This invention relates to a new and improved method of spinning metal workpieces which enables more accurate and more consistent results to be achieved. It has not always been possible by the use of conventional or known spinning techniques to produce quantities of parts of uniform shape and size. This has been particularly true in the case of low angle cones or tubes having thin wall sections. Certain types of materials still further aggravate this problem and render it virtually impossible to spin the parts tight on the mandrel with conventional spinning methods.

The novel spinning method, which forms the subject matter of this invention, effectively overcomes this problem and enables these difficult shapes and materials to be spun tight against the mandrel thereby insuring dimensional accuracy of the finished parts. The new method involves offsetting or staggering the tool rings in the direction of the longitudinal axis of the mandrel so that one ring contacts the workpiece ahead of the other. At the same time, the tool rings are spaced at different distances from the mandrel, the leading ring being set out further than the trailing ring. Thus, the leading ring will perform a primary forming operation on the workpiece while the trailing ring will reduce the workpiece to its final, finished wall thickness and spin it tight against the mandrel. The amount of stagger required between the tool rings depends on the shape being formed and it has been found that a stagger or offset of from \( \frac{3}{4} \) to \( \frac{1}{2} \) of an inch is suitable for low angle cones, and that a stagger of from \( \frac{3}{4} \) to \( \frac{1}{2} \) of an inch is suitable for tubes. The difference between the leading and trailing rings is such that their spacing from the mandrel is concerned, varies with the finished thickness of the workpiece, becoming less as the thickness of the wall section decreases. For low angle cones or tubes having a finished wall thickness of 0.100 of an inch or less, it has been found that the difference in spacing between the leading and trailing rings from the mandrel, i.e., the amount of final reduction in thickness effected by the trailing or finishing ring, should preferably lie in the range of from 0.005 to 0.020 of an inch.

Accordingly, it is an object of the present invention to provide a new method of spinning a workpiece over a mandrel in which the tool rings are offset, or staggered, from one another along the axis of the mandrel. Another object of the invention is to provide a new spinning method employing staggered tool rings in which the leading ring is set out further from the mandrel than the trailing ring so that the latter ring effects a final reduction of the workpiece to its finished thickness. Another object of the invention is to provide a new spinning method whereby low angle cones and tubes may be spun tight against the mandrel thereby insuring that the finished parts will all be of the same shape and size.

With these and other objects in view, which will become apparent from the following description, the invention includes certain novel techniques, the essential elements of which are set forth in the appended claims. A suitable type of spinning machine for carrying out the novel method together with examples of work performed on the machine using the new process have been shown in the drawings and will be described in connection with the drawings which accompany and form a part of this specification.

In the drawings:

FIG. 1 is a plan view of a spinning machine which is suitable for carrying out the new method.

FIG. 2 is a hydraulic diagram of the spinning machine shown in FIG. 1.

FIG. 3 is an electrical diagram showing the synchro system used in connection with the spinning machine shown in FIGS. 1 and 2.

FIG. 4 is a diagrammatic view illustrating the new method of spinning.

FIGS. 5 to 10, inclusive, are cross-sectional views of typical parts which have been spun by the use of the new method.

Similar reference characters have been used to designate similar or identical elements and portions throughout the specification and throughout the different views of the drawings.

The machine hereinafter to be described is similar in many respects to the machine shown in the accompanying patent application of Charles Bierman, Jr., Serial No. 531,519, filed December 20, 1955, now U.S. Patent No. 2,960,951, granted November 22, 1960, to which reference may be had for a more detailed disclosure of the machine construction.

As shown in FIG. 1, the spinning machine includes a bed 15 on which are mounted tool units 16 and 17. Each unit is provided with a set of parallel ways 18 on which main slides 19 and 20 are supported and guided by means of corresponding way surfaces provided on the slides. Each of the slides 19 and 20 is provided with a set of parallel ways 22 disposed at right angles to the ways 18, the ways 22 serving to support and guide cross-slides 23 and 24 for rectilinear movement on the main slides. On the cross slides are pivotally mounted tool ring supports 25 and 26, respectively. Each support is pivoted at 27 on its associated cross slide and is bifurcated to receive a tool ring 28. Suitable means is provided for journaling each of the tool rings in the bifurcation provided in its associated support so that the rings are freely rotatable and thereby able to effect the desired rolling action on the workpiece (not shown). The tool ring supports 25 and 26 are provided with means for angularly adjusting the supports about their pivots 27 so as to set the tool rings at the proper angle with respect to the workpiece to be formed. This adjusting means includes a gear sector 29 formed on each of the supports the teeth of which mesh with corresponding teeth on spur gears 30 journaled in the cross slides. Suitable means is provided for manually rotating the spur gears to thereby adjust the angular positions of the tool ring supports. After the supports have been adjusted to the desired positions, clamping bolts 31 received within arcuate slots 32 formed in the supports 25 and 26 may be tightened to hold the supports in their adjusted positions.

Supported on the bed 15 between the units 16 and 17 is a headstock 35 provided with a spindle on which a face plate 36 is mounted. A mandrel 37 of suitable size...
and shape for the work to be performed, is bolted to the face plate 36 with its central axis in alignment with that of the headstock spindle. Thereby the mandrel may be rotated by a suitable motor (not shown) drivingly connected with the headstock spindle. The workpiece may be held against the end of the mandrel 37 by a tailstock spindle 38 which is contained in bearings 39 mounted on a tailstock 40. The tailstock is supported for sliding movement on ways 41 provided on a base 42 which is secured to the bed 15. Thus, the tailstock spindle 38 may be moved into position to clamp the workpiece against the end of the mandrel 37, or it may be moved away from the mandrel to permit the finished workpiece to be removed.

To provide for power movement of the main slides 19 and 20 along the ways 18, the supports 16 and 17 have attached thereto cylinders 45 and 46, respectively, which are fitted with pistons 47 and 48. The pistons are connected by rods 49 and 50 with the main slides 19 and 20. A similar provision is made for effecting power operation of the cross slides 23 and 24. For this purpose, the main slides each carry a cylinder 51 and 52 which, as shown diagrammatically in FIG. 2, are fitted with pistons 53 and 54 connected by piston rods 55 and 56 with the cross slides 23 and 24. Power operation of the tailstock along the ways 41 to effect clamping and unclamping of the workpiece on the mandrel is effected by a cylinder 59 (FIG. 2) which is fitted with a piston 57 connected by a piston rod 58 with the tailstock 40.

In order to cause the tool rings 28 to follow the contour of the mandrel 37 as the main slides are moved lengthwise therealong, a tracing mechanism is provided for controlling the flow of hydraulic fluid to and from the cross slide cylinders 51 and 52. This control is effected by servo valves 63 and 64 which are operated by operating template 67 and 68, respectively. The templates are supported in fixed relation with respect to the mandrel 37 by horizontal rails 69 which are supported at their ends on posts 70 attached to the supports 16 and 17. The servo valves 63 and 64 are supported on brackets 71 and 72 carried by the cross slides 23 and 24, respectively. The brackets are adjustable on the brackets toward and from the templates 67 and 68 by handwheels 73 and 74 which operate feed screws connected with nuts secured to the valve casings. Thus, a predetermined spacing of the tool rings 28 from the surface of the mandrel 37 may be effected by suitable adjustment of the tracing fingers 65 and 66 toward end from the templates by the handwheels 73 and 74.

The hydraulic circuit of the spinning machine is shown in FIG. 2 of the drawings. As herein shown there is provided a hydraulic pump 89 which is arranged to be driven by any suitable source of power such as an electric motor (not shown). The pump withdraws hydraulic fluid from the tank or reservoir 81 and delivers it at a predetermined pressure, as determined by the setting of a relief valve 82, to a pressure line 83. Fluid is returned to the reservoir 81 by means of an exhaust line 84. Movement of the main slide 19 is controlled by a solenoid valve 85 containing a spool 86 which is normally biased to a neutral position as shown in FIG. 2. When solenoid SOL-1 is energized by depression of a push button or other suitable control means (not shown), the spool 86 is moved toward the right thereby connecting the pressure line 83 to the main line 87. The main line 87 is connected through the exhaust line 84. At the same time, a motor line 88 connected with the top of the cylinder 45 will be connected through a throttle valve 89 and the valve 85 with the exhaust line 84. Thereby, the main slide 19 will be moved upwardly as shown in FIG. 2, or to the right as viewed, by way of the setting of the throttle valve 89. After the part has been spun, the main slide may be returned to its starting position by deenergizing solenoid SOL-1 and energizing solenoid SOL-2 thereby shifting the spool 86 to the left. This connects the motor line 88 to the pressure line 83 through a check valve 90 which now opens and bypasses throttle valve 89 thereby permitting unrestricted flow of fluid into the upper end of the cylinder 45. At the same time, the motor line 87 will be connected to the exhaust line 84 thereby permitting fluid from the lower end of the cylinder to be voided in a housing 39. When both solenoids are deenergized, the valve will be in its centered position in which the motor lines are blocked so as to maintain the main slide in a position of rest.

Movement of the tailstock 40 is similarly controlled by a solenoid operated valve 55. This valve is fitted with a spool 56 which is normally maintained in a centered position by suitable biasing means. When it is desired to clamp a workpiece against the end of the mandrel, the solenoid SOL-3 is energized thereby moving the spool 56 to the right so as to connect a motor line 97 with the pressure line 83. This causes fluid under pressure to be admitted to the lower end of the cylinder 59 thereby moving the tailstock 40 toward the mandrel. When it is desired to remove the finished workpiece after the spinning operation is completed, solenoid SOL-4 is energized so as to connect a motor line 98 with the pressure line 83 thereby introducing pressure into the upper end of the cylinder 59.

As mentioned earlier herein, the servo valves 63 and 64 control the flow of fluid to and from the cross slide cylinders 51 and 52 so as to cause the tool rings to follow the contour of the mandrel. As shown in FIG. 2, the servo valve 63 is fitted with a spool 103 to which the tracing fingers 65 and 66 are connected. The spool is normally urged by a spring 104 toward the left, as viewed in FIG. 2, so as to press the finger into engagement with the edge of the template 67. During a spinning operation, the main slide 19 moves upwardly as viewed in FIG. 2 thereby causing the spool 103 and tracing fingers 65 and 66 to move upwardly with respect to the template 67. The rise on the template causes the spool 103 to be moved toward the right thereby connecting a motor line 105 with the pressure line 83 to move the cross slide 23 toward the right. At the same time, a motor line 106 will be connected by the spool 106 with a predetermined spacing between the ring and the mandrel as determined by the setting of the handwheel 73. To retract the cross slide at the end of the spinning operation and prior to the return stroke of the main slide, it is only necessary to bias the spool 103 to the right against the urgency of spring 104 by any suitable means whereby the cross slide 23 will likewise be moved to the right. The main slide may then be returned to the position shown in FIG. 1. After the finished workpiece has been removed and a new one inserted, the spool 103 may be released whereupon the spring 104 will urge the spool to the left thereby connecting pressure from the line 83 to the right hand end of the cylinder and exhausting the left hand end of the cylinder. Thereby, the cross slide 23 will be moved toward the mandrel and such movement will continue until the tracing finger 65 engages the template 67 to again center the spool 103 within the motor line 87. The spool 103 will then be further inwardly moved of the cross slide. Spinning of the workpiece is then initiated by energizing solenoid SOL-1 to cause the main slide to move the tool ring against the workpiece as it is revolved with the mandrel 37 whereupon the workpiece will be rolled into contact with the mandrel.

The servo valve 64, like the valve 63, is fitted with a spool 108 which is urged to the right by a spring 109 so as to move the tracing finger 66 into contact with the edge of the template 68. The spool 108 controls the flow of hydraulic fluid to and from the cylinder 52.
through motor lines 110 and 111 in the manner previously described in connection with the valve 63 so as to cause the cross slide 24 and the tool ring 28 associated therewith to follow the contour of mandrel 37 but with a fixed spacing from it as determined by the setting of the handwheel 74.

In the present machine, provision is made for causing the main slide 20 to follow the movement of the main slide 19 through a synchro tie provided between the slides. For this purpose the slide 19 carries a ball nut 115 (FIG. 2) which cooperates with a ball screw 116 which drives a synchro transmitter TDX. As shown in FIG. 3, the differential synchro transmitter is connected with a synchro differential transmitter TDX which in turn is connected with a control transformer CT. The output of the control transformer is applied to a servo-amplifier which controls the differential energization of torque coils TC-1 and TC-2 which, in turn, control the positioning of a spool 117 of an electro hydraulic servo valve 118. This valve controls the flow of pressure fluid from the line 83 to the cylinder 46 for the main slide 20 through motor lines 119 and 120. The main slide 20 is also fitted with a ball nut 121 which drives a ball screw 122 and is connected to the armature of the control transformer CT. Thus, as the main slide 19 is caused to advance along the mandrel under the control of the solenoid valve 85 and the throttle valve 89, the main slide 20 will be caused to move in synchronism therewith through error signals produced by the control transformer and amplified by the servo-amplifier to energize torque coils TC-1 and TC-2 and thereby bias the valve 118 as required to reduce the error signal to zero and maintain synchronism. Any desired degree of offset between the main slide 19 and the main slide 20 may be effected by a dial 121' connected with the rotor shaft of the synchro differential transmitter TDX. Thus, the amount of stagger between the tool rings may be preset by means of the dial 121', or the stagger may be progressively varied during the spinning operation by suitable manipulation of the dial.

When starting with a flat blank, it is desirable to have the tool rings contact the blank at the same instant and remain together until the piece has been formed around the end of the mandrel. Hence, the dial 121 may be set for zero stagger at the start and then adjusted to provide the desired amount of stagger as the operation proceeds.

The principle of my novel spinning method employing offset or staggered tool rings is illustrated in FIG. 4 and the drawings. As therein shown, a workpiece 125 is clamped to the end of mandrel 37 by the tailstock spindle 38 and is being rolled to the form of the mandrel by a leading tool ring 126 and a trailing tool ring 127. As indicated in the figure, this original thickness of the workpiece, or preform, corresponds to the dimension P which thickness is reduced by the leading tool ring 126 to a thickness R. The stagger between the tool rings 126 and 127 is indicated by the dimension S and the finished thickness of the workpiece, i.e., the spacing between the finishing tool ring 127 and the surface of the mandrel 37, is indicated by the dimension T. The final form of the finished workpiece is indicated by the dot-dash outline 128. The finished workpiece may be trimmed along the lines X and Y to provide a part of prescribed length as indicated by the dimension L. Likewise, the diameter of the tool, indicated by the dimension T, and the diameter of the bottom of the workpiece, indicated by the dimension B, will both correspond to the specifications for the finished part provided the workpiece fits snugly against the mandrel when finished. The purpose of the present invention is to provide a new method of spinning which will insure a tight fit of the part on the mandrel when finished.

The tool rings 126 and 127 may be carried by cross slides 23 and 24, respectively, though it may be found preferable to associate the tool ring 126 with the cross slide 24 and the tool ring 127 with the cross slide 23 since the latter cross slide is carried by the main slide 19 which is the master slide insofar as the synchro system is concerned. Therefore, since the ring 127 is the finishing tool ring, slightly better results may be obtained if the tool ring 126 is carried by the cross slide 24 since the latter cross slide is carried by the main slide 19.

In FIGS. 5 to 11, inclusive, are shown six specific examples of work which have been performed using the novel spinning technique disclosed herein. In each of these examples, which will hereinafter be described in detail, the parts were spun on a machine of the type hereinbefore described in connection with FIGS. 1 and 3 of the drawings.

**Example 1 (FIG. 5)**

A part 130 having a finished shape as shown in FIG. 5 was spun from a preform 131 having the shape shown in dot-dash outline in FIG. 5. The material used in making this part was 6061 aluminum which was solution heat treated prior to spinning. The preform had a wall thickness P of 0.080 of an inch which was reduced to a finished thickness F of 0.040 of an inch in the final spin. The stagger S between the tool rings used for the final spin was ¼ of an inch, plus or minus ¼ of an inch, and was maintained constant throughout the length of the part. The leading tool ring was set out for 0.010 of an inch thicker wall section than the trailing ring. In other words, \( R = F = 0.010 \) of an inch. The length L of the finished part after being trimmed along the lines X and Y, as indicated in FIG. 5, was approximately 33 inches and the outside diameters T and B were approximately 4 and 12 inches, respectively.

**Example 2 (FIG. 6)**

A part 132 having a finished shape as shown in FIG. 6 was spun from a preform 133 having a shape as shown in dot-dash outline in FIG. 6. The material used in making this part was 6061 aluminum which was solution heat treated prior to spinning. The preform had a wall thickness P of 0.165 inch which was reduced to a finished thickness F of 0.081 inch in the final spin. A constant stagger S of ¼ plus or minus ¼ of an inch was used in producing the finished part from the preform. The leading tool ring was set out for 0.010 of an inch thicker wall section than the trailing ring. In other words, \( R = F = 0.010 \) of an inch. The length L of the finished part after being trimmed along the lines X and Y, as indicated in FIG. 6, was approximately 9½ inches and the outside diameters T and B were 1½ and 5½ inches, respectively.

**Example 3 (FIG. 7)**

A part 134 having a finished shape as shown in FIG. 7 was spun from a preform 135 having the shape shown in dot-dash outline. The material used in making this part was 6061 aluminum which was solution treated prior to spinning. The preform had a wall thickness P of 0.165 inch which was reduced to a finished thickness F of 0.081 inch in the final spin. A constant stagger S of ¼ plus or minus ¼ of an inch was used in producing the finished part from the preform. The leading tool ring was set out for 0.010 of an inch thicker wall section than the trailing ring. In other words, \( R = F = 0.010 \) of an inch. The length L of the finished part after being trimmed along the lines X and Y, as indicated in FIG. 7, was approximately 24 inches and the outside diameters T and B were approximately 6 and 12 inches, respectively.

**Example 4 (FIG. 8)**

A part 136 having a finished shape as shown in FIG. 8 was spun from a preform 137 having the shape shown in dot-dash outline in this figure. The material used in making this part was 6061 aluminum which was solution heat treated prior to spinning. The preform had a wall thickness P of 0.204 inch which was reduced to a finished...
wall thickness F of 0.095 inch in the final spin. A constant stagger S of \(\frac{1}{8}''\) plus or minus \(\frac{3}{16}\) of an inch was used in producing the finished part from the preform. The leading tool ring was set out for a 0.013 of an inch thicker wall section than the trailing ring. In other words, \(R - F = 0.013\) of an inch. The length L of the finished part after being trimmed on the line Y as indicated in FIG. 8 was approximately 3.5 inches and the outside diameters T and B were approximately 6 and 16 inches, respectively.

**Example 5 (FIG. 9)**

A part 138 having a finished shape as shown in FIG. 9 was spun from a preform 139 having the shape shown in dot-dash outline in this figure. The material used in making this part was 321 stainless steel. The preform had a wall thickness P of 0.172 inch which was reduced in the final spin to a finished thickness F of 0.065 inch over the major portion of the part except for the bottom portion 140 where it was 0.156 inch. The stagger S of the tool ring used in producing the finished part from the preform was maintained constant at \(\frac{1}{8}''\) plus or minus \(\frac{3}{16}\) of an inch toward the leading tool ring was set out for an 0.011 of an inch thicker wall section than the trailing ring. In other words, \(R - F = 0.011\) of an inch. The length L of the finished part after being trimmed on the line Y as indicated in FIG. 9 was approximately 24 inches and the outside diameters T and B were approximately 6 and 12 inches, respectively.

**Example 6 (FIG. 10)**

A part 141 having a finished tubular shape as shown in FIG. 10 was spun from a tubular preform 142 having the shape shown in dot-dash outline in this figure. The material used in making this part was 6061 aluminum which was solution heat treated before spinning. The preform had a wall thickness P of 0.250 inch which was reduced in four spin passes to a finished thickness F of 0.081 inch over all but the left hand end of the part where a flange 143 was formed by the stock provided on the preform. The part was reduced in thickness by approximately 0.040 of an inch on each spin pass. A stepped type tool ring 144 was employed in spinning the tube and the stagger S of the tool rings used in producing the finished part from the preform was maintained constant at \(\frac{1}{2}''\) inch. The leading tool ring was set for a 0.010 of an inch thicker wall section than the trailing ring. In other words, \(R - F = 0.010\) of an inch. The length L of the finished part after being trimmed along the line Y as shown in FIG. 10 was approximately 28 inches and the outside diameter of the tube was approximately 12 inches.

In the performance of the work exemplified by the foregoing examples, it was found that for the best results in spinning low angle cones, the stagger should preferably lie between \(\frac{3}{16}\) and \(\frac{3}{8}\) of an inch. Experience with these particular jobs showed that any stagger smaller than \(\frac{3}{8}\) of an inch would not yield the benefits sought to be obtained by the new method while any stagger exceeding \(\frac{3}{16}\) of an inch would be apt to cause buckling of the material between the tool rings or backward extrusion of the material back to the part becoming tight on the mandrel ahead of the trailing tool ring. An exception to this exists in the case of a straight tube or cylinder where it was found that the stagger could be increased to as much as \(\frac{1}{2}\) inch with good results. In this situation, however, since the diameter of the mandrel is out of the part becoming tight on the mandrel due to the forward extrusion of the material does not exist and consequently greater staggering may be used than in the case of low angle cones.

In using the staggered tool ring method of spinning, it is essential that the leading tool ring shall effect the major portion of the desired reduction in thickness of the part and that the trailing tool ring shall merely wipe the part tightly against the mandrel. In the examples set forth herein, where the final thickness of the part was less than 0.100 of an inch, it was found that this final reduction by the trailing ring was desirable within the range of from 0.005 to 0.020 of an inch. Any reduction smaller than 0.005 of an inch is apt to produce inconsistent results while any reduction greater than 0.020 of an inch is apt to cause either buckling of the work between the tool rings or backward extrusion of the material back to the part becoming tight on the mandrel ahead of the trailing tool ring. In the foregoing examples, it was found that for the best results in spinning low angle cones, the stagger should preferably lie between \(\frac{3}{16}\) and \(\frac{3}{8}\) of an inch. Experience with these particular jobs showed that any stagger smaller than \(\frac{3}{8}\) of an inch would not yield the benefits sought to be obtained by the new method while any stagger exceeding \(\frac{3}{16}\) of an inch would be apt to cause buckling of the material between the tool rings or backward extrusion of the material back to the part becoming tight on the mandrel ahead of the trailing tool ring. An exception to this exists in the case of a straight tube or cylinder where it was found that the stagger could be increased to as much as \(\frac{1}{2}\) inch with good results. In this situation, however, since the diameter of the mandrel is out of the part becoming tight on the mandrel due to the forward extrusion of the material does not exist and consequently greater staggering may be used than in the case of low angle cones.

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tool ring and from 0.005 to 0.020 of an inch closer to the mandrel than the first tool ring to thereby effect a further reduction in the thickness of the workpiece and to spin it tight on the mandrel.

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