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Metal Spinning- Design Consideration and parameter of spinning process and its terminology

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***Abstract* - Metal spinning is one of the oldest methods of chip-less formation. Spinning have gradually matured as metal forming process for the production of engineering component in small to medium batch quantities. Spinning being utilised increasingly due to great flexibility for producing complicated parts never to net shape and reduce weight and cost. In this paper classification, types of spinning, spinning terminology, design parameter and its consideration are introduced.**

***Keywords* - Types and classification of Metal spinning, spinning terminology, work piece parameter, tolling parameter, process parameters**

I. INTRODUCTION

Metal spinning is one of the oldest method of chip-less formation. Metal spinning is the technique to produce axisymmetrical part or component over rotating mandrel with the help of rigid tool known as roller .During the process both the mandrel and blank rotated while the spinning tool contract the blank and progressively induce a change according to the profile of the mandrel. Spinning process help to produce a lightweight component. The component of metal spinning are cylinders, drums, Domes, hemispheres, cones, cups etc. as shown in Figure.1 .These component are used for domestic purpose, aerospace application , automobile application etc. Over the last few decades, sheet metal spinning has developed significantly and spun products have been widely used in various industries. This method has been developed to reduce the material deformation and wrinkling failure of the spinning process. By using these techniques in the process design, the time and materials wasted by using the trial-and-error could be decreased significantly. In addition, it may provide a practical approach of standardised operation for the spinning industry and thus improve the product quality, process repeatability and production efficiency[1].

Fig.1. Spinning Component

II. SPINNING CLASSIFICATION AND PROCESS FEATURES[2]

The term metal spinning refers to a group of three processes: conventional spinning, shear spinning and tube spinning. A common feature of the three processes is that they allow production of hollow, rotationally symmetric parts. The main difference between the three is apparent in the wall thickness of the formed part. In conventional spinning, the wall thickness remains nearly constant throughout the process, so the final wall thickness of the formed part is equal to the thickness of the blank. In contrast, the wall thickness is reduced in shear spinning and tube spinning; in shear spinning, part thickness is dictated by the angle between the wall of the component and the axis of rotation; in tube spinning, the final thickness is defined by the increase in length of the work piece. Furthermore, while in conventional spinning and tube spinning parts can be formed in a single step or a number of steps, in shear spinning, forming is done in a single step. A comparison of the main features of the three processes is shown in Fig.2
The classification of spinning into conventional spinning, shear spinning and tube spinning is widely accepted. However, the only formal standard classification is that of the German DIN Standard8582, in which processes are classified according to the instantaneous internal stresses which cause yielding in the material. Following this standard, Lange(1985)describes conventional spinning as a tensile-compressive forming process, grouping it with the sheet forming processes of bending, deep drawing and collar drawing. Shear spinning on the other hand, is classified as a compressive forming process, along with the bulk forming processes of rolling.Kalpakjian (1989) broadly classifies all forming processes as sheet or bulk forming, and places both conventional and shear spinning in the group of sheet metal forming processes, together with bending, stretching and deep drawing.

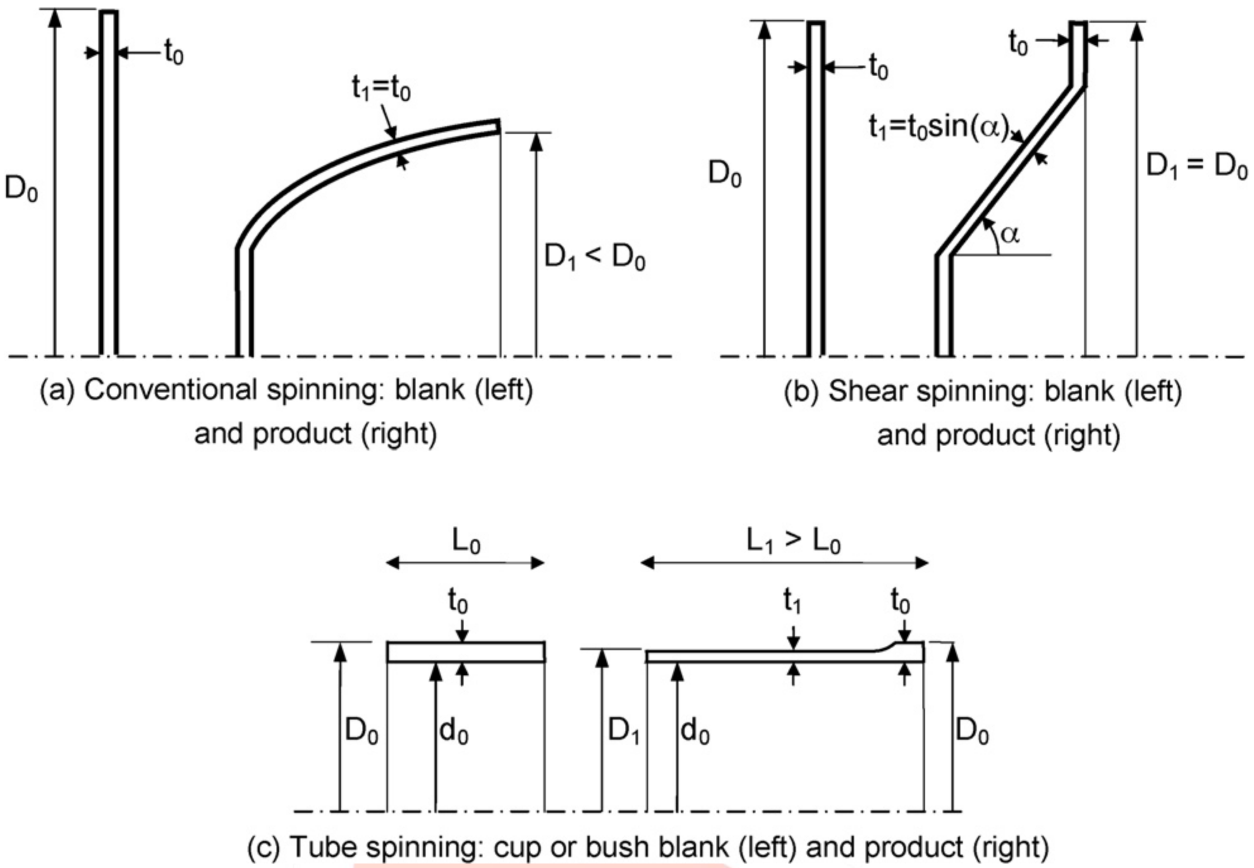

Fig.2. Classification of Spinning

III. TYPES OF METAL SPINNING [2]

1. **Flexible spinning -** Since a specific mandrel is required for each product, conventional spinning processes are not strictly flexible. To make a spanning process flexible five approaches are identified-spinning pre-formed shells, replacing the mandrel with a roller, spinning with a moving blank holder, spinning with a simple cylindrical mandrel and spinning with a multi-roller tool.
2. **Asymmetric Spinning -** In addition to being inflexible, conventional spinning is limited to production of axisymmetric parts. The challenge of extending the processes to other areas of application has given rise to research on producing non-axisymmetric parts with spinning. In this area, four approaches have been identified; using spring-controlled rollers, using a radially offset mandrel, using a radially offset roller and using a feedback control system.
3. **Hot Spinning -** Conventional spinning processes are typically performed cold, but for thick parts and high strength materials, heating is sometimes applied to reduce the forming forces. An improvised approach to hot spinning is widely used in industry: in-process heating of the sheet is achieved by a hand held oxyacetylene flame. However, heating in this way has its disadvantages: the temperature often work piece cannot be controlled accurately, strength-reducing diffusion can occur, as can reactions with the atmosphere and changes of microstructure. Furthermore, the formed part must be unclamped, annealed and re-clamped several times during the process.

Spinning terminology [3]

During spinning different parts and tolls are used. These parts and tool have a specific terms and nomenclature. These terminology are as follows

Terms	Alternative	Explanation
Mandrel	Former, chuck	Rigid tool which bears the final profile of thedesired spun product.
Backplate	Tailstock	Circular disk which clamps the blank onto the mandrel
Roller nose radius	Roller round off radius	Blending radius between the two flat surfaces on the outer surface of the roller
Roller path	Tool path	The trace of roller movement
Forward path	Rim-directed movement	Roller feeds towards the edge of the blank
Backword path	Centre-directed movement	Roller feeds towards the centre of the blank
Feed rate	Feed	Feeding speed of the roller (unit: *mm/min*)
Spindle speed	Mandrel speed, rotational speed	Rotational speed of the mandrel (unit: *rpm*)
Feed ratio	Feed per revolution	Ratio of feed rate to spindle speed (unit: *mm/rev*)

Conventional spinning	Multi-pass spinning	Spinning process which deliberately reduces the diameter of the workpiece but without changing the wall thickness by using multiple roller passes
Shear spinning	Shear spinning, power spinning	Spinning process which maintains the diameter of the workpiece and deliberately decreases the wall thickness by a single roller pass
Spinnability	Formability	The ability of a sheet metal to undergo deformation by spinning without wrinkling or cracking failures

IV. DESIGN PARAMETER AND DESIGN CONSIDERATION [3]

There are 3 main process parameter are consider for spinning process. These process parameter are as follow

1. **Workpiece Parameters**
   a. Blank thickness
   b. Blank Diameter
   c. Blank Material
2. **Tooling Parameters**
   a. Roller Diameter
   b. Roller Nose Radius
   c. Mandrel Diameter
   d. Blank Support Unit
3. **Process Parameters**
   a. Feed Rate
   b. Spindle speed
   c. Feed Ratio
   d. Temperature
   e. Lubricant

1. **Work piece Parameters**

Blank Thickness [1]

Blank thickness is nothing but thickness of blank .The process of metal spinning is capable of forming workpiece with thickness of 0.5 mm to 30mm. To obtain uniform thickness during a spinning it required high speed ratio but this will reduce the geometrical accuracy which applicable for shear spinning. To calculate the thickness of component sine law is used.

$$t_f = t_0 \text{ X } \sin\alpha$$

By using this formula we calculate the final thickness of component, where

t_f = final thickness
t_0= Initial thickness
α = inclined angle

For metal spinning low feed rate and large nose radius are recommended for uniform thickness. In metal spinning high offset value tend to reduce wall thickness. Maximum axial and maximum radial forces are as a function of wall thickness. The inclined angle of the mandrel determine the degree of reduction normal to the surface .The greater the angle, the lesser will be the reduction of wall thickness.

Blank Diameter

Blank diameter is a diameter of metal sheet which is used for producing spun component. Different type of blank diameter used in metal spinning according to product requirement. Generally in metal spinning cylindrical, hemispherical and cone shaped component are produced, and according to this shape and size blank diameter will change. By equating the area of the blank and area of the designed component the the required diameter of the blank is calculated.

Surface area of blank = surface area of the designed component

Blank material l[4]

To produce a component in metal spinning sheet metal is used. Almost all metal are available in the form of sheet, but following metal are generally used in this process like aluminium, stainless steel ,copper , brass, tin , silver, gold.

2. **Tolling Parameter**

Roller Diameter [2]

Roller acts as a tool which applies the force on the metal sheet over the mandrel. Rollers are available in different diameter and different thickness. This roller deforms the metal sheet over the mandrel in several no of passes. According to Hayama low mandrel speed, small roller diameter and low viscosity lubricant give low surface finish. Roller diameter can be calculated by using the following formula

$$D_r = 0.1D + (120 \pm 60) \text{ mm}$$

Where,

D_r= Roller diameter in mm
D = Original diameter of blank in mm

Roller diameter is always less than the diameter of the component so that while selecting the diameter of the roller by using the above relation selected diameter of the roller is less than that of components diameter.

Roller nose radius [2]

Roller nose radius has a significant effect on a dimensional accuracy. Large the nose radius result in uniform thickness distribution and low surface roughness. Which is applicable for conventional spinning .In shear spinning the roller diameter and nose radius has a significant effect on tangential force component and using a large nose radius lead to better surface quality.

$$Nr = (0.012 \sim 0.05)\, D$$

By using this formula we calculate a nose radius where,

Nr = Nose radius in mm
D = Blank diameter in mm

Force Calculation [3]

Most of the process of spinning is conducted by trial and error basis. Force between the work piece and Roller generated during shear forming can be resolved into three mutually perpendicular component, namely the axial (Fa), Radial (Fr) & Tangential (Ft). It has been experimentally observed that tangentially force is smaller than axial & radial forces. Feed ratio, mandrel speed, sheet thickness, roller diameter, roller nose radius affect the tool forces. Mandrel rotational speed has an optimum value. For sheet thickness there is a linear directly proportional relationship exist between thickness and all three forces. The influence of roller diameter and roller nose radius on tool force was examined by avitzur and yang he report that the tangential force decrease with increase in both parameter, whereas axial and radial forces increases.

The axial forces are the highest among three force components, while the tangential force is the lowest; ratios between maximum radial forces to maximum tangential forces of all the four roller path profiles remain unchanged as 5:1. However, the ratios of maximum axial force to maximum tangential force vary between 13:1 for the convex roller path and 17:1 for the linear roller path.

F_a = Axial force
F_r = Radial forces
F_t = Tangential force

The Tangential forces are as fallow

$$F_t = (t_0 - C_s) \sin \alpha \, f \int \sigma \, d\epsilon$$

We know that,
t_0 = Initial Blank thickness
C_s= Over-roll Depth
α = Half-cone angle
f = Roller feed
σ = Effective Stress and
$d\epsilon$ = Infinitesimal effective strain

According to Hooks law,

$$\sigma \;\alpha\; \epsilon$$
$$\sigma = E \times \epsilon$$

Where,
σ = Stress
ϵ = Strain
E = Young modulus of elasticity.

For Aluminium,

$\sigma = 110$ MPa = 110 N/mm^2
$E = 69 \times 10^3$ N/mm^2

$$\epsilon = \frac{\sigma}{E} = \frac{110}{69 \times 103} = 1.594 \times 10^{-3}$$

Assume,

C_s = Over-roll Dept = 0.1 mm

$$F_t = (t_0 - C_s) \sin \alpha \, f \int \sigma \, d\epsilon$$

By using this formula approximately tangential force wil be calculated

The ratios of maximum axial force to maximum tangential force vary between 17:1[3]

$$\frac{Fa}{Ft} = \frac{17}{1}$$

By using this relation approximately axial force will be calculated

The ratios between maximum Radial forces to maximum tangential forces 5:1.[3]

$$\frac{Fr}{Ft} = \frac{5}{1}$$

By using this relation approximately radial force will be calculated

Mandrel Design

Mandrel is a supporting as well as a rotating member in the metal spinning set up. The shape of final component is same as that of the designed mandrel. According to requirement of shape of final component mandrel is designed. With the help of mandrel the sheet metal is rotated and this metal sheet is deformed over the mandrel with the help of roller by applying force on it. The mandrel is a solid part and material used for mandrel is cast iron, mild steel, Aluminium, Magnesium and plastic coated wood. When it is necessary to produce a parts to close tolerances, the mandrels are typically made entirely of steel and cast iron, cored casting of steel or cast iron are preferred in order to reduce the rotating weight. Mandrels must be statically balanced, and when used at high speed and the mandrels should also dynamically balance.

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

3. Process parameter

Feed Ratio [5]

Feed ratio is defined as it is ratio of roller feed rate to spindle speed. High feed ratio help to maintain original blank thickness. It also leads to material failures & rough surface finish. Low Feed ratio is better for spinning process because good surface finish obtained and no failure of component take place. For Aluminium feed ratio is 0.9 mm/rev and for mild steel feed ratio is 1.8 mm/rev.

Feed Rate [2]

The roller feed rate, which is one of the important parameter affecting the formability and forming quality. It is a Distance of the tool advances into or along the work piece each time is called as feed rate. It is measure in mm/sec or mm/ min. Due to the high feed rate rough surface finish & wrinkling may be occur. A decrease in feed rate will improve the surface finish while increase in feed rate will make a work piece fit to mandrel and the finish of work piece will become coarser. In order to realize synchronous motion control of mandrel and roller, the number of pulse signal for mandrel rotation, mandrel feed and roller feed are maintained constant for a given time interval. During 1 path spinning the roller move from mandrel slope is set to 2.4 mm/sec.

Spindle Speed [2]

The best quality for most components is achieved when spinning at high speed. According to hayama the effect of mandrel speed on to the tool forces is negligible. He point out that the effect of the mandrel speed is negligible, and gives a wide range of feasible mandrel speed. The influence of rotational speed on the variation of axial and radial forces is negligible. For aluminium material we take Spindle speed 800 to 900 rpm

$$N = \frac{(9500 \sim 320000)}{Do}$$

Mandrel speed is calculated by using this formula where,

N= mandrel speed in rpm

$D_{0=}$ original blank diameter in mm

Temperature [2]

The use of elevated metal temperatures is sometimes required during metal spinning to reduce the flow stress and increase the ductility of the component, particularly if the machine capacity is insufficient for cold forming the component or if the alloy ductility is too low. Spinning process are typically performed cold, but for thick part and high strength material, heating is sometime applied to reduce the forming forces. In this method heating of the sheet metal is done by hand held oxyacetylene flame. Sometime hot air is also used to heat the blank .

Lubricant [2]

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

V. FUTURE SCOPE

Future scope for this research is to provide the in depth guidance for the process study and designing the set up of spinning to minimize defects and failure of the component.

VI. CONCLUSION

By using this workpice parameter, tolling parameter and process parameter good surface qualiy and good dimensional accuracy of the product is achived. It also help to improve the mechanical property of the spun component. Spinning process also help to reduce the tooling cost of the process which will help to minimize the operating cost of the product.

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