# A Study on a Power-Analysis of Shear Spinning

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# 전단 스피닝의 동력해석에 관한 연구

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## Introduction

With a large cone angle, wrinkles are apt to form on the frange, while with a small cone angle, fractures are liable to appear on the wall and the limit of shear spinning is determined by the appearance of either the wrinkles or the fracture. Then the feed of fracture is regarded as the important working condition in shear spinning that has an influence on spinnability (Kim, 1981). The clearance between the roller and the mandrel was kept to to sin $\alpha$ and the roller was not controlled by oil pressure (Choi, 1980). Among many kinds of working conditions having an influence upon fracture, the most important factor is feed of roller V (Hayama, 1963).

For various values of feed of roller, there is no crack formation and the cone is finished at V=0.71mm/rev (Hayama, 1966), but at= 0.74mm/rev, a crack is found at the top of cone. But this crack does not propagate and does not interfere with the subsequent working. At far larger feed of roller V=0.8mm/rev (Hayama, 1966), A facture occurs. Therefore, it is recognized that there is a safely limit to the rate of feeding of roller. When cone angle is large, even at large feed of roller, fracture does not process is wide, on the other hand in small cone angle, it is limited (Murodo, 1965). Below this limit, a metal sheet may be worked successfully even when the cone angle is below 20 degrees. So it is precipitate to decide that the minimum angle to which a cone may be shear spun from a blank is 30 degrees (Hudo, 1966). In this paper, the theoretical estimation of the working forces in shear spinning of cone is important on the selection of the roller as well as on designing of the spinning lathe. The roller is assumed to be obtained geometrically or modified by introducing the special contact factor. The calculated results and compared with the experimental results for many different working conditions obtained by the outher.

## General Description

Assuming that a fracture occurs when the stress acting on the crack reaches the fracturing stresses of the material, the effective sectional area can be obtained by dividing the fracturing force of feed Ps by the fracturing stress $\sigma_B$ of the material.

Table 1. Example of working conditions and calculated factors used for comparison of experimental results.

| Working conditions | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Cone angle of mandrel (rad) | | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Minimum diameter of mandrel dm (mm) | | 60 | 60 | 60 | 60 | 60 | 60 |
| Roller diameter $D_R$ (mm) | | 120 | 71 | 30-120 | 120 | 74 | 119 |
| Radius of round off roller $\rho_R$ (mm) | | 12 | 4 | 4 | 4-12 | 12 | 4 |
| Feed of roller V (mm rev) | | 0.25-1.0 | 0.5-2.0 | 1.0 | 1.0 | 1.0 | 0.8-1.0 |
| Blank thickness $t_0$ (mm) | | 2 | 2 | 2 | 2 | 2 | 1.5-3 |
| Blank diameter $D_0$ (mm) | | 150 | 150 | 150 | 150 | 150 | 150 |
| Roller position $r_a$ (mm) | | 35 | 40 | 40 | 35 | 40 | 40 |
| Deformation resistance $\sigma_m$ (kg, mm$^2$) | | 13.5 | 13.5 | 13.5 | 13.1-13.5 | 13.5 | 13.6-12.7 |
| Young's modulus E (kg mm$^2$) | | 7200 | 7200 | 7200 | 7200 | 7200 | 7200 |
| Speed of rotation of mandrel N (R.p.m) | | 110 | 440 | 440 | 110 | 440 | 110 |
| Calculated values of $m_O, r_O, a_1, E_1$ | $m_O$ | 0.749 | 0.851 | 0.924 | 0.812 | 0.849 | 0.650 |
| | $r_O$ | 47.23 | 41.55 | 45.28 | 45.09 | 43.05 | 48.09 |
| | $a_1$ | −0.004 | −0.004 | −0.028 | −0.034 | −0.06 | −0.01 |
| | $E_1$ | 1.189 | 2.876 | 5.963 | 6.943 | 10.16 | 1.859 |

As the thickness of the wall is known, the effective width $\ell$ for fracturing can be calculated. It is shown in Table 2.

On the other hand, the theoretical contact length $\ell_{th}$ between the roller and the blank is obtained as Table 2.

Table 2. Relationship between fracturing stress of wall and contact length ($t_0$:1mm)

| Cone angle deg | Fracturing stress of tensile stress $\sigma_B$ kg/mm$^2$ | Fracturing force of feed Ps kg | Effective contact lengh mm | Theoretica contact length mm |
|---|---|---|---|---|
| 35 | 15.7 | 29.0 | 6.12 | 3.78 |
| 40 | 14.3 | 30.0 | 6.11 | 6.56 |
| 45 | 14.7 | 31.8 | 5.64 | 7.55 |
| 60 | 14.3 | 36.0 | 5.03 | 9.47 |

So it is assumed that the wall stress $\sigma_W$ is decided by dividing the fracturing force of feed $P_s$ by $\ell_{th}$ x $t_0$ sinα The relationship between $\sigma_W/\sigma_B$ and $\ell_{th}$ can be obtained as in Fig. 1. Even $\sigma_W/\sigma_B<1$, if $\sigma_W$ works over a certain width, the crack propagath. On the other hand, even $\sigma_W/\sigma_B>1$, if $\sigma_W$ works concentratively, the crack does not propagate and the cone can be finished (Kalpakcioglu, 1961). From the above consideration, the determination of the critical feed of roller is more important than the discussion of the critical cone angle, and it is possible to be shear spun by a very small cone angle, if the choice of roller is appropriate.

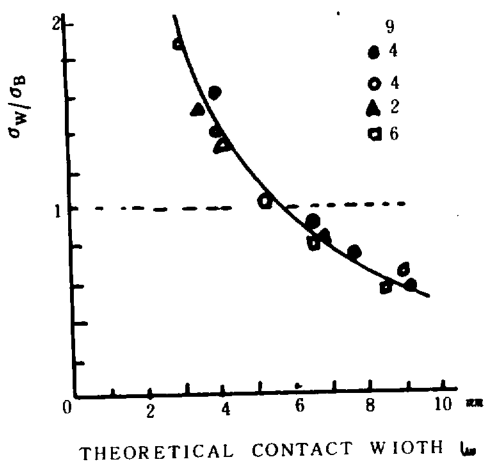

Fig. 1. Relationship between $\sigma_w/\sigma_B$ and 1th.

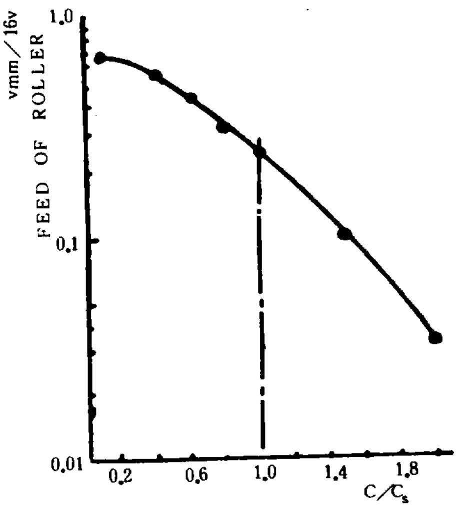

Fig. 2. Effect of deviation from sine-law thickness on the critical feed of roller.

Then the investigation of the effect of a few working conditions on the critical feed of roller will be useful guide in practice. The variation of $\rho_R$ brings about the difference of the bending process in the initial deformation, and has an influence on the deformation of a constriction part. But it is presumed that the critical condition of fracturing is the same one as in Fig. 1. by adding the date for $\rho_R$=2mm (to be marked ◇) and 6mm (to be marked ☐) to $\rho_R$=4mm. As the increasing number of revolution of mandrel has little effect on fracture and tends to increase the critical feed, so it is beneficial to shear spinning process (slatter, 1978).

As in Fig. 2, it is observed that the critical feed of roller increases as the part is over-reduced and decreases when under-reduced. When the wall is over-reduced, the region pushed out back-ward the roller increases and also the radial force Pr (force component in perpendicular direction to the roller axis) becomes larger, while the feed force Ps little increases. Then the compressive stress region becomes wider just under the roller, so it is difficult for a crack source to occur and it is profitable to form a cone without fracturing (Hayang, 1968). The working forces are composed of two different forces of deformation, one is the deformation of the blank on the round-off of the roller $r_c>r>r_0$ and the other is on the top of the roller $r_c>r>r'_a$, $r_0$ denotes the border that the blank is squeezed between the roller and the mandrel as shown in Fig. 3.

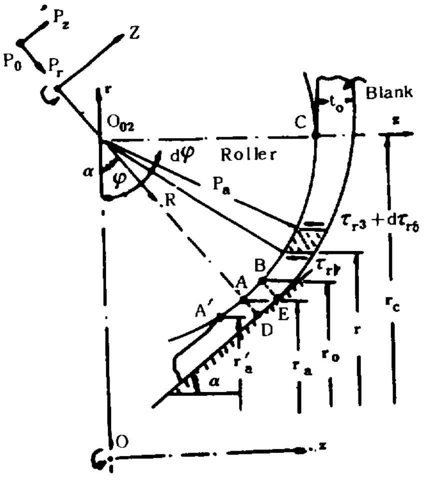

Fig. 3. Illustration of deformation of blank on roller.

$$\left.\begin{aligned} r_a' &= r_a - V\sin\frac{\alpha}{2} \\ r_o &= r_a + (\rho_R + t_o \quad \sin\alpha - \\ &\quad \sqrt{\{\rho_R^2 - (t_o\cos\alpha)^2\}}\cos\alpha \\ r_c &= r_{o2} = r_a + \rho_R \cos\alpha \end{aligned}\right\} \quad (1)$$

The feed force is derived from the bending and shearing deformation of the blank on the roller. In order to obtain the component of the feed force about an arbitrary element, a new equation is proposed as follows.

$$\frac{dP_{z_1}}{\sigma m} = \left\{\frac{E_1'}{\sigma_{Zm}} \frac{\eta_m}{S_m} + \frac{4t_o}{\sqrt{3}\rho_R^2}(r_c - r)\eta_m\right\}\cos\alpha \, dr \quad (2)$$

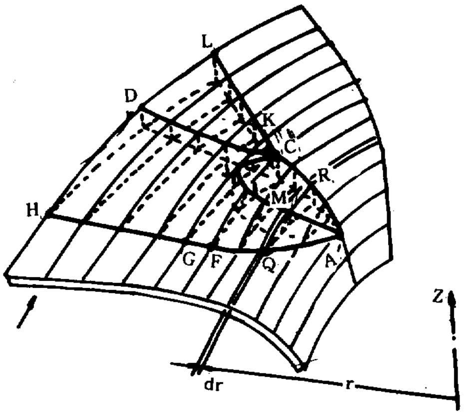

Fig. 4. Model of deformation of blank in shear spinning.

$E_1'$ : The bending energy consumed on the bending line of contact A'QFG in Fig. 4.

$\eta_m\, dr/S_m$: A multiplyer to get on an arbitrary element of the blank.

$S_m$: The projection of the actual contact area on the $\eta$-r plane in Fig. 5.

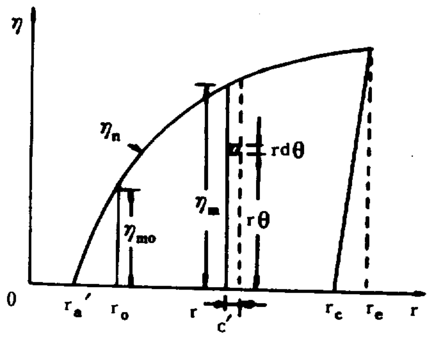

Fig. 5. Illustration of deformation of blank by $\eta$-r plane

$$E_1' = \frac{E_1}{\sigma_m} = \frac{t_o^2}{4}\int_{r_a'}^{r_e}\frac{\Delta_z}{8\eta_\rho}\,\frac{16(1-m)^3 + \eta_\rho m m_r + 2\eta_{\rho r}(1-m)(2-m)\}^2}{(1-m)^{5/2}}\,dr$$

$$\Delta Z_m = \int_{r_a'}^{r_e} \Delta Z \, dr\,(r_e - r_a') \quad (3)$$

$$S_m = \int_{r_a'}^{r_e} \eta_m \, dr - (r_e - r_c)\,\eta_{me}/2$$

$\sigma_m$ : The mean deformation resistance of sheet metal obtained from the stress strain curve in the tensile test.

Suffix e: The value at r=re shown in Fig. 5.

Suffix r: The differentiation with respect to r.

The force components in the axial direction of the mandrel acting over the contact area is given as follows.

$$P_s = \int_{\rho_o}^{\rho_c} 2k\sin(\pi - 2\rho)\, t_o \eta_m \, d\phi \quad (4)$$

considering $r_c - r = \rho_R \cos\phi$,

$$P_s = \frac{4t_o}{\sqrt{3}\,\rho_R^2}\,\sigma_m \cdot \int_{r_o}^{r_c} (r_c - r)\eta_m \, dr \quad (5)$$

The other components of forces about can element can be obtained as follows.

$$\frac{dPr'}{\sigma m}=\frac{dP_{t_1}}{\sigma m},\ \frac{\cos\theta}{\tan\phi} \qquad (6)$$

$$\frac{dP\theta'}{\sigma m}\quad\frac{dP_{t_1}}{\sigma m}\quad\frac{\sin\theta}{\tan\phi}$$

As $\theta$ and $\phi$ is the directional angle of the force defined by the coordinate centered of the roller, So it is necessary to transfer to the coordinate centered of the mandrel by the following equations.

$$\tan\theta=\frac{r\sin\theta}{R_o+(r_{o2}-r\cos\theta)\cos\alpha+(Z_\eta-Z_{\theta 2})\sin\alpha} \qquad (7)$$

$$Z_n=Z+\Delta Z-(1-m)\ \Delta Zr\theta/\eta_m$$

The blank is squeezed between the roller and the mandrel.

Then the component of the radial force is derived directly by assuming two dimensional compression.

$$P_{r2}/\sigma_m=1.155\ \eta_{mo}\,t_o\cos\alpha/2 \qquad (8)$$

Finally, we can complete the equations to get the tree components of the working forces in shear spinning of cone by using the equation (2) (6) (8).

$$\frac{P_s}{\sigma_m}=\int_{r_o}^{r_c}\frac{dP_{z1}}{\sigma_m}+\frac{P_{z2}}{\sigma_m}$$

$$\frac{P_r}{\sigma_m}=\int_{r_o}^{r_c}\frac{dP_{r1}}{\sigma_m}+\frac{P_{r2}}{\sigma_m} \qquad (9)$$

$$\frac{P_\theta}{\sigma_m}=\int_{r_o}^{r_c}\frac{dP_{\theta 1}}{\sigma_m}+\frac{P_{r2}}{\sigma_m}$$

## Result and Discussion

In order to calculate Equation (9), we have to decide the actual area of contact between the blank and the roller.

1. (1) The limit of shear spinning process is determined by the appearance of either the wrinkle or the fracture. With a large cone angle, wrinkles are apt to form on the flange, a while with a small cone angle, flactures are liable to appear on the wall. For these failures, feed of roller is the most important factor. Therefore, the critical of roller should rather be discussed than the critical cone angle.
2. (2) When the tensile stress $\sigma_W$ acted on the wall is concentrated, the crack does not propagate even through $\sigma_W$ is over the the fracturing stress $\sigma_\theta$ of tensile test. On the other hand, when $\theta$w spreads around the crack, the crack leads to the fracture of the wall, though $\sigma_W/\sigma_B$ so it is not proper that the fracture should occur $\sigma_W/\sigma_B$ under the condition of $\sigma_W=\sigma_B$
3. (3) The critical feed of roller for fracturing is affected by the shape of rolle and mandral, blank, tempering of sheet, especially the clearance between the roller and the mandrel.
4. (4) The optimum value of $m_e$ $r_e$, a, and E, are decided by minimizing the total energy $E_t$ consumed during the process.
5. (5) The three components of working forces can be extimated theoretically by solving the newly proposed equations.

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## 國 文 抄 錄

이 연구는 전단스피닝의 동력계산이전에 가공중 유발할 수 있는 파괴의 요인을 규명하였다. 즉, 기계의 진동과 작업의 불안정(변형의 처음상태에서 압축현상)과 로-라와 접촉한 면이나 점에 인장응력이 국부적인 집중현상으로 일어날 수 있다.

계산으로부터 원추전단스피닝에서 가공력의 3성분은 단지 작업조건과 금속판의 기계적인 성질을 제시함으로 이론적으로 규명하였다. 동력해석은 가공력을 파악하고 소성가공에서 가공조건을 선택하는데 활용되며 기계설계자료에 유익할 것이라 사료된다.