displacement of the metal from the flat blank into the spun shape conforms to the sine law (see page 203). In tube spinning, the sine law does not apply, and metal displacement follows a purely volumetric rule.

Manual Spinning

Any metal ductile enough to be cold formed by other methods can be spun. Most spinning is done without applying heat to the work metal, although sometimes the metal is preheated to achieve one of two objectives: (*a*) to increase the ductility of hard-to-form metals such as beryllium, refractory metals, or magnesium; or (*b*) to reduce the strength of work metals, thus permitting greater thicknesses to be spun.

Applicability. Manual spinning is used for forming flanges, rolled rims, cups, cones and double-curved surfaces of revolution such as bells. Several typical shapes formed by manual spinning are shown in Fig. 1. Products regularly produced by manual spinning include light reflectors, tank ends, covers, housings, shields, and components for musical instruments. Manual spinning is also extensively used for the production of aircraft and aerospace components, often with mechanical assistance for increased force, because of large blank size (see Example 274, which describes hot spinning of an alloy steel blank into a hemisphere in three stages).

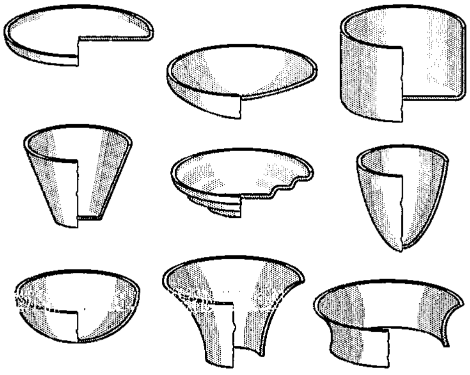
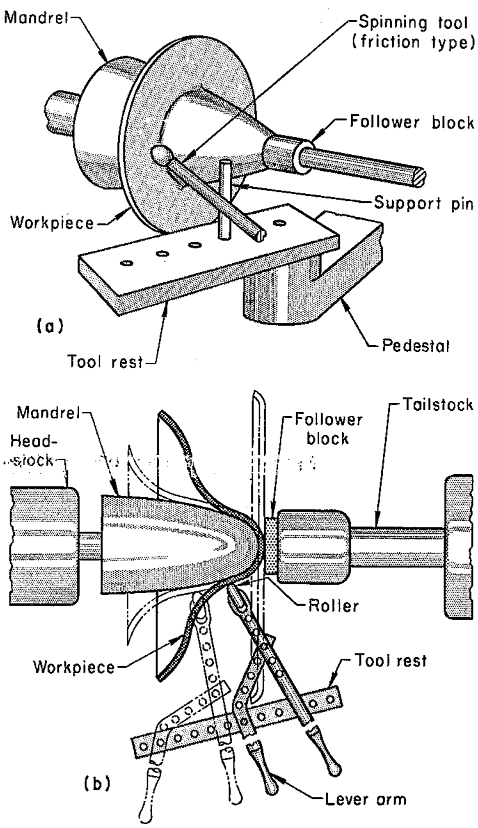


Fig. 1. Typical conical, cylindrical and dome shapes formed by manual spinning



(a) Setup using a simple hand tool, applied like a pry bar. (b) Setup using scissorlike levers and a roller spinning tool.

Fig. 2. Manual spinning in a lathe

The practical maximum thickness of low-carbon steel that can be spun without mechanical assistance is ⅛ in. In this thickness, the diameter can be as great as 72 in. Diameters can be greater when the sheet steel is thinner, but the maximum practical diameter is often limited by the availability of equipment. The upper limit of thickness increases as work-metal ductility increases or strength decreases. For instance, manual spinning of aluminum as thick as ¼ in. is feasible.

Advantages and Disadvantages. Manual spinning has the following advantages over a competitive process such as press forming: (*a*) tooling costs less, and investment in capital equipment is relatively small; (*b*) setup time is shorter; (*c*) design changes in the workpiece can be made at minimum expense; and (*d*) changes in work-metal composition or thickness require a minimum of tool changes.

Disadvantages of manual spinning include the following: (*a*) skilled operators are required, because uniformity of results depends greatly on operator skill; (*b*) manual spinning is usually slower than press forming; and (*c*) available force is more likely to be inadequate in manual spinning than in press forming. The last disadvantage is overcome to some extent by the use of mechanical assistance for increasing force in manual spinning.

Equipment for Manual Spinning

A typical tool and workpiece setup for manual spinning is shown in Fig. 2(a). The mandrel is mounted on the headstock of a lathe. The circular blank (workpiece) is clamped to the mandrel by the follower block. An antifriction center is used between the follower and the tailstock spindle, and pressure is applied at the tailstock by

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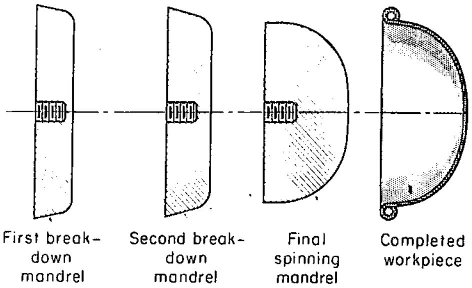
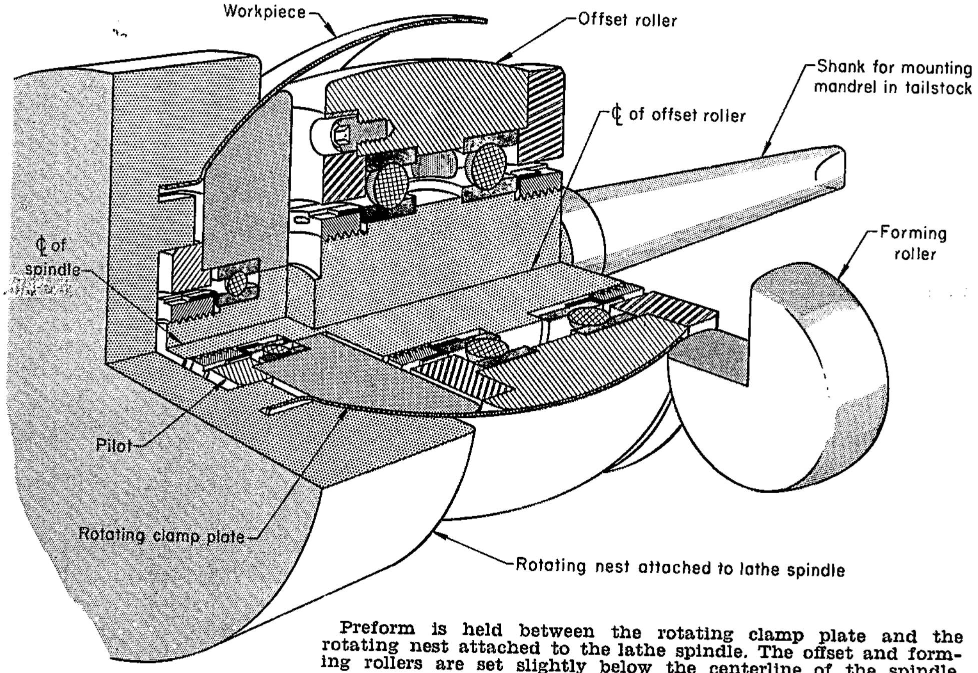


Fig. 3. Breakdown and final mandrels used in three-stage manual spinning of a cup



Preform is held between the rotating clamp plate and the rotating nest attached to the lathe spindle. The offset and forming rollers are set slightly below the centerline of the spindle.

Fig. 4. Tailstock-mounted mandrel with offset roller used for spinning of re-entrant shapes

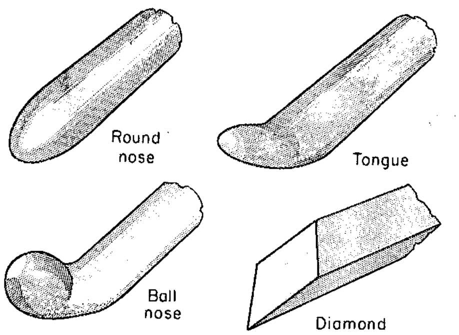
means of a screw, or by air or hydraulic pressure, depending on the size and type of lathe. The tool rest and pedestal permit the support pin (fulcrum) to be moved to various positions by swinging the tool rest and moving the support pin from one hole to another as needed. Spinning is done by manually applying the friction-type spinning tool like a pry bar.

Figure 2(b) shows a more complex setup for manual spinning. Here, the spinning tools (rollers) are mounted in the fork sections of long levers, and the tool support has a series of holes for rapid changing of tool position. The tool is manipulated by pulling, pushing or pivoting the two scissorlike handles, with the roller against the workpiece.

Lathes. Several sizes of standard horizontal spinning lathes are available that can spin blanks ranging from ¼ in. to 72 in. in diameter. Special pit lathes permit the spinning of blanks as large as 192 in. in diameter. Standard lathes can be fitted with special chucks for making oval parts. Lathes should be equipped with variable-speed drives to permit quick changes of speed as udged necessary by the operator.

Mandrels, also known as form blocks or spin blocks, are usually made of seasoned hard-maple wood. Most hardwood mandrels are constructed by gluing strips of maple 1 to 2 in. thick into the main block to create a cross-laminated structure, and then turning the glued structure to the desired shape. Such mandrels are stronger and more durable than mandrels turned from a solid block. Some wooden mandrels are steel-reinforced at the ends and at small radii to ensure maintenance of radii in the spun workpieces. Sharp corners can be produced in workpieces by spinning them over mandrels cornered with steel, but minimum inside radii of 1⁄16 in. are more common than sharp corners, and ⅛-in. minimum radii are preferred where possible.

Some mandrels are made up of alternating wood and steel plates or rings, to obtain a more economical yet durable mandrel. Other materials include fiber compositions, steel, cast iron, aluminum, magnesium, and plastic-coated wood. Few mandrels are made entirely of heavy metals like steel and cast iron, except for close-tolerance work. Cored castings of these metals are then preferred, because of the saving in weight. Solid steel or cast iron mandrels must be statically balanced, and for use at high speed they should also be dynamically balanced.



Round-nose, tongue and ball-nose tools are used for spinning; diamond tool, for trimming.

Fig. 5. Typical shapes of working ends of tools used in manual spinning

Mandrels are usually made to the shape of the completed workpiece. When the workpiece is to have a shape more complex than can be spun in one setup, or when it needs intermediate heat treatment, a series of mandrels can be used. Mandrels for earlier stages of the workpiece are called preform or breakdown mandrels (see Fig. 3).

Mandrels can be made collapsible, for use in spinning workpieces that have a turn-in or re-entrant shape smaller than the largest diameter of the workpiece. A collapsible mandrel is an assembly of sections held in place by one key section. When the key section is removed, the mandrel collapses and the remaining sections can be removed from the spun workpiece one at a time.

Another method of spinning workpieces having re-entrant sections is to make the mandrel from a low-melting alloy (some have melting temperatures as low as 117 F). After spinning, the mandrel and workpiece are heated and the mandrel is melted. This method, however, is seldom used except for prototype work.

For production quantities of re-entrant shapes, the use of off-center setups and internal rollers is the most practical approach. Usually, the main shape of the workpiece is preformed by spinning in the conventional manner. To form the re-entrant shape, the mandrel is mounted in the tailstock, and the follower block is mounted on the spindle. The mandrel consists of a rotating clamp plate and an offset roller. A pilot, used to support the end of the mandrel, is fastened to the rotating clamp plate. A nest attached to the spindle serves as a follower block to hold the preformed shell against the clamp plate. The nest also has a recess to receive the mandrel pilot. In operation, the preform is placed on the mandrel, and the tailstock is moved forward to clamp the work in the nest. The preformed shell is then worked down to the offset roller by the forming roller set slightly below the center of the spindle (see Fig. 4).

(Example 598, on page 422, describes the spinning of a workpiece with a re-entrant curve from a drawn shell, using a mandrel that was split radially at the minor diameter.)

Spinning Tools. Simple spinning tools are usually made by forging carbon or low-alloy tool steels (such as W1 or O1) to the desired shape, and then hardening the working ends to about Rockwell C 60 and polishing them. Several typical shapes are illustrated in Fig. 5. Tools of shaped aluminum bronze are also satisfactory, especially for the spinning of steel. Tools made of hardwood have performed satisfactorily in spinning thin-gage ductile metals.

With the lever arrangement (Fig. 2b), the tools usually consist of rollers (sometimes called tool rings) mounted in forks. Most rollers are made of hardened tool steel or of aluminum bronze.

Manual Spinning Practice

Because of the low tooling cost, manual spinning is used extensively for prototypes and for production runs of 1000 pieces or less. Larger lots can usually be produced at lower cost by power spinning or press forming.

For instance, the part in the middle of the second row in Fig. 1 is a stainless steel cover for a food-processing machine, produced in one plant at the rate of 100 per year. The parts were produced satisfactorily by manual spinning, using only two hardwood mandrels, the cost of which was only a fraction of the tooling cost for press forming the same shape.

The relation of quantity and cost for producing a flanged cylinder by manual spinning versus drawing in a press is described in the following example.

Example 271. Cost of Steel Shells: Spinning vs Drawing (Fig. 6)

Figure 6 shows a part that was producible by either spinning or drawing, and plots graphically the per-piece costs, in arbitrary units, for producing various quantities of the part by the two methods. As shown, the breakeven point for the two methods was 700 pieces — spinning being the lower-cost method for quantities of less than 700 pieces, and drawing in a press for larger quantities.

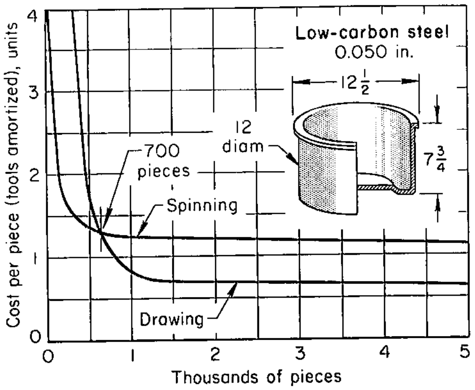


Fig. 6. Relation of quantity and cost for producing a flanged cylindrical part by manual spinning vs drawing in a press (Example 271)

Conical parts (like the shape on the left in the middle row in Fig. 1) are ideal for spinning, because only one tool is required whereas drawing in dies would require four or five operations. Many such cones, depending on their included angle, can be spun in one operation at a moderate production rate. For this reason, manual spinning is often used for quantities up to medium production (less than 1000 units). For large-quantity production, power spinning (shear spinning) is generally cheaper than manual spinning.

Control of quality, including freedom from wrinkles and scratches, and maintenance of dimensional accuracy, is largely a function of operator skill in manual and power-assist spinning. Dimensional tolerances that are practical to maintain in manual spinning increase as the diameter of the blank increases, as shown in Table 1. These tolerances are typical of demands for commercial products and parts for aerospace applications.

Speeds (in surface feet per minute) best suited for manual spinning depend mainly on work-metal composition and thickness. For instance, a given blank of stainless steel is successfully spun at 200 sfm (based on the diameter of the starting blank), and it is determined by "operator feel" that this is maximum for the conditions. Under otherwise identical conditions, changing to a blank of aluminum will permit speeds of 400 to 600 sfm. Similarly, if the thickness of the stainless steel blank were decreased to half the original thickness (no other changes), speed could be safely doubled or tripled.

Selection of optimum speed depends largely on "operator feel". In many spinning operations, speed is changed (usually increased) during the operation by means of a variable-speed drive on the headstock.

Lubricants should be used in all room-temperature spinning operations regardless of work-metal composition, workpiece shape, or type of spinning tools used. The usual practice is to apply the lubricant to the blank with a swab or brush before loading the blank into the machine. In some instances, additional lubricant is added during operation as judged necessary by the operator. The need for additional lubricant depends on the tenacity of the lubricant used and blank-rotation speed.

The most important property of a lubricant used for spinning is its ability to adhere to the rotating blank. Ordinary cup grease is often used. It can be heated to reduce its viscosity, thus making it easier to apply to the blank. Upon application to the cold blank, viscosity of the grease increases. Also, cup grease can be easily removed.

Other lubricants used for spinning include soaps, waxes and tallows (and proprietary mixtures of two or more of these materials), and pigmented drawing compounds. All of these, however, are more difficult to remove than simple grease. For this reason, the more tenacious lubricants are not used if an easier-to-remove lubricant will provide acceptable results. Methods of cleaning formed metal parts are described in the articles that begin on page 307 of Volume 2 of this Handbook.

Power Spinning

Virtually all ductile metals are processed by power spinning. Products range from small hardware items made in large quantities (metal tumblers, for instance) to large components for aerospace applications in unit or low-volume production.

Blanks as large as 240 in. in diameter have been successfully power spun. Plate stock up to 1 in. thick can be power spun without applying heat; when heated, blanks as thick as 5½ in. have been successfully spun.

Conical and curvilinear shapes are those most commonly produced from flat (or preformed) blanks by power spinning. The mechanics of the process should be known, and the rules followed, when planning manufacturing processes that include power spinning.

Mechanics of Cone Spinning

The application of shear spinning to conical shapes is shown schematically in Fig. 7. The metal deformation is such that forming is in accordance with the sine law, which states that the wall thickness of the starting blank and that of the finished workpiece are related as follows:

$$t_2 = t_1(\sin \alpha)$$

Where t_1 is the thickness of the starting blank, t_2 is the thickness of the spun workpiece, and α is one-half the apex angle of the cone.

Table 1. Typical Dimensional Tolerances for Manual Spinning

Diameter of blank, in.	Tolerance, in.	
	Commercial	Aerospace
Up to 12	±1/64	±0.008
13 to 36	±1/32	±0.015
37 to 54	±1/16	±0.020
55 to 96	±1/8	±0.030
97 to 144	±1/4	±0.040

Reducing wall thickness by 50% in accordance with the sine law is illustrated in Fig. 7, where:

D = diameter (the same in starting blank and cone)
t_1 = flat plate thickness
t_2 = wall thickness of side of spun cone
α = 30° (which is half the included angle).

Using the sine law for Fig. 7,

$$t_2 = t_1(\sin \alpha) = 0.500 \times 0.5 = 0.250 \text{ in.}$$

When spinning in accordance with the sine law, the axial thickness is the same as the thickness of the starting blank (Fig. 7).

When spinning cones to small angles (less than 35° included angle), the best practice is to use more than one spinning pass with a different cone angle for each pass, as illustrated in Fig. 8. When using this technique, the workpiece is annealed or stress relieved between passes.

This practice permits a high total reduction while maintaining a practical limit of 50 to 75% between process anneals. The reduction between successive annealing operations is determined by the maximum acceptable limits of deformation for the metal being spun (see Table 2 on the next page), obtained by multiplying t_1 by a factor (0.5 for 50%, 0.25 for 75%, and so on) and then dividing the result by t_1 to obtain the sine of the required half angle.

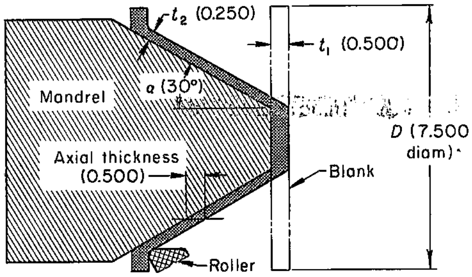


Fig. 7. Setup and dimensional relations for one-operation power spinning of a cone. See text for application of sine law in relation to this illustration.

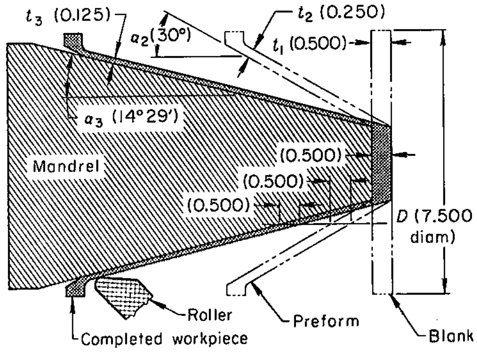


Fig. 8. Setup and dimensional relations for two-operation spinning of a cone to a small angle (less than 35° included angle)

Table 2. Maximum Reductions for Power Spinning of Various Metals Without Intermediate Annealing

Work metal	Maximum reduction, % Cone	Hemisphere	Tube
Alloy Steels			
4130	75	50	75
4340	65	50	75
6434	70	50	75
D-6ac	70	50	75
H11	50	35	60
Maraging steel (18% Ni)	65	50	82
Stainless Steels			
321	75	50	75
347	75	50	75
410	60	50	65
17-7 PH	65	45	65
Heat-Resisting Alloys			
A-286	70	55	70
René 41	40	35	60
Waspaloy	40	35	60
Aluminum Alloys			
1100	75	50	75
2014	50	40	70
2024	50	..	70
2219	50	40	70
3003, 3004	75	50	75
5052, 5056	50	35	75
5086	65	50	60
5154	55	50	75
6061	75	50	75
7075	65	50	75
Titanium Alloys (Spun Hot)			
Commercially pure	45	..	65
Ti-6Al-4V	55	..	75
Ti-6Al-6V-2Sn	50	..	70
Ti-3Al-13V-11Cr	30	..	30
Other Metals (Spun Hot)			
Beryllium	35	..	..
Molybdenum	60	45	60
Tungsten	50	..	..

Even in multiple-pass spinning, the original blank diameter is retained and the exact volume of material is used in the final part. At any diameter of either the preform or the completed workpiece, the axial thickness equals the thickness of the original blank. For instance, if a flat plate has a diameter of 7½ in. and a thickness of ½-in., the spun preform has this same ½-in. axial thickness but the wall thickness is only ¼ in. (t_1 in Fig. 8), thus satisfying the sine law. Likewise, the final workpiece has an axial thickness of ½ in., but in accordance with the sine law has a wall thickness of only ⅛ in. (t_3 in Fig. 8).

The sine law applies to multiple-operation spinning as follows, wherein a total reduction of wall thickness of 75% is obtained without exceeding 50% in any one operation:

t_1 = flat-plate thickness
t_2 = preform wall thickness
t_3 = final-part wall thickness = 0.125 in.
α_2 = half angle of preform
α_3 = half angle of final part = 14° 29′

$$t_3 = t_1(\sin \alpha_3)$$

To find the flat-plate thickness and the preform cone angle and thickness, the following procedure is used:

$$t_1 = \frac{t_3}{\sin \alpha_3} = \frac{0.125}{0.250} = 0.500 \text{ in.}$$

To satisfy the requirement for a 50% maximum reduction:

$$t_2 = t_1 \times 0.5 = 0.500 \times 0.5 = 0.250 \text{ in.}$$

The half angle required to achieve this reduction is found by:

$$\sin \alpha_2 = t_2/t_1 = \frac{0.250}{0.500} = 0.500 \text{ or } \alpha_2 = 30°$$

Effects of Deviation From the Sine Law. Deviation from the sine law is usually expressed in terms of overreduction or underreduction. In overreduction, the final thickness of the workpiece is less than that dictated by the sine law; in underreduction, the thickness is greater. In overreduction, the flange will lean forward; in underreduction, the flange will lean backward. If a thin blank is spun with severe underreduction, the flange will wrinkle. This phenomenon corresponds to a deep-drawing operation in which the blankholder pressure is insufficient.

In power spinning, overreduction has an additional effect on the shape of the workpiece. As the workpiece is overreduced, back extrusion (Fig. 9) can occur. For a given amount of reduction, the likelihood of back extrusion increases with increasing mandrel angle (Fig. 9).

The phenomenon of back extrusion in spinning is explained in terms of compressive stress in the spun workpiece that pushes the spun section backward. If the tailstock of the machine is removed, it is possible to obtain curvilinear shapes on a conical mandrel by varying the amount of overreduction during spinning.

Machines for Power Spinning

Most power spinning is done in machines specially built for the purpose. Significant components of such a machine are shown in Fig. 10. Although Fig. 10 illustrates power spinning of a conical shape, similar machines are used for spinning of tubes (see the article on Tube Spinning, which begins on page 317 in this volume).

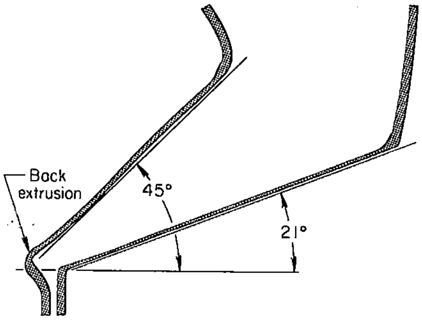


Fig. 9. Back extrusion as a result of overreduction in power spinning of low-carbon steel

Machines for power spinning are usually described by specifying the diameter and the length, in inches, of the largest workpiece that can be spun, and also the amount of force that can be applied to the work. For instance, a 45 by 70-in. by 75,000-lb spinning machine can spin a workpiece measuring 45 in. in diameter by 70 in. long, and the greatest force that can be applied by each tool is 75,000 lb. It is also common practice to specify that the machine can spin a given thickness of metal at a 50% reduction in thickness in one pass.

The capacity of spinning machines ranges from 18 by 15 in. by 4000 lb to machines capable of spinning workpieces as large as 240 in. in diameter by 240 in. long. Force on the work can be as great as 800,000 lb. Machines have been built that spin steel 5½ in. thick.

Spinning machines can be vertical or horizontal. Machines used for spinning workpieces 70 in. or more in diameter are usually vertical because they are better suited for handling large work.

Machines for power spinning can be automated to various degrees. The majority of spinning machines utilize template guides that control the shape and accuracy of the workpiece. Most machines used for production spinning are 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, thus making them fully automatic.

Tools for Power Spinning of Cones

Mandrels, rollers and other tools are subjected to more rigorous service in power spinning than in manual spinning; thus, more careful consideration must be given to design and materials of construction.

Mandrels. A typical mandrel profile is illustrated in Fig. 11. Dimensions A and B and angle α can vary as required. Usual practice is to have an integral flange to permit bolting the mandrel to the headstock and a boss of suitable diameter and at least ⅝ in. thick that fits into the headstock of the machine (Fig. 11). Radius R can vary from a minimum of $\frac{1}{32}$ in. to a round nose.

Mandrel wear or failure is frequently a problem in power spinning of conical shapes. Mandrels used in production spinning must be hard, to resist wear, and must also be resistant to fatigue resulting from normal eccentric loading.

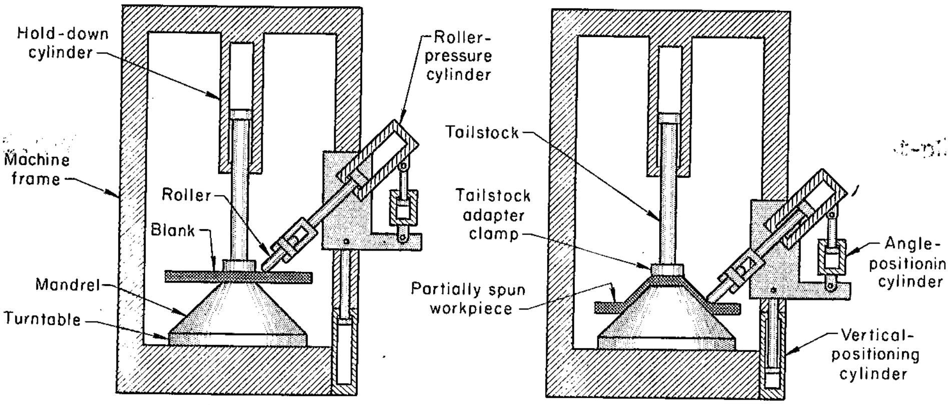


Fig. 10. Schematic illustration of power spinning in a vertical machine

Failure is often caused by spalling (flaking off). Mandrels can also be damaged by the rollers plunging into the workpiece at the start of metal flow. The need for plunging can sometimes be eliminated by machining a ring on the preform to a depth equal to the depth the rollers would otherwise be plunged. This technique permits the rollers to enter the machined space before they start moving along the mandrel, thus eliminating the severe stress on the mandrel as spinning is begun.

Materials for mandrels used in cone spinning depend mainly on the number of identical workpieces to be spun. Based on quantity, the most commonly used materials are:

1. Gray iron (as cast), for low-production spinning of soft metals (10 to 100 pieces)
2. Alloy cast iron (sometimes flame hardened in areas susceptible to high wear), for spinning 100 to 250 pieces
3. Steel — 4150 or 52100 hardened to about Rockwell C 60, for spinning 250 to 750 pieces
4. Tool steels such as O6, A2, D2 or D4 hardened to Rockwell C 60 or slightly higher, for high production.

Finish of mandrels should be no rougher than 60 micro-in. The various diameters should be within ±0.001 in. and concentric with each other within approximately 0.002 in. TIR.

Rollers. Three types of rollers are shown in Fig. 12. Rollers usually are 12 to 20 in. in outside diameter, depending on the type and size of the spinning machine. Roller widths are usually 2 to 3 in., and inside diameters range from 10 to 15 in. The shape of the rollers depends largely on the shape of the workpiece to be spun. Full-radius rollers (Fig. 12a) are usually used for producing curvilinear shapes, whereas those illustrated in Fig. 12(b) and (c) are preferred for the spinning of cones.

Angle α shown in Fig. 12(b) and (c) is necessarily varied to suit the work being spun (particularly the angle of the cone). This angle is intended for clearance and should be such that the work metal does not touch face A (Fig. 12b), or either face A or face B (Fig. 12c). The radius *R* should not be less than the final wall thickness.

The type of roller illustrated in Fig. 12(b) is widely used in cone spinning. A typical setup, using two of these rollers opposed, is illustrated in Fig. 13. When two rollers are used to spin a part from flat plate, the rollers are set the same. However, when spinning is done from a preformed shape, common practice is to make one the lead roller and to set it ahead of the other by 1/16 to 1/8 in. If more than two rollers are used, this increment is continued between successive rollers. The angle between the axis around which the rollers revolve and the workpiece (angle α in Fig. 13) is usually about 10°, whereas the angle between the same roller axis and the peripheral face of the roller (angle β in Fig. 13) may vary, and is shown in Fig. 13 as approximately 30°.

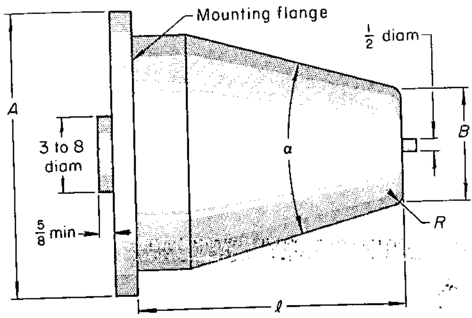


Fig. 11. Typical profile of a mandrel for power spinning of cones

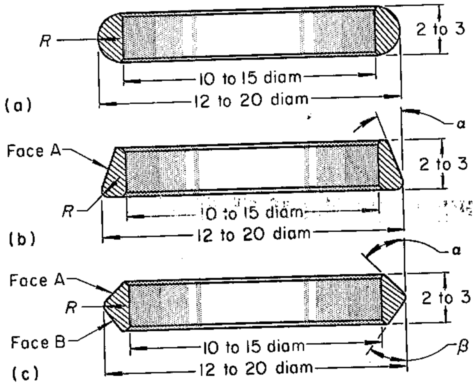


Fig. 12. Typical rollers used in spinning of cones and hemispheres

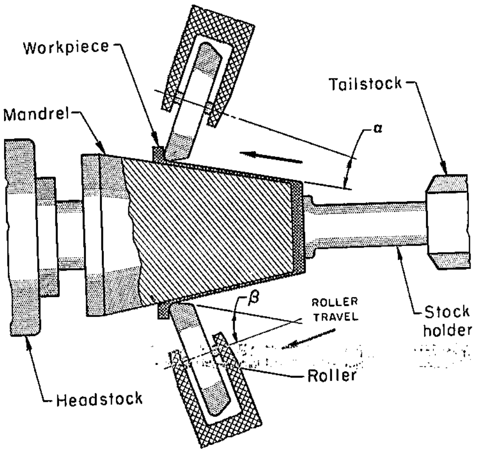


Fig. 13. Relative positions of rollers and workpiece in spinning a cone

Rollers are made from a variety of hard materials. The five materials most widely used for power spinning of conical shapes, in order of ascending wearability and cost, are W2 tool steel, O6 tool steel, D2 tool steel, D4 tool steel, and carbide. Choosing among these materials is usually done on the basis of quantity of workpieces to be spun. The less costly W2 and O6 are generally suitable for low to medium production quantities. Tool steels D2 and D4 are preferred for high production quantities. Carbide is seldom used except for specialized applications in which the need has been proved and the high cost can be justified.

Rollers made from any of the above tool steels should be hardened to Rockwell C 60 to 65. All rollers should be polished to a maximum surface roughness of 10 micro-in.

Auxiliary tools for cone spinning include tailstock adapters, tracer templates, tracer followers, and stripping devices. A tailstock adapter clamps the work to the mandrel (Fig. 10) and is made of carbon or alloy steels such as 1045 or 4150, or of tool steel. The clamping face of the tailstock adapter must be ground square to the spindle axis.

Tracers are used for spinning workpieces that vary in wall thickness or shape. Tracer templates are made of low-carbon steel such as 1020, 1/8 to 3/16 in. thick. Large templates have lightening holes for easier handling. Tracer templates are made to the same standards of accuracy as are dies and similar tools. Tracer followers can be ball bearings or hardened tool steel fingers, depending on cone shape.

Stripping devices may be full rings or fork-type fingers, attached to the roller carrier. The need for stripping devices depends on the size and the shape of the workpiece.

Preforms for Spinning Cones

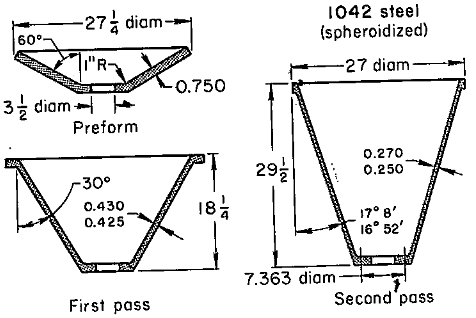
The use of preforms is common in cone spinning when the included angle of the cone is less than 35° or when the percentage of wall reduction is high.

Preforms are usually prepared by cold forming in a die, although hot forging or machining or a combination of both can be used. Some preforms are made by spinning.

The following example describes a procedure for producing a narrow cone from a preform.

Example 272. Power Spinning a Narrow Cone From a Preform (Fig. 14)

The final workpiece shown in Fig. 14 represents the near-maximum reduction that can be obtained without intermediate annealing.



Spinning Conditions

Speed, first pass	400 to 1450 sfm(a)
Speed, second pass	400 to 1600 sfm(b)
Feed, first pass	1.5 to 4 ipm(c)
Feed, second pass	6 ipm
Lubricant and coolant	(d)

Tool Costs

Die for preforming	$1500
Mandrels (2 required)	4000
Tailstock pieces (2 required)	300
Rollers (4 required)	1000
Checking fixture (after second pass)	300
Total tool cost	$7100(e)

Operation	Production rate, pieces per hour	Cost per piece(f)
Production Rates and Costs		
Gas cutting	5	$1.50
Drilling	5	1.70
Grinding	15	0.70
Forming	80	0.40
First spinning pass	4	7.50
Second spinning pass	6	5.00
Total production cost		$16.80

(a) At 200 to 210 rpm. (b) At 230 rpm. (c) Continuously varied by electronic control. (d) Workpieces were initially coated with proprietary spinning oil, and a chemical emulsion was used as coolant. (e) Amortized over 500 pieces. (f) Total production cost (not including material and overhead) was $17.32 per piece in lots of 500 ($16.80 + 1/500 of setup cost). Setup cost for forming and spinning was $260.

Fig. 14. Steps in production of narrow cones by two-pass spinning of a preform (Example 272)

The cones were produced by gas cutting 30-in.-diam blanks, drilling the 3½-in.-diam center hole, grinding the edges to remove burrs and slag, and then making the 120° preforms (Fig. 14) in a 2000-ton press. The preforms were then spun to an included angle of 60° (denoted as "First pass" in Fig. 14) in a 100-hp spinning machine. The workpiece was completed in a second spinning pass. Total wall reduction was:

$$\frac{0.750\text{ in.} - 0.250\text{ in.}}{0.750\text{ in.}} = \frac{0.500\text{ in.}}{0.750\text{ in.}} = 66\tfrac{2}{3}\%$$

Processing and cost details are given in the table with Fig. 14.

Speeds and Feeds for Cone Spinning

Most metals spin best at high speeds. The minimum speed considered practical is about 400 sfm, but speeds this low are seldom used except for spinning small-diameter workpieces. Sometimes for such workpieces machine spindles cannot rotate fast enough to achieve the desired surface speed. Speeds of 1000 to 2000 sfm are most widely used, regardless of work-metal composition, workpiece shape, or reduction per pass.

Feed. Most cone spinning operations are done at feeds of 0.010 to 0.080 ipr. In practice, however, feeds are usually calculated in inches per minute (ipm). Most machines used in cone spinning are equipped with electronic or hydraulic devices that steplessly change the rate of feed as the diameter on which the rollers are working changes continuously. The rate of feed usually ranges from 1½ to 15 ipm.

Feed rate is important, because it controls the workpiece finish and the fit of the workpiece to the mandrel. With all other factors constant, an increase in feed rate will make the workpiece fit tighter on the mandrel, and the finish of the workpiece will coarsen. On the other hand, a decrease in feed rate will cause a loose fit, and workpiece finish will improve. The diameter of the mandrel should be the same as the inside diameter required on the workpiece (no allowance for springback), and the workpiece should be spun to fit the mandrel. The fit may be loose, snug or tight. For example, a feed rate of 0.005 to 0.010 in. per revolution per roll will result in a loose fit, because this approaches a ring-rolling operation, in which the workpiece is caused to increase in diameter rather than in length. A feed rate of 0.015 to 0.020 in. per revolution per roll will result in a snug fit, and a feed rate of 0.025 to 0.030 in. per revolution per roll will result in a tight fit on the mandrel. Closest tolerances are obtained by a snug-to-tight fit between the workpiece and the mandrel.

To find the optimum combination of speed, feed and pressure, a few pieces should be spun experimentally when a new job is set up. During continuous operation, the temperature of the mandrels and spinning tools changes; therefore, after the first hour or so, it is often necessary to adjust the pressure, speed and feed for uniform results.

Power Spinning of Hemispheres

The use of preforms to control percentage of reduction has enabled power spinning to be applied to the forming of hemispheres, ellipses, ogives and, in general, any curvilinear surface of revolution. However, design of the preform for curvilinear shapes is more complicated than for conical shapes. In spinning of conical shapes, it is possible to find an axial thickness of the spun part that corresponds to the thickness of the blank (see Fig. 8 and the discussion of this figure). No such relationship exists for a curvilinear surface. In the path from the pole to the equator, the axial thickness of the metal on a hemisphere changes from stock thickness at the pole to infinity at the equator (the inverse of sin 90° being infinity). The blank thickness must be back-tapered to compensate for the change in thickness that will take place during spinning. This is shown in Fig. 15, where the machined taper started at 0.150-in. thickness (in the center of the blank) and ended at 0.300-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 0.212 in., and at the 15° line 0.580 in. Below the 30° line, however, reduction was greater than permissible for the material, and the operation was planned as if spinning a cylinder. The blank for this portion had a flange with a thickness proportional to the percentage reduction. A usable blank can be designed thus:

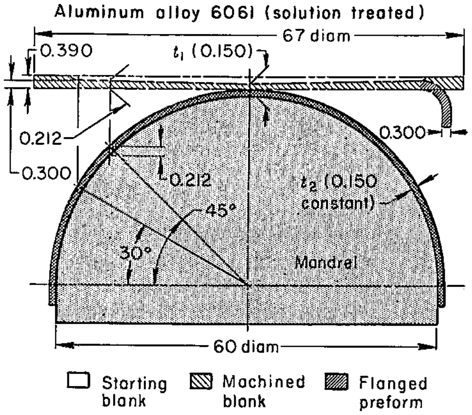
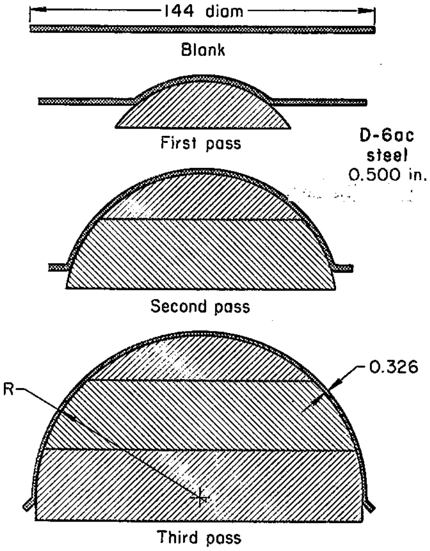


Fig. 15. Hemisphere spun from a machined and preformed blank (Example 273)



Processing Details

Type of machine	Power-assisted conventional manual spinning machine
Speed	800 to 1200 sfm
Lubricant	Molybdenum disulfide in oil
Time per piece	20 min per pass(a)

Tool Details

Spinning tool	Full-radius roller; H11 tool steel
Mandrel material	Gray iron

(a) Plus setup time

Fig. 16. Breakdown sequence used for forming a large hemisphere by power-assisted hot spinning (Example 274)

Find in Table 2 the allowable reduction for the work metal to be used. Select a beginning stock thickness that, with this amount of reduction, will give the thickness desired on the sphere. Use the ratio of finished stock thickness to original stock thickness as the sine of an angle. This will be the angle of the surface at the latitude where preforming must start, because beyond this point the reduction required to make the hemisphere will be greater than is permissible for the work metal. There will be no reduction at the pole because there blank thickness and final thickness will be the same. At 45° from the pole, final part thickness will be 0.707 times blank thickness. At a corresponding circle on the blank, therefore, the stock must be 1.414 times final part thickness. Other latitudes can be similarly chosen and necessary stock thickness at a corresponding circle on the blank determined. At the circle corresponding to the limiting latitude (maximum permissible reduction has taken place), preforming must start.

In a cross-sectional view, the circles will appear as points and the thickness of the stock at these points can be determined. Fairing between the known points will give a smooth curve that can be machined to produce a blank of the correct thickness. When the points are laid out, a dozen or more points are connected to give the final shape. Trigonometric calculations can replace layouts; then as many as 180 to 360 points can be used, resulting in a more accurate curve. Calculations are now being replaced in many plants by the use of computers, with which it is common practice to use 1200 to 1500 points on a shape such as a large hemisphere.

The starting-blank thickness can be obtained by multiplying the known thickness of the finished part by an appropriate factor. Likewise, by dividing the starting-blank thickness by the appropriate factor, the thickness of the finished part is obtained. The factors are related to the percentage reduction and are the reciprocal of the difference between the percentage reduction (expressed as a decimal) and one, as follows:

For 50% reduction, use a factor of 2.
For 66⅔% reduction, use a factor of 3.
For 75% reduction, use a factor of 4.
For 82½% reduction, use a factor of 5.

Use of this system is illustrated in the example that follows.

Example 273. Forming a 60-In.-Diam Hemisphere by Power Spinning (Fig. 15)

Large hemispheres (Fig. 15) were power spun from solution treated 6061 aluminum alloy, using the following calculations.

From Table 2, it was determined that a 50% reduction could be made with this alloy. Preliminary calculations for thickness of the starting blank were as follows:

$$t = \text{final wall thickness} \times \text{factor for percentage reduction} = 0.150 \times 2 = 0.300\text{ in.}$$

In calculating the blank thickness at various points on the sphere, it was found that at the pole, or 90° point, the thickness had to be reduced to 0.150 in., and that some 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 0.300 in. Beyond this point, a flange would be preformed by spinning and an additional thickness would be required. It was estimated that an increase in blank thickness of 30% would be enough, and initial blank thickness was established at 0.390 in.

Machining of the blank to graded thickness was done in a tracer-controlled vertical boring mill, with the blank held on a vacuum chuck. Following machining, the flange was preformed to the desired contour by conventional power spinning, accomplishing a reduction in wall thickness that provided a uniform 0.300-in. wall.

Final spinning was accomplished in one pass of the rollers after the alloy was given a controlled amount of room-temperature aging (usually 13 to 18 hr). During final spinning, one roller led the other by a vertical offset of ¹⁄₁₆ to ⅛ in., using ¾-in.-radius tool rings at a feed of about 0.090 in. per revolution. Speed varied from 300 rpm max down to 40 rpm at the flange.

The procedure described in Example 273 has also been successfully applied to the forming of hemispheres and ellipses 6 to 70 in. in diameter from 17-7 PH and type 410 stainless steels, from alloy steels such as 4130 and 4140, and from aluminum alloys 5086, 2014 and 2024 (as well as 6061). In one instance, the procedure was used for hot spinning an ogive 30 in. in diameter and length from molybdenum.

An application involving hot manual spinning of a hemisphere by the use of three breakdown operations is described in Example 274.

Hot Spinning of Hemispheres

The use of heat for decreasing the strength and increasing the ductility of the work metal is sometimes required either because the machine capacity is insufficient for cold forming the thickness to be spun or because the room-temperature ductility of the work metal is too low.

Hot spinning is done only when necessary, because heating, subsequent cleaning, and increased tool deterioration all contribute to increased cost. A specific application where high-strength steel was heated for spinning is described in the example that follows.

Example 274. Hot Spinning of 144-In.-Diam Alloy Steel Blanks (Fig. 16)

A manually operated machine with hydraulic power assist was used to spin 100-in.-diam hemispherical heads from 0.500-in.-thick by 144-in.-diam circular blanks of D-6ac alloy steel. Spinning to final shape was accomplished in a series of three breakdowns (Fig. 16) by heating to 1550 F with oxyacetylene torches. Temperature was determined with an optical pyrometer. After spinning, the workpiece was stress relieved, sand blasted, and inspected by the magnetic particle method. A minimum wall thickness of 0.272 in. was specified. However, measurements taken after spinning indicated an actual minimum thickness of 0.326 in. To guarantee a uniform wall thickness after spinning, it was necessary to machine both the inside and the outside surfaces. Machining also removed decarburizatio resulting from elevated temperatures.

Lubricants and Coolants for Power Spinning

Power spinning requires the use of a fluid that serves as both a lubricant and a coolant. Because of the large amount of heat generated, a water-base fluid is most commonly used. Usually, a colloidal suspension of zinc in lithium soap or molybdenum disulfide paste is mixed with water to function as the lubricant. These lubricant-coolant combinations are satisfactory for most metals, although zinc-free lubricants and coolants should be used for spinning stainless steel to avoid surface contamination.

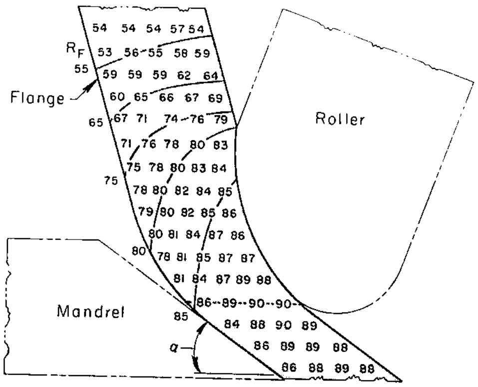


Fig. 17. Distribution of hardness (Rockwell F) in a copper workpiece reduced 43% by spinning

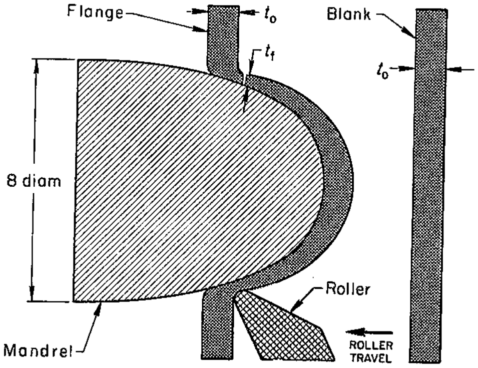


Fig. 18. Setup for testing shear spinnability

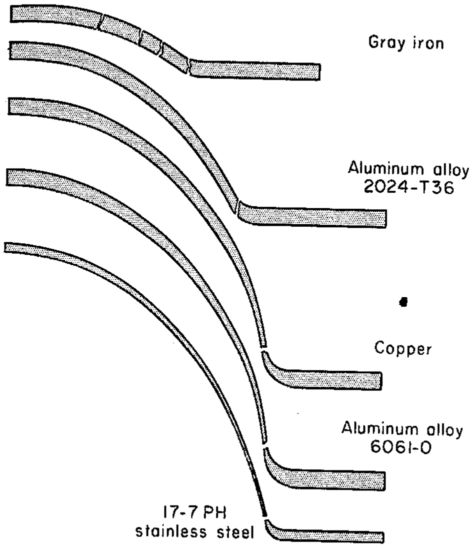


Fig. 19. Location of fracture in specimens of five different metals that were tested for shear spinnability

Various oils and oil mixtures, such as 10% lard oil in kerosine, have also been used successfully for power spinning. Regardless of composition, the fluid must be free flowing and applied by pumps in copious amounts or both workpieces and tools will be damaged from heat.

When spinning aluminum or stainless steel, the workpieces or mandrels, or both, are sometimes coated with the lubricant before spinning. During spinning, workpieces and tools are floode with a coolant such as an emulsion o soluble oil in water.

Effects of Spinning on Work-Metal Properties

Power spinning is a severe cold working operation and therefore has a marked effect on mechanical propertie of the work metal. Grain size is refine and made directional by power spinning. Surface finish of a spun workpiece is usually good enough so that n additional machining is required afte spinning. Spun finishes are commonl about 60 micro-in., although finishes a smooth as 20 micro-in. have been produced by power spinning.

Strength and Hardness. In spinning tensile and yield strengths increase and ductility decreases. The magnitude o effect depends on the amount of wall reduction and the susceptibility of the metal to work hardening (see Tables 2 and 3 in the article on Tube Spinning pages 321 and 322).

In many applications, the increase in strength caused by spinning is highly desirable because it eliminates the need for heat treating. In other applications the change in mechanical properties is not desired and the workpieces must be annealed after spinning.

To measure the work hardening in the deformation zone, Rockwell F readings were taken on the cross section of a spun copper workpiece that was reduced 43%. The results are shown in Fig. 17. It is evident that the area near the roller contact has higher hardness than at the mandrel side.

Shear Spinnability of Metals

Spinnability is defined as the maximum reduction a metal can withstand before failure during spinning.

The setup for testing shear spinnability shown in Fig. 18 consists of a half-ellipsoid mandrel 8 in. at its lesser diameter. According to the sine law, when a flat blank is shear spun on this shape of mandrel, the thickness of the spun part will vary gradually from its original to zero. All metals will fail somewhere between these two limits. Shear spinnability is defined as the maximum percentage reduction in thickness a metal can undergo before failure. Thus, maximum spinning reduction percentage is:

$$\frac{t_o - t_f}{t_o} \times 100$$

Several specimens tested by this method (Fig. 19) show that gray iron and 2024-T36 aluminum alloy fractured in a brittle manner under the roller. In contrast to this type of fracture, copper, 6061-O aluminum alloy, and 17-7 PH stainless steel all failed in tension behind the roller.

Experiments on the influence of roller corner radius, roller swivel, roller axial velocity, and speed of mandrel rotation have indicated that none of these process variables has a significant effect on maximum reduction. Nor was any appreciable difference in spinnability observed between results with dry

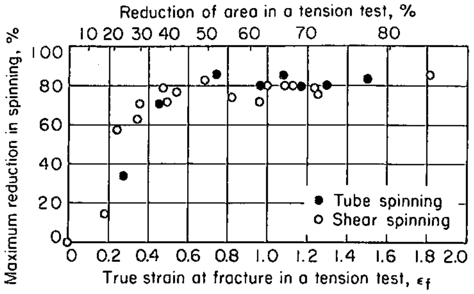


Fig. 20. Correlation of maximum reduction in spinning with reduction of area in a tension test

and lubricated mandrels. The variable that influenced maximum reduction the most was deviation from sine-law thickness. Thus, if the spun section was thicker than that dictated by the sine law, the maximum reduction was less than when the thickness was less than the sine-law thickness. The difference in spinnability, however, was only a few per cent for a deviation from sine-law thickness of ±30%.

In comparing the values of maximum reduction in shear spinning with conventional mechanical properties of the metals used in the spinnability tests, it was found that the best correlation is with reduction of area in a tension-test specimen. Figure 20 shows such data and indicates a transition in the type of failure of spun parts (metals included those shown in Fig. 19). For metals with a true necking strain, ϵ_f, of 0.6 (corresponding to about 45% reduction of area) or greater in a tension-test specimen, the maximum shear-spinning reduction for one pass is about 80%. Further increase in the ductility of the metal does not appreciably increase this maximum spinning reduction. For metals with a true necking strain below 0.6, spinnability depends on ductility. In production spinning and in spinnability tests, the minimum included cone angle to which a metal can be shear spun from a flat blank in one pass is approximately 30°.

Spinnability of tubes is described on page 322. A setup for testing the spinnability of tubes is also shown.

Tube Spinning

Tube spinning, one of the major applications of the power spinning process, is described in the article beginning on page 317 in this volume.

Combination Processes

In some applications, two types of spinning can be used in combination with each other or in combination with other fabricating methods to produce a required shape. The following example describes a procedure for producing tank halves by using two types of spinning and machining.

Example 275. Aluminum Alloy Tank Halves Produced by Manual Spinning, Machining and Tube Spinning (Fig. 21)

Storage-tank halves were produced by first manually spinning a flat blank to the shape shown in Fig. 21(a), and then machining the workpiece as shown in Fig. 21(b). Next the workpiece (aluminum alloy 6061) was solution treated by heating to 970 F, water quenching, and aging at 70 F for 17 hr. It was then tube spun in two passes to reduce the wall thickness by approximately 66% (Fig. 21c). The end portion was heated to 600 F, and the flange was manually spun (Fig. 21d).

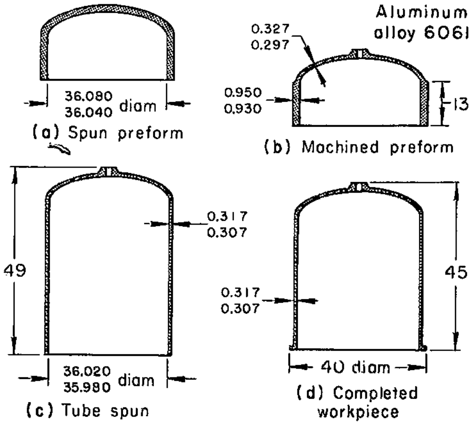


Fig. 21. Sequence of shapes in production of a tank half by manual spinning, machining and tube spinning (Example 275)

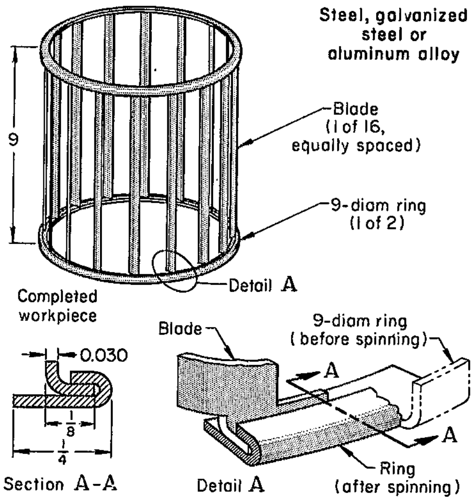


Fig. 22. Blower wheel that was assembled by spinning (Example 276)

Assembly by Spinning

Spinning is frequently employed for less conventional applications than those described earlier in this article and in the article on Tube Spinning, page 317. It is often the cheapest means of joining two or more parts to form an assembly. For instance, a tube can be inserted through a hole in a plate, and then the protruding end of the tube can be spun to secure it to the plate. Small parts are assembled by this technique with a special tool rotated by a drill press.

Assembly of components by spinning is not, however, restricted to small parts, as illustrated by the example that follows.

Example 276. Use of Spinning to Assemble a Blower Wheel (Fig. 22)

Spinning was used to assemble the blower wheel shown in Fig. 22. The 16 blades were picked up in order by a template, which held them in position for assembly into the end rings. The assembly was placed in a special spinning machine that had a 3-hp motor. As the assembly rotated, the flange on the end rings was spun over and flattened on the tabs of the blades (Fig. 22) by a guide-rail shoe. After both flanges were spun, the template was removed and used to collect blades for the next assembly. Assemblies were produced at a rate of 91 per hour.

Production of the blower-wheel blades is described in Example 103 in the article on Press Bending of Low-Carbon Steel.

Selected References

J. P. Vidosic, "Metal Forming and Forming Technology", Ronald Press Co., New York, 1964, 558 p. Chapter 10 (19 p) is an illustrated account of spin forming, written for students.

Erich G. Thomsen, Charles T. Yang, and Shiro Kobayashi, "Plastic Deformation in Metal Processing", Macmillan Co., New York; Collier-Macmillan Ltd., London (England); 1965; 486 p. Chapter 19 (23 p) analyzes mathematically the force components and the movements of material in spin forging, a form of spinning with high forces in which each element of sheet is substantially reduced in thickness by a squeezing operation, which avoids radial displacement. Tubes may be made by spin forging.

Richard L. Kegg, A New Method for Determination of Spinnability of Metals, *Journal of Engineering for Industry (Transactions ASME), Series B*, 83, 119 to 124 (May 1961). Maximum spinning reduction possible is determined by tests in a shear-spinning machine, using an ellipsoidal mandrel.

Serope Kalpakcioglu, On the Mechanics of Shear Spinning, *Journal of Engineering for Industry* (*Transactions ASME*), *Series B*, 83, 125 to 130 (May 1961). Flow of metal was studied by the grid-line technique.

Serope Kalpakcioglu, A Study of Shear-Spinnability of Metals, *Journal of Engineering for Industry (Transactions ASME), Series B*, 93, 478 to 484 (Nov 1961). An analysis of the flow of metal in shear spinning explains how overreduction may cause fracture and how back extrusion takes place. The minimum angle to which a metal may be shear-spun from a flat blank is about 15°.

S. Kobayashi, I. K. Hall, and E. G. Thomsen, A Theory of Shear Spinning of Cones, *Journal of Engineering for Industry (Transactions ASME), Series B*, 83, 485 to 495 (Nov 1961). Power-spinning forces as predicted by theory agree with those for aluminum and lead.

Other Examples of Spinning Applications in This Volume(a)

Type of spinning	Number of passes	Type of alloy	Example number
Stainless Steel			
Manual	4	305	476
Power	1	430	477
Heat-Resisting Alloys			
Power(b)	...	A-286	496
Tube(c)	3	A-286	497
Tube(d)	...	N-155	503
Refractory Metals			
Power	1	C-103	506
Power	3	Ta-10W	507
Power	1	Tungsten	508
Aluminum Alloy			
Power(e)	Multiple	6061-O	531
Beryllium			
Power(f)	...	Powder sheet(g)	572
Manual	2	Powder sheet(g)	573
Manual	9	Powder sheet(g)	574
Copper and Copper Alloys			
Manual(h)	...	Alloy 110	597
Manual(j)	...	Alloy 220	598
Magnesium Alloy			
Manual(k)	1	HK31-H24	608
Titanium Alloys			
Power(m)	1	Ti-6Al-4V	614
Power	1	Ti-13V-11Cr-3Al	615
Tube	2	Ti-13V-11Cr-3Al	616

(a) See also the section on Spinning, page 434, in the article "Forming of Nickel Alloys" in this volume. (b) Operation was changed from spinning to deep drawing. (c) Starting groove was machined. Flange was left on each end to avoid distortion. (d) Direction of grain circumferential to resist hoop stress.

(e) Hemisphere produced. (f) Sheet was sandwiched between two steel sheets. (g) Cross rolled. (h) Partly formed on mandrel; partly free formed. (j) Hourglass shape spun on a split mandrel. (k) Sizing operation on a welded preform. (m) Spun at room temperature. The same alloy, twice as thick, was spun at 800 F.