Design, Development and Analysis of Four Roller Spinning Head for Spinning Machine

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Abstract— Tube spinning is an excellent process to produce seamless thin walled tubular work pieces in the diameter range from a few millimetres to several meters. During tube spinning, the rollers advance spirally over the tube blank resting on a rotating mandrel and apply compressive force to the surface of tube blank, causing the metal to flow axially through reducing wall thickness. In spinning process performed in spinning machine unbalanced load imposed on the mandrel aggravated the circular run-out and eccentricity of the mandrel, thus influencing the forming process of tube spinning and decreasing the forming precision of as spun tubular work pieces, such as wall thickness uniformity and circularity of as spun tubular work pieces. The problem is solved by increasing the number of roller in the spinning machine from 3 rollers to 4 rollers. Increase in number of rollers will lead to the balancing of mandrel between 4 rollers. Distribution mode analysis made for both three and four roller spinning machine.

Keywords: Tube spinning, Rollers, Distribution mode analysis.

I. Introduction

Tube spinning is an excellent process to produce seamless thin walled tubular work-pieces in the diameter range from a few millimetres to several meters. During tube spinning, the rollers advance spirally over the tube blank resting on a rotating mandrel and apply compressive force to the surface of tube blank, causing the metal to flow axially through reducing wall thickness. Since the spinning process localizes plastic deformation to small zones, the working force reduces greatly compared with other plastic forming processes, such as forging and extrusion. Owing to high productivity and low consumption of materials and energy, tube spinning has gained wide application in automobile, aviation, aerospace and weapon industries. Tube spinning produces a axisymmetric cylindrical work pieces from hollow tubes, Pre machine blanks forged or deep drawn parts the initially part is clamped again the rotating mandrel with a tail stock system three forming rollers are distributed equally in a circle, each 120 degrees apart and can be moved axially and longitudinally once the system rotates the rollers push against the materials in the axial direction all along the length of preform. Consequently, the material stretched in the moving direction, thinning the preform wall to keep the initial material volume. Flow forming typically requires one to three axial strokes each one stretching and reducing wall thickness. The number of strokes depends on different factors such as the preformed initial thickness and final part thickness relationship, material formability and machined forces. After the flow forming operation is finished, the machines extractor system ejects the work piece.

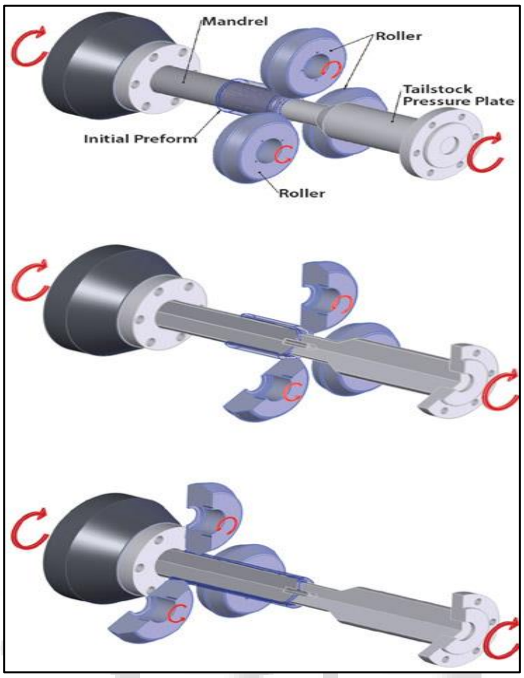

Fig. 1: Tube spinning by three roller spinning head

II. Problem Statement

During tube spinning, the roller distribution modes, usually included two-roller and three-roller have important effect on the forming quality of tubular work-pieces since they influence the load exerted on the mandrel by the rollers. Unbalanced load imposed on the mandrel aggravated the circular run-out and eccentricity of the mandrel, thus influencing the forming process of tube spinning and decreasing the forming precision of as-spun tubular work-pieces, such as wall thickness uniformity and circularity of tubular work pieces.

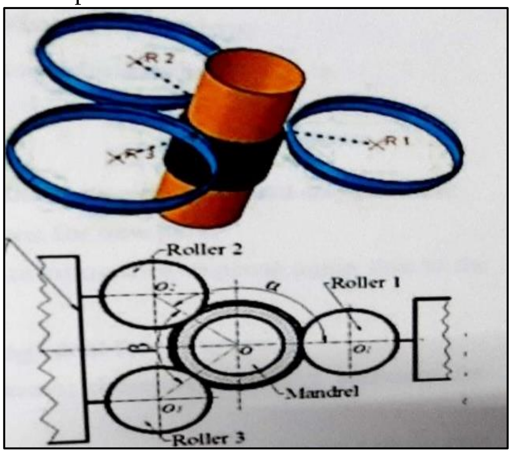

Fig. 2: FEA model of distribution mode in three roller tube spinning

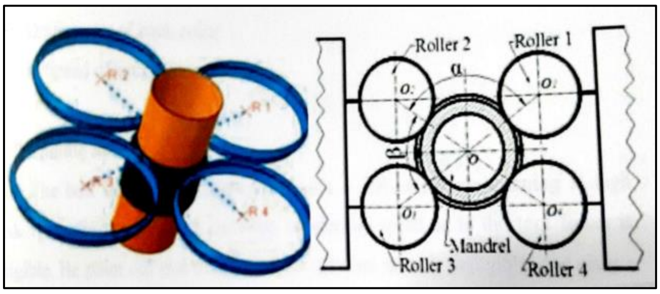

Fig. 3: FEA model of distribution mode in four roller tube spinning.

III. Literature Review

C.C. Wong, T.A. Dean, J. Lin, 2003 studied about spinning, shear forming and flow forming processes. They also studied about 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, all of which are vital, especially in automotive industries.

Gangfeng Xiao, Qinsiang Xia, Xiuquan Cheng. Yujing Zhou, 2014. According to Xiao the power spinning method has significant influence on the equivalent strains distribution of the spun parts, but has little influence on the maximum and minimum equivalent strains of the spun parts.

Mr. M.B. Patwardhan, Mr. K.V. Gurav, 2014. Authors have worked on Metal Spinning Design Consideration and parameter of spinning process and its terminology. 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 utilized increasingly due to great flexibility for producing complicated parts never to net shape and reduce weight and cost.

Wenchen Xu, Xiaokai Zhao, Hao Ma, Debin Shan, HenglongLin, 2016. According to the authors of this paper the deformation characteristics and the evolution of spinning forces were investigated by FE simulation and the mandrel deflection was measured online in the tube spinning experiment under various roller distribution modes.

IV. Necessity

1) To balance the mandrel position using four rollers.
2) To study the spinning forces acting on front fork suspension inner tube during end cap sealing.

V. Specifications of Existing Roller Head

1) Spun diameter: 32-33.7 mm
2) Inner tube length: 564.5 – 570.5 mm
3) Angle between three rollers- 120 degrees
4) Spindle speed – 800- 900 rpm
5) Plating material – nichrome
6) Percentage of elongation – 50 – 68%
7) Roller diameter - 60 mm

VI. Parameters Affecting Spinning Process

A. *Parameters that cannot change*

1) *Work-piece parameters*

1) Blank Diameter
2) Blank Thickness
3) Blank Material

B. *Parameters that can be changed*

1) *Tooling parameters*

1) Roller Diameter
2) Roller Nose Radius
3) Mandrel Diameter

2) *Process Parameters*

1) Spindle Speed
2) Feed Rate
3) Feed Ratio

VII. Design Calculations

Material: Tool steel, heat resistant stainless steel
Thickness – 0.5 mm to 30 mm
Diameter – 10 mm to 5 meter

A. *Mechanical Properties*

$$s_{yt}=36 kgf/(mm)^2 \quad (275 MPa)$$
$$s_{ut}=63\text{-}71 kgf/(mm)^2 \quad (275 MPa)$$
$$\sigma_{yt}=s_{yt}/(F.O.S=275/2=137.5 N/(mm)^2$$
$$\sigma_{ut}=s_{ut}/(F.O.S)=350/2=175 N/(mm)^2$$
(Assume load factor 2)

B. *Tooling Dimensions*

1) *Rolling Radius*

$$D_r=0.1D+(100\pm60)\ mm$$
D = Blank diameter in mm
= 60 mm
$$D_r=0.1D+(100\pm60)\ mm$$
$$D_r=166\ mm$$
$D_r=46$ mm (Consider this diameter)

2) *Roller Nose Radius*

$$N_r=(0.012\sim0.05)D$$
$$N_r=3\ mm$$

C. *Roller Path Profiles*

1) Concave
2) Convex
3) Linear

D. *Force Calculation*

$$Fr/Ft=5/1$$
$$Fa/Ft=13/1 \text{ (For convex path)}$$
$$Fa/Ft=17/1 \text{ (For linear path)}$$

Where,
Fr = Radial force,
Ft = Tangential force,
Fa=Axial force

$$F_t=(t_o-C_s)*\sin\alpha*F\int \sigma\, d\epsilon$$

Where,
t_o=Initial blank thickness=2 mm
C_s=Overall roll depth =1.5 mm (assume)
F = Roller feed
α=Half cone angle

E =Modulus of elasticity = 200 Mpa
According to hooks law,

$$\sigma = E * \in$$

$$\in = \frac{\sigma}{E} = \frac{175}{200 * 10^3} = 8.75 * (10)^{-4}$$

$$F_t = (t_o - C_s) * sin\alpha * F \int E * \in d \in$$

$$F_t = (2 - 1.5) * sin60 * 850 * 10^3 * (200 * 10^3) * \left(\frac{8.75 * 10^{-4}}{2}\right)$$

$$F_t = 28.17\ N$$

The ratios for maximum axial force to 17:1 maximum tangential force

E. Calculations for selection of bearing

$$Fr/Ft = 5/1$$

$$F_r = 140.85\ N$$

$$Fa/Ft = 13/1$$

$$F_a = 479.05\ N$$

1) *Equivalent dynamic load from equation*

$$P = X * F_r + Y * F_a$$

2) *Relation between life in million revolutions and life in working hours*

$$L_{10} = (60 * n * L_{10h})/10^6$$

$$L_{10h} = \text{Rated life in hours}$$

$$= 20{,}000 \text{ hours (for 24 hours operation)}$$

n = Speed of rotaion in rpm = 850 rpm
n = Speed of rotation in rpm = 850 rpm

$$L_{10} = \frac{60 * 850 * 20000}{10^6} = 2040$$

3) *Relation between dynamic load carrying capacity, the equivalent dynamic load and bearing life*

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

(Considering ball bearing)
From bearing table on the basis of trial and error for shaft of 15 mm diameter
Trial I:
Take $C_o = 2500\ N$

Principle Dimensions	Basic load rating	
	C	C_o
15	1560	815
	5590	2500
	7800	3550

Table 1: Bearing load rating selection

$$F_a/F_r = 3.4011$$

$$\frac{F_a}{C_0} = \frac{479.05}{2500} = 0.19162$$

$$\frac{F_a}{F_r} > e$$

F_a/C_0	E
0.130	0.310
0.183	E
0.250	0.371

Table 2: X and Y Factor for single deep groove ball bearing

By using linear interpolation

$$(x - x\_1)/(x\_2 - x\_1) = (y - y\_1)/(y\_2 - y\_1)$$

$$(0.3364 - 0.31)/(0.37 - 0.31) = (Y - 1.4)/(1.2 - 1.4)$$

Y=1.3120

$$P = X*Fr + Y*Fa$$

X and Y are Factor for single deep groove ball bearing

$$X = 0.56\ Y = 1.3120$$

$$P = 707.38\ N$$

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

$$C = 707.38 * 2040^{1/3}$$

$$C = 8971.45$$

$$C < C_0$$

Hence design is safe

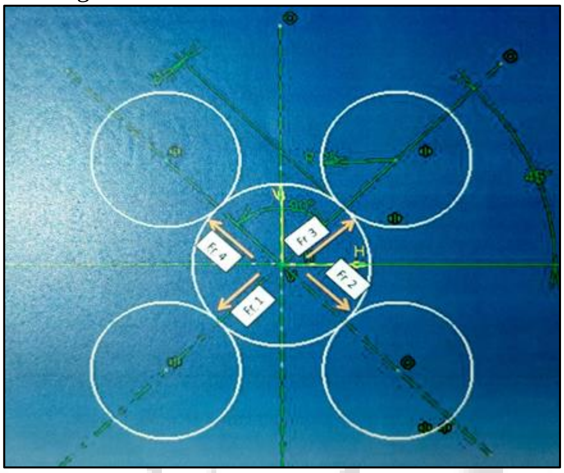

Fig. 4: Schematic diagram of radial spinning force exerted on mandrel with uniformly distributed rollers

VIII. Assumption

As Ft is very small we have to consider Fr and Fa only. The Fa acts on rigid support of the roller and radial force acts on the circumference of the roller. We have to consider the equal amount of forces to the both sides of centre of roller. For symmetrical distribution of material over the mandrel we should have equal amount of Fr on both sides of roller thus to obtain equal magnitudes of the radial forces, we have to consider angle between centre of the roller and vertical to roller mandrel is 90^0.

Fr is the major parameter considered during design as it causes the major effect on the head. It lead for the accuracy of the spinning and helps in maintaining the circularity of the inner tube.

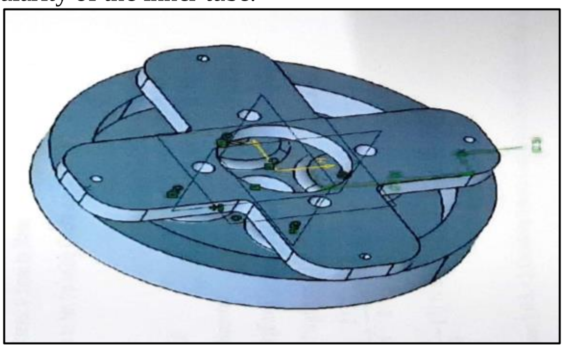

Fig. 5: Assembly of four roller spinning head

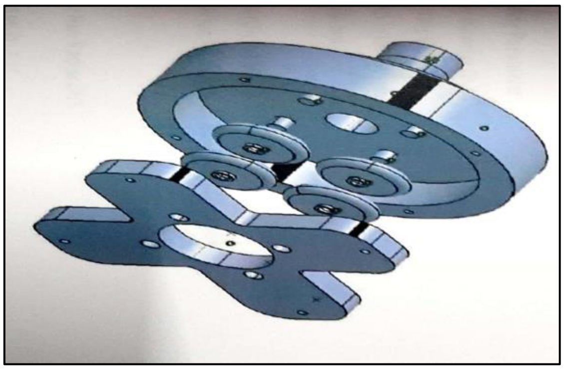

Fig. 6: Exploded view of four roller spinning head

IX. FABRICATION OF ROLLER

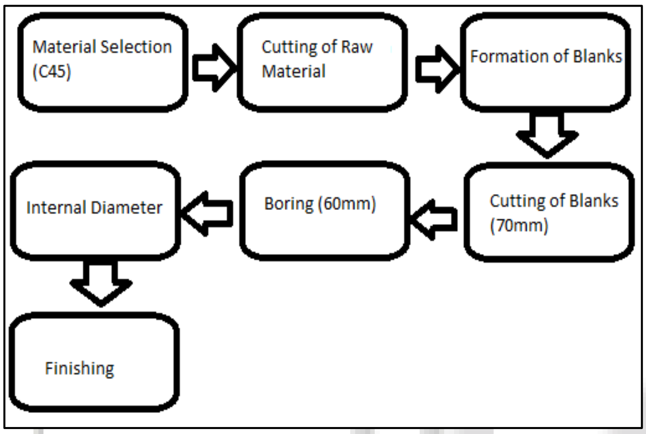

Fig. 7: Process sheet for fabrication of roller

X. OUTCOMES

The mechanical properties of the raw material increased by 2 to 2.5 times in spinning processes.

Four roller spinning can keep balance of the mandrel.

The spinning accuracy level and quality of end cap is increased.

Rejection rate of inner tubes used in front fork assembly got reduced from 10-12 to 2-3 pieces per week.

XI. FUTURE SCOPE

The four roller distribution helps for spinning of complex geometries as the four rollers can balance the forces acting on circumference in radial direction.

The forces on either side can balance the other side. Therefore it can be used for high finish spinning operation because the area of contact between roller and spin area get increased.

To increase area of contact between the roller and work-piece there is scope for further research.

XII. CONCLUSION

1) The distribution and number of rollers have important influence on spinning process. Owing to the non-uniform roller in multi-roller spinning, the stress distribution exhibit non-periodic change along circumferential direction.
2) No of rollers and central angles between two rollers around the mandrel determines quality of surface finish of spin area.
3) Spinning process with non-uniform roller distribution, the resultant radial force deviates in X- and Y-axis.
4) Spinning process with three roller distribution is unbalanced and with four rollers it gets balanced.
5) Radial Force acting on circumference of four rollers gets evenly distributed.
6) The mandrel balanced because the forces of four rollers are counter reacting themselves.

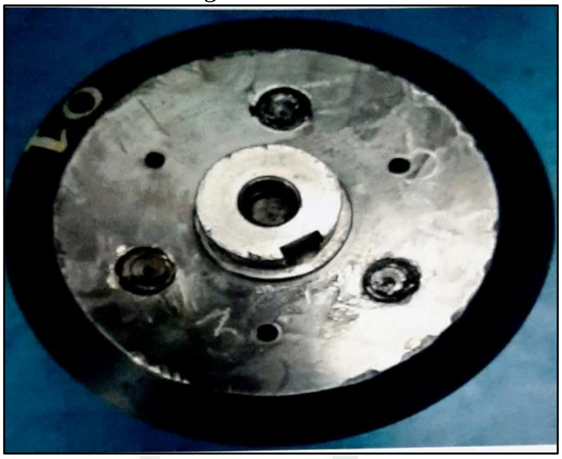

Fig. 8: Previous product (3 roller spinning head)

Fig. 9: Final product (4 roller spinning head)

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