SPINNING AND FLOW FORMING PROCESSES IN MANUFACTURING INDUSTRIES: A REVIEW

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Abstract - Over the last many years, spinning and flow forming have gradually matured as metal forming processes for the production of engineering components in small to medium batch quantities. Combined spinning and flow forming techniques are being utilized increasingly due to the great flexibility provided for producing complicated parts nearer to net shape, enabling customers to optimize designs and reduce weight and cost. It offers remarkable utilization of metal, high strength high precision rotationally symmetric components with very high specific strength, excellent surface finish and close dimensional tolerances within the envelope of reasonable economics the ever-increasing strength demands of automotive industries, defense and aerospace sectors have given considerable impetus to research work in this area. In this paper, process of spinning and flow forming are introduced. The state of the art is described and developments in terms of research and industrial applications are reviewed. Also, the direction of research and development for future industrial applications are indicated to this end, it is the intent of the authors to provide the readers with an accurate overview on the main scientific approaches proposed by researchers and scientists working in this specific area. The research works description represents the main part of this literature review.

Key words - Spinning, flow forming, flexibility, incremental forming.

I. INTRODUCTION

Metal spinning is one of the oldest conventional methods of chip less forming, but over the last many years, many new process has been emerged other forming process such as deep drawing and ironing. However, due to the inherent advantages and flexibility of the process such as simple tooling and low forming loads, plus the rapid emerging trend in modern industries towards cylindrical shape manufacturing product of thin sectioned lightweight parts. In addition, spinning is also known to produce components with high mechanical properties and smooth surface finish. It has been suggested that the process of metal spinning emerged from the art of potting clay using a manual-powered potter wheel by the Pharaohs in ancient Egypt. At the beginning of the 20th century, spinning was considered an art rather than science, as it required operators with considerable experience and skill. As a result, spinning was employed mainly to produce domestic products such as saucepans and cooking pots. On a simple lathe-like machine where repeatability in dimensional tolerances is not very critical. Though labor cost is elevated due to the skilled operators required, this is off-set considerably by the low tool cost later in the mid 20th century, thicker sheets were required to be spun to components of higher dimensional accuracy. This led to the emergence of new designs and variations in terms of higher power and automation of spinning machines. One of the driving forces behind this development was from the aircraft and aerospace industries. Typical components produced by mechanically powered spinning machines are components for gas turbine engine, rocket nose cones and dish aerials. It is also because of the incorporation of hydraulic power and automation that the flow forming technique has evolved, to meet further demands of originals equipment manufacturing industries The ability to enable metal to flow in complicated paths using simple tools not only eliminates multi-production stages on presses, thus reducing costs, but also offers the potential for the production of lightweight, net shape parts. This paper begins by describing process details of spinning and flow forming and follows by outlining developments in machine tools. In addition, research carried out in the area of these manufacturing processes is reviewed. Finally, based on current trends, the future directions of research in this area are discussed.

II. SPINING AND FLOW FORMING PROCESSES: A REVIEW

2.1. spinning, shear forming and flow forming processes

This paper explained about spinning and flow forming processes. Spinning is commonly known as a process for transforming flat sheet metal blanks, usually with axis symmetric profiles, into hollow shapes by a tool which forces a blank onto a mandrel. The blanks are clamped rigidly against the mandrel by means of a tailstock and the shape of the mandrel bears the final profile of the desired product. During the process, both the mandrel and blank are rotated while the spinning changes in its shape according to the profile of the mandrel. As the tool is applied locally on the work piece, the total forming forces are reduced significantly compared to conventional press forming. This not only increases the possibilities in terms of large reductions and change in shape with less complex tooling, but also reduces the required load capacity and cost of the forming machine.

2.2. Spinning process details

Spinning, in conventional terms, is defined as a process whereby the diameter of the blank is deliberately reduced either over the whole length or in defined areas. The paper is structured as follows. Firstly, the international state of the art on the scientific approaches addressing the ergonomic workstation design is proposed. Note that the state of the art description is splitted into two different subsections: the first subsection presents the research works related to the approach based on the direct analysis of the real workstations, while the second one describes the research studies that use computerized models to design workstations ergonomically. Then, some gaps are identified and ongoing research solutions are presented together with some application examples in

Different manufacturing areas

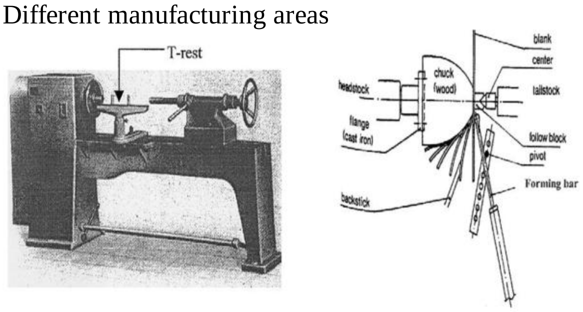

Fig.1: Traditional type spinning lathe with T-rest

2.2.Process variables

Although conventional spinning is different from shear and flow forming in terms of deformation characteristics, the set of process variables governing conventional spinning also determines the qualities of a shear or flow formed product. There are numerous process variables that contribute to the successful production of a spun product. Some of the more significant process variables and their effects on conventional spinning, investigated by other researchers, are discussed below.

(i) Feed ratio:

Feed ratio is defined as the ratio of the roller feed rate to the spindle speed. As long as the feed ratio remains constant, the roller feed and the spindle speed can be changed without any significant effect on the quality of the product. Maintaining an acceptable feed ratio is vital as high feed ratios generate higher forces that may lead to cracking. In contrast, too low a feed ratio will cause excessive material flow in an outward direction, which unnecessarily reduces work-ability and unduly thins the wall. An increase of spindle speed would lead to two effects. One is an increased magnitude of spinning force due to the high deformation rate; the other is that the deformation energy required per revolution is likely to decrease because the feed rate is inversely proportional to the spindle speed (mm/rev).

(ii) Roller path:

The roller path is particularly important in affecting the quality of a spun part. Different roller paths such as linear, concave, convex, involutes and quadratic relative to the work piece have an influence on the deformation of the blank. The tendency to buckle and cause wrinkles as well as cracking can be avoided by introducing the correct roller path. A concave roller path is the most widely used one in conventional spinning. The thinning rate in designing a roller path for the first-pass should be taken into account as it plays a decisive role in the final wall thickness. The stress and strain distribution of the first-pass of conventional spinning with different roller paths, namely linear, involutes and quadratic, to convert the shape of the blank to that of the mandrel. They reported that both the radial and the tangential stress and strain are the smallest for the involutes curve. They concluded that a comparison of the distribution of stresses and strains under the three different paths could provide a theoretical basis for selecting a suitable roller path in conventional spinning.

(iii) Roller design

The design of the roller needs to be considered carefully as it can affect the component shape, wall thickness and dimensional accuracy. Although roller diameter has little effect on the final product quality, too small a roller nose radius will lead to higher stress and ultimately lead to poor thickness uniformity.

(iv)Spinning ratio

Spinning ratio is defined as the ratio of blank diameter to mandrel diameter. The higher the spinning ratio, the more difficult is the spinning process. If the spinning ratio is too large, the remaining material cross section is no longer able to transmit the very high radial tensile stresses generated in the wall. This will lead to circumferential splitting along the transition from the flange to the wall. On the other hand, the spinning ratio is at its upper limit when the wrinkling in the flange becomes so large that subsequent passes of the tool cannot remove them

2.3. Flow forming process details

Flow forming, also known as tube spinning, is one of the techniques closely allied to shear forming. In this process, the metal is displaced axially along a mandrel, while the internal diameter remains constant. It is usually employed to produce cylindrical components Most modern flow forming machines employ two or three rollers and their design is more complex compared to that of spinning and shear forming machines. The starting blank can be in the form of a sleeve or cup. Blanks can be produced by spinning, deep drawing or forging plus machining to improve the dimensional accuracy. Advantages such as an increase in hardness

2.4. Process variables

(i) Power and forces:

For the past few decades, several researchers have undertaken theoretical analyses of power and force in tube spinning. The plastic flow mechanism of tubes involving the use of grid-line analysis for each individual working condition and constant. The effective strains and roller forces were then calculated using the plastic work deformation by assuming that the strain path during deformation is linear and the strain components in three principal directions can be evaluated from the total displacement after deformation. They reported that the values of axial, radial and tangential force show good agreement with the experimental results for commercially pure copper.

(ii) Feed rate:

Using the basis of minimizing the resultant spinning force, concluded that the optimal angle of attack decreases with increasing roller diameter and friction factor, but increases with larger feed rate, reduction and initial thickness of the tube wall. When high feed rates are employed, defects such as non-uniform thickness, reduction in diameter as well as a rough surface will result If the feed rate exceeds a certain limit, it can spoil the surface finish and produce thread-like serrations on the tube. It is concluded that among the process variables considered, nose radius, roller angle and feed, only feed rate had a significant influence on spinnability.

2.5. Combined spinning and flow forming

In recent years, a technique of combined spinning and flow forming has been employed extensively to produce parts with complicated geometries. Nowadays, the choice of production is no longer dictated by batch sizes and tooling costs. Manufacturers, especially in the automotive industries, are designing complex components to optimize car designs and are looking at the fastest way to produce complex shapes, i.e. producing complex components in one single cycle, as secondary processes are to be avoided if possible. One of the examples of adopting the combined method is the forming of aluminum wheels. he automotive market for vehicle wheels is still predominantly dominated by w lded steel structures and the search of a light weight alloy to substitute for steel wheels has led to a number of designs from North America and Japan. The interest in Europe on a one-piece wheel saw the development of a combination of splitting spinning and flow forming to produce the internal nave and rim of an alloy wheel from rolled plate .Typically, the material is an aluminum alloy, AIMg2Mn0.8 (A5351).

2.6. Conclusion

In this paper, the principles and developments of spinning and flow forming have been reviewed. It can be seen that although spinning and flow forming can be a very complicated process in terms of deformation characteristics, they have a great potential in the development, for the manufacture of complex shapes which are being required in increasing numbers by global manufacturing industries. Future prospects for these techniques should see research directed to the manufacturing of parts with even greater complex geometries with higher accuracy and improved performance. Of particular interest are single components consisting of different cross sections with flanges, sidewalls and undercuts.

2.7. Metal forming: an analysis of spinning processes

This paper analyses a simple experimental shape produced by spinning. The chosen form was spun using a variety of different diameter blanks. The theoretical strains are considered under two idealized models. The first is a spinning process that leaves the thickness unaltered and the second a process of pure shear forming where the hoop strain is zero. With shear forming or spin forging, the radial position of any element is unaltered. Conversely, when the radial position of any element changes significantly, it is termed conventional spinning and the objective is to maintain an unchanged wall thickness from blank to finished workpiece.

The nature of multi-pass spinning, Consider the flange after each pass, there is reduction in the outside radius implying circumferential or hoop compressive strains and radial tensile strains. It is assumed that the sheet thickness is constant. In the forming action, the hoop strain εh is compressive, the radial strain εr is tensile (i.e. the strain lying in a plane tangent to the sheet in a direction away from the axis of rotation) and that the thickness strain εz is zero.

2.8 Shape chosen for experimental work:
A simple shape was chosen to provide a variety of forming conditions. The shape consisted of final diameter 100 mm with central section consisting of a spherical surface of radius 95 mm with a blend radius between the cylindrical and the spherical sections of 17 mm. It is a similar shape to that used in an investigation of working forces in conventional spinning. A steel former to these dimensions was used but with the addition of a 20 mm central flat to allow the tailstock to clamp the blank against the former. The strains involved in producing this part can be considered in terms of the two theoretical processes: (1) shear forming, (2) constant thickness deformation`

2.9. Shear forming
In shear forming we can consider an element any distance Rn from the spinning axis. In the case of the chosen profile the shape that the element takes in the formed part is determined by its position on the sphere or fillet radius. If α is the angle that the surface normal of this element makes with the spinning axis and t is the thickness of the blank then the thickness of the part after shear forming is t $\cos\alpha$. While shear forming the radial position of each part remains unchanged, i.e. the normal distance Rn from the axis of spinning is unchanged. It follows that the circumference of any circular element $2\pi Rn$ is also unchanged. If the circumference of any element is unchanged then the hoop strain εh is zero. If volume constancy is now considered it is apparent that there must be a strain in a direction perpendicular to the thickness strain. As εh is zero this strain must be in a radial direction so let $d\varepsilon r$ denote this strain. The change in thickness is t cos α-t and so the thickness strain εt is given by (t $\cos\alpha$-t)/t or $\cos\alpha$-1 when simplified. Volume constancy tells us that $(1+\varepsilon r)(1+\varepsilon t)(1+\varepsilon h)=1$ for engineering strains but since $\varepsilon h=0$ we can write that$(1+\varepsilon r)(1+\varepsilon t)=1$ and substituting for εt we can write that $(1+\varepsilon r)(1+(\cos\alpha-1))=1$ and so we can solve for εr and we find that the corresponding perpendicular strain from volume constancy is $\varepsilon r=(1/\cos\alpha)-1$.

2.10. Constant thickness forming
In order to evaluate the strains involved consider any arbitrary portion of the blank of radius r then the volume of this portion of the blank is $\pi r^2 t$, where t is the thickness of the blank. Next consider the portion of the final shape that is formed by this volume of metal. Its volume is given by $2/3\pi\ ((R+t)^3-R^3)(1-\cos\varphi)$, where φ is the cone angle and R is the radius of the spherical part of the required shape, i.e.95 mm. Since the volume of this arbitrary part is known. The circumferential or hoop strain can now be considered. The original circumference is $2\pi r$, the new circumference is $2\pi R$ sin f so the hoop strain is $(2\pi R \sin\varphi-2\pi r)/2\pi r$ or $(R \sin\varphi-r)/r$. This is valid only for the spherical part of the worked shape, however, the strain for the part of the worked shape with radius 17 mm between the spherical and cylindrical sections can be evaluated in a similar way by considering the geometry involved. This part is toroidal in shape where RT and rT are the determining radii. For the chosen part these have values of (95-17) sin $\varphi 1$ and 17, respectively, where $\varphi 1$ is the limiting angle for the spherical portion of the part.

2.11. Experimental work:
As previously described a spherical shape of radius 95 mm blending via a 17 mm radius into a 100 mm diameter cylinder was used for these experiments. A mild steel former having these dimensions was used. The lathe was powered by a 250 W motor, which drove the spindle at 450 rev min^{-1}. The lathe itself was a manual lathe intended for hand turning of soft materials (wood). The tool rest was adapted to provide a pivoting support for the spinning tool Rollers of mild steel and nylon66 were used and the latter gave better results in that there was less tendency to groove the work piece and it was therefore easier to achieve a uniform result. Strain measurements were obtained from a pattern of circles of known size etched onto the blanks before spinning and measuring the size of these after spinning. The measurements were made using a Baty R400 optical projector. A variety of different diameter blanks was used. The part was spun from a blank of 136 mm. The angle was too strong to allow the part to be easily formed. However, parts spun from smaller blanks presented no difficulty in being deformed to a fully spun condition but they did not extend around all of the 17 mm radius to the cylindrical part where some difficulty might be expected. A size of

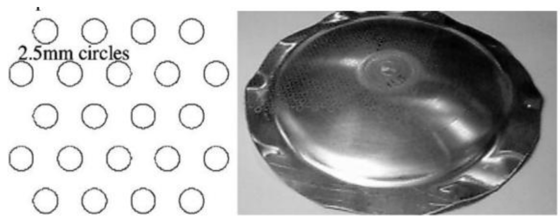

Fig. The pattern used and an etched part.

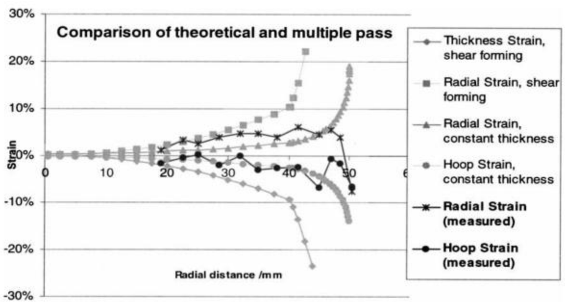

Fig. Graph of strains arising after a multi-pass spinning operatio

115 mm diameter was chosen for further investigation. Two specific conditions of spun part were examined. The first being a single pass spinning operation on a 115 mm diameter blank, and the second a fully formed part produced from the same size blank. Fig. Shows the profiles achieved for each component.

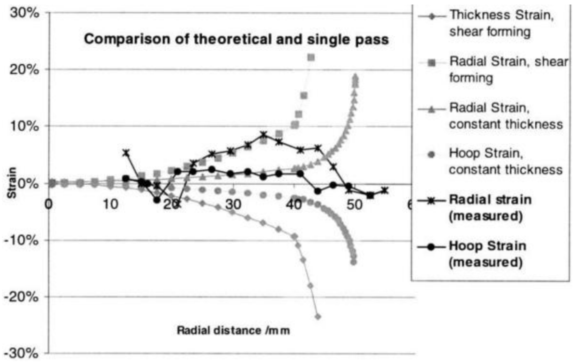

Fig. Graph of strains arising from a single pass.

It can be seen that both hoop and radial strains are positive, i.e. there is both axial and radial stretching. However, the radial strain is significantly larger than the hoop strain and in fact it follows the theoretical shear forming radial strain curve along its middle section, i.e. at radial distances between 20 and 35 mm. This suggests that the first pass in a conventional spinning operation is very much a shear forming process. Compressive strains in the hoop direction are developed in subsequent passes

Rationale for multi-pass spinning:
It can be observed that there are a number of distinct stages in the production of a part using multi-pass spinning. The first stage is when the roller comes into contact with the spinning disc or blank the disc is bent elastically as a cantilever. This is the approach stage of the first pass and (The roller was brought into contact with a non-rotating blank) the second stage creates the initial doming of the blank. It can be considered that the bending has reached the plastic limit and so a permanent deflection of the blank from its original flat stage is achieved as it is rotated under the action of a traversing roller. In fact there are two different mechanisms of plastic deflection. On the outer part of the blank the mechanism is the bending, deforming of the dome can now take place by a series of roller passes. While this is a useful insight into what happens during the spinning process it is still very much a three-dimensional problem. he work piece is being held by the tailstock and ultimately working forces have to be carried through this clamped area, when the work piece is touching the former and transmitting roller forces directly to the formers a thorough practical guide to spinning and the various process parameters involved. Means of optimizing parameters such as processing time, accuracy of size shape and surface finish are well developed.

CONCLUSION

(i) Calculations show that for conventional spinning the strains involved are much less than for shear forming.
(ii) Experiments show that there is some degree of shear forming involved in the first roller pass of conventional spinning.
(iii) Further modeling of the deformation modes and associated regions of plastic strain could usefully complement an approach to the problem using the finite element method where a relatively large overhead in computing time is involved in modeling incremental forming processes.

FINAL CONCLUSION

The main objective of the paper is to present a literature review concerning the spinning and flow forming. In this paper, the principles and developments of spinning and flow forming have been reviewed. It can be seen that although spinning and flow forming can be a very complicated process in terms of deformation characteristics, they have a great potential in the development, for the manufacture of complex shapes which are being required in increasing numbers by global manufacturing industries. The research may be directed to manufacture parts with higher accuracy, improved performance for greater complex geometries, asymmetric parts. In recent years, a technique of combined spinning and flow forming has been developed to produce parts with complicated geometries. Further investigation in characterization of roller-induced defects created during high-strain flow forming, establish a distinct crisscrossed fibrous structure in the pipe material, hard to work materials and different materials that can be flow formed are to be conducted. Finally, the literature review is completed with a brief description of ongoing research activities that give a significant contribution to the actual state of the art. To this end different application examples in different manufacturing areas are briefly presented and discussed.

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