Design of Metal Spinning Parameters for General Lathe

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***Abstract* - Sheet metal spinning is one of the metal forming processes, where a flat metal blank is rotated at a high speed and formed into an axisymmetric part by a roller which gradually forces the blank onto a mandrel, bearing the final shape of the spun part. The aim is to design the workpiece parameters, process parameters, tooling parameters to reduce failure of the workpiece, wrinkling failure, material deformation in metal spinning for general lathe. with the help of these three parameter improve the mechanical property and quality of product.**

***Index Terms*- Tooling parameters, process parameters, workpiece parameters.**

I. INTRODUCTION

Metal spinning is the technique to produce axis symmetrical part or component over rotating mandrel with the help of rigid tool known as roller. The spinning process also enables components to be produced with both improve mechanical properties of almost 2 to 2.5 times their value in the raw material condition as well as with high dimensional accuracies and surface finishes. such components mostly find application in the air craft and missile industries which require a high strength to low weight ratio for their component. 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. Metal spinning refers to a group of forming processes that allow production of hollow, axially symmetric sheet metal components. The basic technique of spinning, which is common to this group of processes, consists of clamping a sheet metal blank against a mandrel on a spinning lathe, and gradually forming the blank onto the mandrel surface by a roller, either in a single step or series of steps[1].

II. DESIGN OF METAL SPINNING PARAMETERS

Design workpiece parameters

1. Blank Thickness[4]

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=Initialthickness

To calculate max. % of thickness reduction[1]

$$= \frac{(to - tf)}{t0} \times 100$$

The Chart below show that Percentage of Reduction in Thickness of Component according to variation of half-apex angle of Mandrel [1].

Table 1 Max % of thickness reduction of blank

Angle A	Initial Blank Thickness (t_0)	Final Component Thickness (t_f)	Percentage of Reduction $\frac{to - tf}{to} \times 100$
12	0.5	0.103	79 %
	1	0.207	79 %
	2	0.413	79 %
15	0.5	0.129	74 %
	1	0.255	74 %
	2	0.517	74 %
45	0.5	0.353	29 %
	1	0.707	29 %
	2	1.414	29 %

60	0.5	0.433	13 %
	1	0.866	13 %
	2	1.732	13 %

2. Blank Diameter[4]

Blank diameter is a diameter of metal sheet which is used for producing spun component. Different size 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.

D = Diameter of blank
R = Large Radius of cone
r = Small Radius of cone
S = Slant height of cone

Surface area of blank = surface area of cone

$$\pi/4 \times (D)^2 = \pi \times (R + r) \times S$$

D = calculate

From calculation prove that D in mm blank diameter required to produce outer diameter in mm

3. Blank material[5]

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.

1. Aluminium - Aluminium is very ductile material among all the type of material and there is different type of grade present in aluminium. It is elastic in nature and does not required any heat treatment .Following are the grade of aluminium,
   a. 1100- H14 - This type of aluminium is pure in nature. It is soft metal among all type of aluminium grade. The percentage of elongation is 60% which is greater than all type of aluminium grade. It has 99% aluminium and 1% alloy.It is commonly used in chemical processing equipment, light reflectors, and jewellery.
   b. 3003- H14 - This type of aluminium harder than 1100-H14 because it contain 98% Al, 0.12% cu and 1.2 % Mn. The percentage of elongation is 30%. It is often used in stamping and drawn parts, mail boxes, cabinets, tanks, and fan blades
   c. 5052- H32 - This type of aluminium harder than 3003- H14. It is hard to deform, it contain 97% Al, 2.5% m_g, 0.25% Cr. The percentage of elongation is 25%.. Common applications include electronic chassis, tanks, and pressure vessels
   d. 6061- T6 - This type of aluminium harder than all type of all type of Aluminium. The percentage of elongation is 25%.Aluminium is most widely used in metal spinning because it has ability to easily deform. It is used in modern aircraft structures
2. Stainless steel - It is also in elastic nature and stretch before tearing .The percentage elongation is 50-68% but disadvantage of stainless steel is it requires more force to deform the metal.
3. Copper - The main property of copper is it is good in formability and have double its tensile strength when work hardened. It is hardened before the part is finished then the part must required to annealed to prevent cracking. It contains 99% Cu. The percentage of elongation of copper is about 60%.
4. Brass - Brass is a copper zinc alloy and has same properties to Cu. It require the more force to deform and it works hardens less. It contains 65% Cu and 35% Zn. the percentage of elongation of brass is 64%. But we select a Aluminium 1100 grade material for blank due to its good ductility and high percentage of elongation

Temper Designation System

Aluminium city utilise a temper designation system similar to the ISO 2107 "alternative a temper designation system "which is widely recognised internationally and closely approximates that the aluminium association. The system defines the sequence of basic treatments use to achieve the various tempers. The temper designation follows the four digit aluminium alloy designation, the two being separated by a hyphen. Basic temper designation consist of letters whereas subdivisions of these basic tempers are indicate by one or more digits following the letters.

A. Basic Temper Designations
   - O Annealed .Applies to wrought products which are annealed to obtain the lowest strenght condition.
   - H Strain-hardened. (rought product only).Applies to products subjected to the application of cold work after annealing (or hot forming),or to a combination of cold work and partial annealing or stabilizing in order to secure the specified mechanical properties.The H is always fallowed by two digits.
   - T Thermally treated to produce stable tempers other than O or H .Applies to products which are thermally trated,with or without supplementary strain-hardening,to produce stabletempers. T always followed by one digit.

B. Subdivisions of H temper : Strain-hardened
   - H1x Strain-hardened only. Applies to products which are strain hardened to obtain the desired strength without supplementathermal treatment. The number following the designation indicates the degree of strain -hardening.

- H3x Strain-hardened and stabilised. Applies to products which are strain-hardened and whose mechanical properties are stabilised by a low temperature thermal treatment which result in slightly lower tensile strength and improved ductility. The number following the designation indicates the degree of strain -hardening remaining after the stoving process.

C. Subdivisions of T temper : Thermally Treated

- T3 Solution heat- treated,cold worked ,and naturally aged to a substantially stable condition.Applies to products which are cold worked by a controlle amount to improve their stenght after solution heat-treatment,or in which the effect of cold work in flattening or straightening is recognised in mechanical property limits.
- T6 Solution heat-trated and then artificially aged.Applies to products which are not worked after solution heat-treatment,or in which the effect of cold work in flatteningor straightening may not be recognised in mechanical property limits.

Design Tolling Parameter

1. 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

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

Where, R = Large Radius of cone

D_r = Roller diameter in mm

D = Original diameter of blank in mm

Check condition, If roller diameter always less than diameter of component

Then, $Dr = [0.1\ (Dr) + (D - R)]$

We select a Roller diameter Dr in mm because roller diameter is always less than the blank diameter.

2. 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

3. 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. Although most of the power supplied by the motors driving the chuck is translated through the tangential component.

Feed ratio, mandrel speed, sheet thickness, roller diameter, roller nose radius affect the tool forces. Mandrel rotational speed has an optimum value. Slater and chan et al both report that there is a mandrel speed at which tangential force is negligible. 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 [**2**]

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. the concave path produces the highest radial, axial and tangential forces among these four roller path profiles considered. the lowest axial and tangential forces are observed in the FE models which use the convex roller path. Therefore, it is clear that convex roller path generally produces the lowest tool forces.

Where F_a = Axial force

F_r = Radial forces

F_t = Tangential force

The Tangential forces are as fallow [6]

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

We know that,

t_0 = Initial Blank thickness = 2 mm

C_s= Over-roll Depth

α = Half-cone angle = 15^0

f = Roller feed = 1000 mm/ min

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,

σ = 110 MPa = 110 N/mm^2

E = 69 × 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

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

$F_t = (2 - 0.1) \times \sin 15 \times 1000 \times \int E \times \epsilon\, d\epsilon$

$F_t = (2 - 0.1) \times \sin 15 \times 1000 \times E \times \int \epsilon\, d\epsilon$

$F_t = (2 - 0.1) \times \sin 15 \times 1000 \times E \times \left(\frac{\epsilon^{\wedge}2}{2}\right)$

$F_t = (2 - 0.1) \times \sin 15 \times 1000 \times 69 \times 10^3 \times \frac{(1.594 \times 10^{\wedge}{-3})^{\wedge}2}{2}$

$F_t = (2 - 0.1) \times \sin 15 \times 1000 \times 69 \times 10^3 \times 1.2704 \times 10^{-6}$

F_t = 43.106 N = 4.394 Kg

The ratios of maximum axial force to maximum tangential force vary between 17:1[3] $\frac{Fa}{Ft} = \frac{17}{1}$

But tangential force is F_t = 43.106 N then Calculate Axial force F_a

$F_a = 17 \times F_t$

$F_a = 17 \times 43.106$

F_a = 732.802 N = 73.280 Kg

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

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

But tangential force is F_t = 43.106 N then Calculate Radial force F_r

$F_r = 5 \times F_t$

$F_r = 5 \times 43.106$

F_r = 215.53 N = 21.553 Kg

4. Selection of Bearing for Roller [7]

A Bearing is a mechanical element that permits relative motion between two parts, Such as the Shaft and the housing, with minimum friction. The functions of bearing are as fallows;

a. The bearing ensures free rotation of the shaft or the axle with minimum friction.
b. The bearing Supports the Shaft or the axle and holds it in correct position.
c. The bearing takes up the forces that act on the Shaft or the axle.

Bearing are classified in different ways. Depending upon the direction of force that acts on them, bearing are classified into two categories- Radial and Thrust bearings. A radial bearing supports the load, which is perpendicular to the axis of the shaft. A thrust bearing support the load, which acts along the axis of the shaft. The most important criterion to classify the bearing is the type of friction between the shaft and bearing surface. Depending upon the type of friction , bearing are classified into two main groups-sliding contact bearings and rolling contact bearing .sliding contact bearing are also known as plain bearings, journal bearings or sleeve bearings. Rolling contact bearing are also called antifriction bearing or simply ball bearings. Rolling elements, such as balls or roller, are introduced between the surface that are in relative motion. In this type of bearing, sliding friction is replaced by rolling friction.

Deep Groove Ball bearing: - The most frequently used bearing is deep groove ball bearing. It is found in all most all kind of product in general mechanical engineering. In this type of bearing, the radius of the ball is slightly less than the radii of curvature of the groove in the races. Kinematically this gives a point of contact between the ball and the races. Therefore, the balls and the races may roll freely without any sliding. Deep groove ball bearing has following advantages:

1. Due to relative large size of the balls, deep groove ball bearing has high load carrying capacity.
2. Deep groove ball bearing takes load in radial as well as axial direction.
3. Due to point contact between the balls and races, frictional loss and the resultant Temperature rise is less in this bearing .The maximum permissible speed of shaft depends upon the temperature rise of the bearing. Therefore, deep groove ball bearing gives excellent performance especially in high-speed application.
4. Deep groove ball bearing generates less noise due to point contact.
5. Deep grove ball bearing are available with bore diameter from few million metres to 400 millimetres. Due to all these advantages we select the deep groove ball bearing having following specification,

We know that,

Axial force = Fa

Radial force = Fr

Calculate Equivalent dynamic load from equation [11]

$$P = X F_r + Y F_a$$

The Relation between life in million revolutions and life in working hours

$$L_{10} = \frac{60nL10h}{10^6}$$

Assume,

L_{10h} = Rated bearing life (hours) = 10,000 hr

n = Speed of rotation (rpm) = 600 rpm

$$L_{10} = \frac{60 \times 600 \times 10000}{10^6} = 360 \text{ million rev}$$

The Relation between the dynamic load carrying capacity, the equivalent dynamic load, and the bearing life is given by,

$$L_{10} = \left(\frac{C}{P}\right)^p$$

p = 3 (for ball bearing)

$$C = P (L_{10})^{1/3}$$

From bearing table on the basis of trial and error method for the shaft of 25 mm diameter. Bearing No.16005 is selected. For this bearing, $C_0 = 4000$ N

$$\frac{Fa}{Fr} = 3.4 \quad \& \quad \frac{Fa}{Co} = 0.1832 \quad ; \quad \frac{Fa}{Fr} > e$$

From the catalogue [7]

Table 2 The Value of ratio $\frac{Fa}{Co}$ and e

$\frac{Fa}{Co}$	E
0.130	0.31
0.183	E
0.250	0.37

0.791(0.37- e) = e- 0.31

e = 0.3364

e = 0.3364 ; $\frac{Fa}{Fr} > e$

From the catalogue [7]

Table 3 The Value of ratio $\frac{Fa}{Fr}$ and e

E	$\frac{Fa}{Fr}$
0.31	1.4
0.3364	Y
0.37	1.2

Y- 1.4 = 0.7851(1.2 - Y)

Y = 1.3120

$P = X F_r + Y F_a$

X and Y factor for single row Deep groove ball bearing

X =0.56; Y = 1.3120

P = 0.56(Fr) + 1.3120(Fa)

$C = P (L_{10})^{1/3}$

$C = P \times (360)^{1/3}$

Therefore, using value of C to select bearing is suitable for the application. [11]

5. Mandrel Design [1]

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.

i. Material selection: - The actual mandrel material selection depends on the design, part material and desired life. According to this criteria we select a Mild Steel because,
    - Mild steel contain less than 0.3% carbon
    - Desired life of mandrel is high
    - Used for high production volume
    - Due to low carbon content, they are unresponsive to heat treatment
    - They can be machined and welded easily

ii. Specification of mandrel[8]:- As we want to produce a cone shaped component having range 100 to 120 mm diameter according to this requirement we design the mandrel having
    Large diameter=120mm
    Small diameter=60mm
    Slant height=120mm

iii. Shaft for mandrel: - shaft is a supporting part of a mandrel which holds in the chuck of lathe machine. The material used for mandrel is mild steel due to properties as mentioned above

Design Process Parameter

1. Feed Ratio [4]

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. Variation of feed ratio has considerable effect on the tool forces, wall thickness, Spinability, Surface finish & spring back of the metal spinning process. When higher feed ratio is applied, tool forces will increases. Low feed ratio would result in excessive material flow in the outward direction, which unnecessarily reduces thins the blank but due to low feed rate better surface finish obtained. 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.

2. Feed Rate [3]

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.

3. 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

$$N=\frac{(9500\sim320000)}{Do}$$

Mandrel speed is calculated by using this formula where,

N= mandrel speed in rpm

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

4. Temperature [1**]**

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 used to heat the blank [**2**].

5. Lubricant [1**]**

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 perform; 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.

Lubricants generally need to be used in all metal-spinning operations, regardless of the preform composition or shape or the type of metal-spinning tools that are used. Lubricants are typically required both before and during forming. The need for lubrication during spinning depends on the tenacity of the lubricant used and on the rotational speed of the preform. The lubricant must continue to adhere to the rotating preform during spinning. Ordinary cup grease is often used. It can be heated to reduce its viscosity, for ease of application. Other lubricants used for metal spinning include soaps, waxes and pigmented drawing compounds; in the selection of the most suitable lubricant, the ease of removal of the lubricant after forming has to be considered[2].

III. CONCLUSION

The metal spinning parameter is directly affected to the workpiece surface finsh,tool life, workpiece failure,wrinkling failure. Using this design parameters we have to reduce the defect & failure occurs in metal spinning operation performed on general lathe.

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