Analysis of Power and Forces in the Making of Long Tubes in Hard-to-Work Materials

Sukhwinder Singh Jolly [1] and D.S. Bedi [2]

Abstract

A generalized expression for the estimation of power and forces required in making long tubes is presented, in which the material is assumed to be perfectly plastic and to obey the Von Mises criterion of yielding, and the tools are assumed to be rigid. The analysis can be applied in the design of the equipment. All of the possible parameters with the exception of diametric growth, which has a negligible effect, have been taken into account in determining the power and forces required. The analysis is applied to the case of making of long tubes in Titanium, one of the hard-to-work material.

Key Words : Ductility improvement, Hard-to-Work materials, plane strain conditions, tube making, average yield stress

1. Introduction

Numerous metal forming processes are now employed in metal working industry. Two basic methods adopted are (i) by removing the metal, generally known as metal cutting or machining ; (ii) by moving the metal, popularly known as metal forming such as hot and cold extrusion, forging, rolling, hydrodynamic and explosive forming etc. The philosophy of moving the metal rather than removing it has always fascinated the man and has led to the innovation of newer processes of metal forming.

The analysis of tube making has been undertaken by several researchers. Most of the work is on the soft materials like lead, aluminum, low carbon steel, copper etc. A very few authors have tried with the forming process of hard-to-work materials. A brief description of the work done by other researchers on soft as well as hard-to-work materials is studied here. S. Kalpakcioglu (1961) has studied the mode of deformation and metal flow pattern by the distorted gird method and spinnability of metals. Kegg, R.L. (1961), on the other hand, has studied the spinnability of metals which is defined as the maximum percent reduction in thickness a material undergoes before fracture.

M. Hayama and H. Kudo (1979 I) have studied the diameteral growth and working forces in tube spinning. M. Hayama and H. Kudo (1979-II) have also studied the mechanism of deformation in tube spinning on the basis of the observation of metal flow experimentally.

R.P. Singhal, S.K. Das and Rajnish Prakash (1987) have studied the shear spinning of long tubes which are axially pulled side by side. R.P. Singhal, P.K. Saxena and R. Prakash (1990) have presented a generalized for the estimation of the power required in the spinning of long tubes, in which the material is assumed to be perfectly plastic and to obey the Von Mises criterion of yielding, and the tools are assumed to be rigid. R.P. Singhal and Rajnish Prakash (1990) have carried out an experimental study of shear spinning of tubes of hard-to-work materials. Shear spinning technology for manufacture of long thin wall tubes of small bore has been discussed by Rajnish Prakash and R.P. Singhal (1995). This new process is economically viable for producing tubes in high-strength materials, particularly when the value of production is not high.

Quigley and Monaghan (2000) have presented solution to the difficulties that a finite element modeling of spinning faces. Gotoh and Yamashita (2001) have studied the effect of shearing speed on the quality of shape and edge – face of the sheared – off products. Wong, Dean and Lin (2003) in their paper have introduced process details of spinning and flow forming. Levy, Vane Tyne and String field (2004) have shown in their paper that with the increased use of tubular steel products, especially for hydro forming applications, it is important to be able to predict the performance of tube form sheet tensile stress.

Jansson, Nilsson and Simonsson (2007) carried out the studies on process parameter estimation for thee tube hydro forming process. Bortot, Ceretti and Giardini (2008) have studied the determination of flow stress of tubular material for hydro forming applications. Mori, Ishiguru and Isomura (2009) have discussed about hot shear spinning of cast aluminium alloy parts in their paper.

2. Analysis

For the present study, three roller system has been adopted and these rollers are placed equispaced at 120 interval around the work piece and the work piece alongwith the mandrel keeps floating within the rollers. Therefore, within the limited range of the tube diameters, diameters of the rollers i.e. 80, 90, 100 and 120 mm are selected for carrying out operation of the tube making. (Fig. 1)

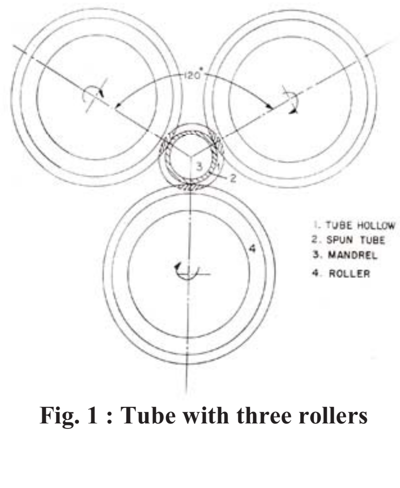

Fig. 1 : Tube with three rollers

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It is assumed that there is no build up of the material ahead of the roller. The deformation is localized in a small volume of the work piece and there is work hardening of material. But for the purpose of analysis the same is not taken into account and the material is assumed to be perfectly plastic obeying Von Mises yield criterion. This assumption permits the use of upper bound analysis for the purpose of estimating forces for designing the equipment. The rollers are assumed to be perfectly rigid bodies.

In the process each element at a given radius is reduced in thickness with a simultaneous elongation in the axial direction. The elongation in length of tube is proportional to the reduction in wall thickness and therefore, the volume constancy condition is applied in the analysis.

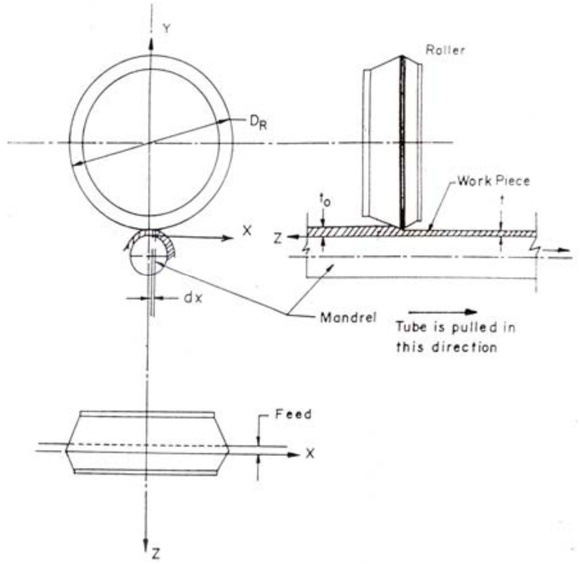

Fig. 2 Schematic diagram of tube making in three planes

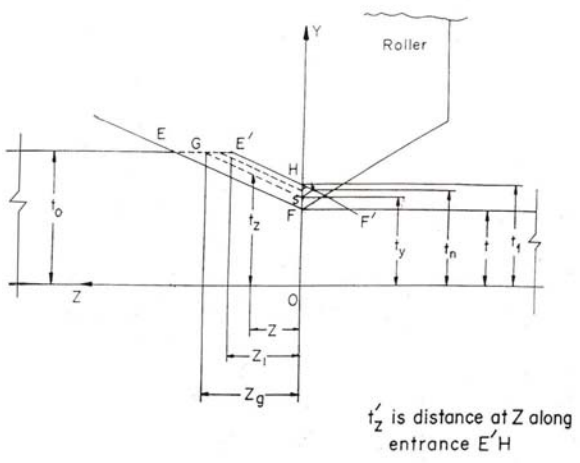

Fig. 3(a),

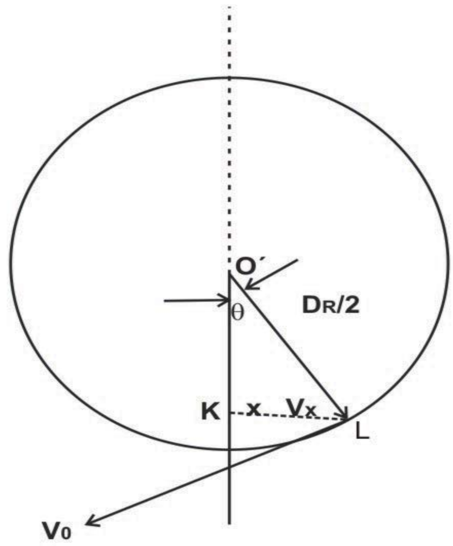

Fig. 3(b)

Fig. 3(a), 3(b) shows how the thickness is being reduced by pulling the tube inside the rollers.

The rollers are making epicycle train with the tube and angular speed ω of the roller is calculated from there and from this V_0 which is the velocity of the deforming material in the tangential direction to the tube at the contact point between roller and deforming tube is calculated.

The percentage reduction 'R' in terms of wall thickness is given by

$$R = \frac{t_o - t}{t_o} \times 100\%$$

Where 't_0 is the initial wall thickness and 't' is the thickness after reduction.

2.1 Velocity Equations

The equation for flow rate

Flow rate =

$$\int_0^{\theta_1} 2\pi \left(V_0^2 \cos^2\theta + V_z^2\right)^{1/2} \left[\frac{D_R}{2} + t\right] \frac{D_R}{2} \sin\theta \, d\theta \; -$$

$$\int_0^{\theta_1} 2\pi \left(V_0^2 \cos^2\theta + V_z^2\right)^{1/2} \frac{D_R}{2} \cos\theta \frac{D_R}{2} \sin\theta \, d\theta$$

Flow rate = I_1-I_2

Also flow rate = area of cross-section x V_z

$I_1 - I_2 = 2\pi\,(t_0 - t)\,KV_o$ $\qquad \because V_z = KV_0$

$F = I_1 - I_2 - 2\pi\,(t_0 - t)\,KV_0$ …(1)

The computer programme was run to find the value of K. This value of K satisfies the condition of volume constancy.

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2.2 Strain Rates

The strain rate in x-direction

$$\dot{\epsilon}_x = \frac{\partial V_x}{\partial x} = \frac{\partial}{\partial x}\left\{ -V_0\left[1-\frac{4x^2}{D_R^2}\right]^{1/2}\right\}$$

Or $$\dot{\epsilon}_x = \frac{4xV_0}{D_R^2\left[1-\frac{4x^2}{D_R^2}\right]^{1/2}} \qquad \ldots(2)$$

Strain rate in Z – direction is

$$\dot{\epsilon}_z = \frac{\partial V_z}{\partial z} = \frac{\partial}{\partial z} KV_0$$

$$= \frac{\partial}{\partial z} K\omega\left[-2t + \sqrt{\frac{D_R^2}{4} - x^2} - z\tan\alpha\right]$$

$$= -K\omega \tan\alpha \qquad \ldots(3)$$

$$\dot{\epsilon}_y = K\omega\tan\alpha - \frac{4xV_0}{D_R^2\left[1-\frac{4x^2}{D_R^2}\right]^{1/2}}$$

...(4)

The equivalent plastic strain is defined as

$$\dot{\epsilon} = \sqrt{4\left[\frac{16x^2V_0^2}{D_R^2\left[1-\frac{4x^2}{D_R^2}\right]} + K^2\omega^2\tan^2\alpha\right] - \frac{4xV_0K\omega\tan\alpha}{D_R^2\left[1-\frac{4x^2}{D_R^2}\right]^{1/2}}}$$

…(5)

3. Estimation of the energy

(a) The energy of plastic deformation under the roller is given by

$$U_i = \frac{2}{\sqrt{3}}\sigma_y \int_0^{\theta_1} \dot{\epsilon}\cdot\frac{1}{2\tan\alpha}\left(t_0^2 - t_y^2\right)\frac{D_R}{2}\cos\theta\, d\theta$$

…(6)

Where σ_y is the average yield strength of the material

(b) The energy due to velocity discontinuity, U_a along the entrance line is, given by

$$U_a = \frac{1}{\sqrt{3}}\sigma_y \int_0^{z_1}\int_0^{t_y'} \sqrt{\left\{\left[-\frac{4xV_0}{D_R^2\left[1-\frac{4x^2}{D_R^2}\right]^{1/2}}.y - K\omega y\tan\alpha\right]^2 + (KV_0)^2\right\}} dy.dz$$

…(7)

(c) The frictional energy consumed on the contact surface between the roller and the blank, U_f is given by

$$U_f = \frac{\sigma_y}{\sqrt{3}} m \int_0^{\theta_1}\int_0^{z_g} |KV_0| \frac{D_R}{2} \cos\theta\, d\theta\, dz$$

…(8)

(d) The energy due to velocity discontinuity at exit of the metal from the roller

$$U_r = \frac{1}{\sqrt{3}}\sigma_y\left(V_z - \omega\frac{D_R}{2}\right)\frac{D_R}{2} \,x\, \theta_1 \,x(t_0 - t)\cos\alpha$$

…(9)

(e) The total energy consumed in the deformation, U_e is given by

$$U_e = (U_i + U_a + U_f + U_r)$$

…(10)

4. Working Forces

The velocity of displacement in the direction of y-axis over the contact area is given by

$$Y_f = \frac{V_0}{V_z}\int_0^{z_1}\int_0^{\theta_1}\left(\dot{\epsilon}_y \cdot \frac{D_R}{2}\cos\theta\, d\theta\right)dz$$

…(11)

The contact are on the x-z place is obtained by

$$S_f = \int_0^{\theta_1} z_1 dx = \int_0^{\theta_1} z_1 \frac{D_R}{2}.\cos\theta\, d\theta$$

…(12)

The radial force P_r is given by

$$P_r = \frac{U_e}{Y_f}.S_f$$

…(13)

The pulling force/axial force P_z,

$$P_z = P_r.\tan\alpha$$

…(14)

4.1 Working Data

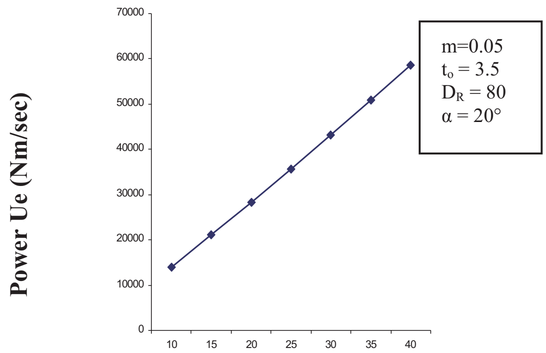
Diameter of the Roller 'D_R'	= 80 mm [80, 90, 100, 120 mm].
Diameter of the mandrel 'd'	= 18 mm.
Thickness of the tube 't_o'	= 3.5 mm
Reduction in thickness 'R'	= 10, 15, 20, 25, 30, 35, 40%
Angle of Roller 'α'	= 10, 15, 20, 25, 30 degrees
Friction factor 'm'	= 0.05 nominal
Average yield stress of the material 'σ_y'	= 791 N/mm^2 (791 MPa)
Angular speed of roller 'ω'	= 69 rad/sec
Constant used in equation for volume constancy 'K'	= 1.95
Maximum inclination of an element in the deformation zone situated at an angle with the vertical 'θ_1'	= 14°

5. Results and Discussion

A simplified analysis is presented where eqns. 6-10 give the variation of the power consumption with the process variables D_R, t, t_0, α, v_0 whilst eqns. 11 to 14 give the variation of force with the same process variables. The effect of variation in the different process variables is shown in the graphs of Figs. 4-16.

5.1 Variation in Power and Forces with Respect to the Variation in %age Reduction

It is obvious that the power consumption increases as the percentage reduction increases, and so do the forces.



Reduction (%) R

Fig. 4 : Relationship between U_e and R

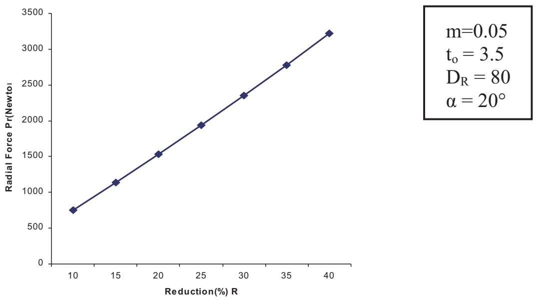


Fig. 5 : Relationship between Pr and R

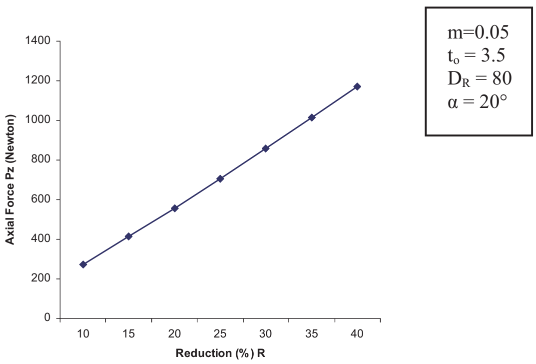
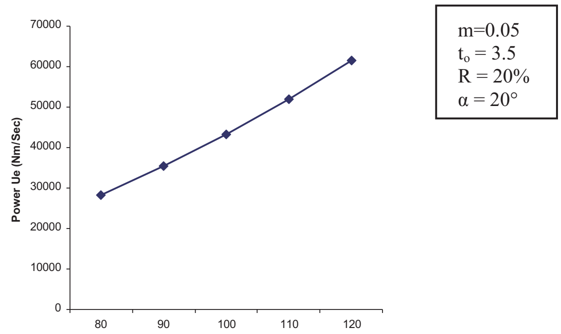


Fig. 6 : Relationship between P_Z and R

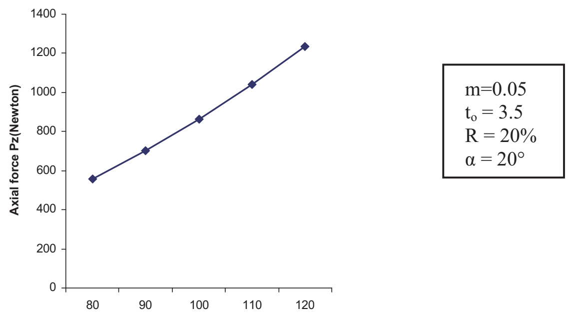
5.2 Variation in the Power and Forces with Respect to Variation in Diameter of the Roller.

This may be because of the fact that as the diameter of the roller increases, the area of contact between the roller and the work piece increases which necessitates more power and larger forces to cause the yield and flow of material.



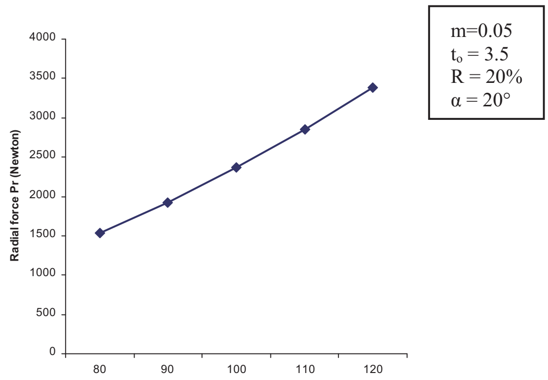
Diameter of Roller (mm) D_R

Fig. 7 : Relationship between U_e and D_R



Diameter of Roller D_R (mm)

Fig. 8 : Relationship between P_Z and D_R



Diameter of Roller D_R (mm)

Fig. 9 : Relationship between Pr and D_R

5.3 Radial and Axial forces Vs Initial Wall Thickness of the Work Piece.

It can be seen that the forces increase with the increase in the initial wall thickness of the workpiece. As the wall thickness increases the volume of the material to

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be pushed over the mandrel also increases necessitating more forces.

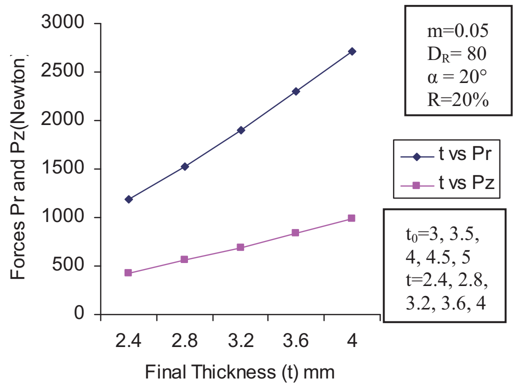

Fig. 10 : Relationship between Pr, Pz and t

5.4 Power consumption Vs Initial Stock Thickness

As expected the power consumption is high as the initial wall thickness is high even though the reduction per pass is kept constant.

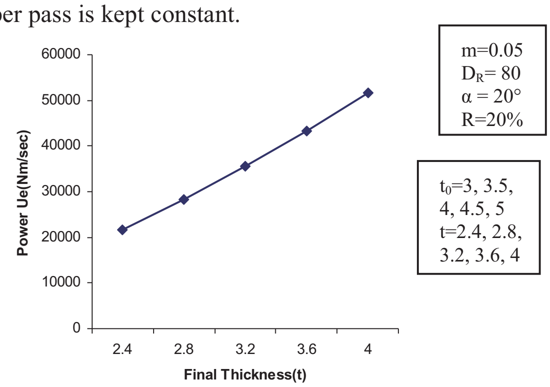

Fig. 11 : Relationship between U_e and t

5.5 Power, Axial Force and Radial Force Vs %age Reduction at Various Values of Roller Angle α

In the graphs, power and axial force the lines with α=15º, 20º, 22.5º and 25º are very close to each other whereas lines with 30º and 35º are considerably spaced. On the other hand in the graph radial force verses %age reduction the lines with α=20º, 22.5º, 25º, 30º and 35º are quite close to each other whereas only one line with α=15º is at considerable space. Combining all these we can conclude that α is optimum between 20º and 25º Hayama and Kudo has reported that roller angle close to 20º-25° is optimum while working on soft materials.

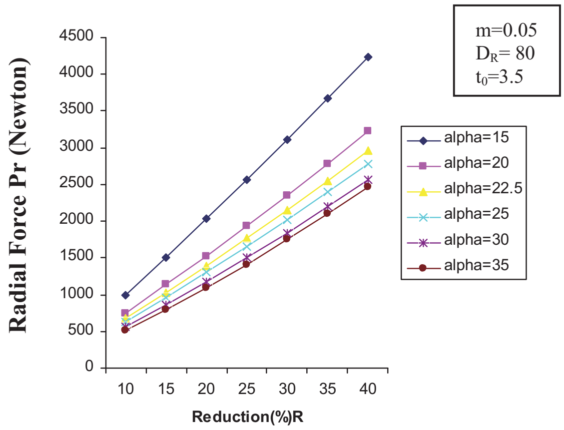

Fig. 12 : Comparison of relationship between Pr and R at different values of alpha

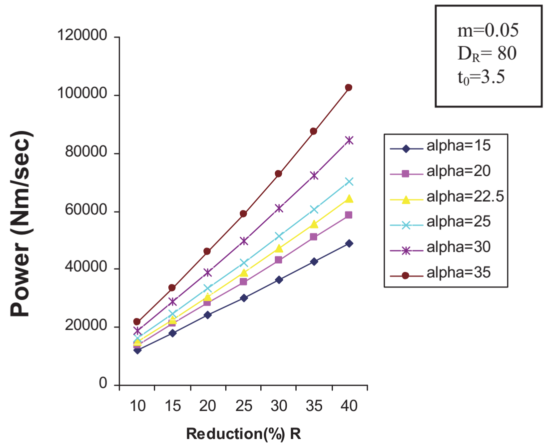

Fig. 13 : Comparison of relationship between Ue and R at different values of alpha

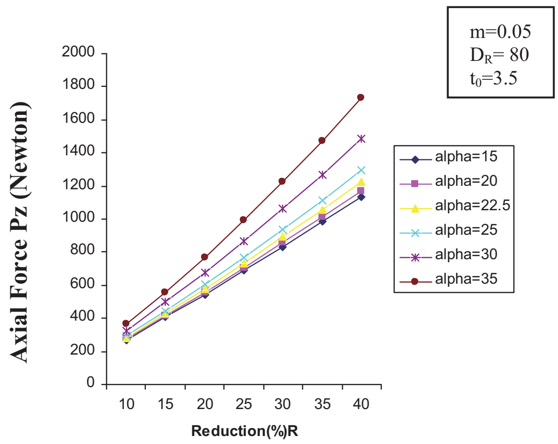

Fig. 14 : Comparison of relationship between Pz and R at different values of alpha

Conclusion

1. With the increase in %age reduction there is increase in power consumption, radial force and axial force. Same trend is observed by Hayama and Kudo while working on soft materials.
2. As the diameter of the roller increases there is increase in power consumption, axial force and the

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radial force. This is due to the fact that as the diameter of the roller increases, more volume of the material comes into contact due to which more power and forces are required.

3. As the initial stock thickness of the tube increases, due to this the volume to be removed increases with increase in %age reduction. Thus more power and forces are required for material removal.
4. The roller angle α is optimum in the range of 20º-25º. The same trend has been found in the work of Hayama and Kudo while working on soft materials.

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