Grinding Force and Feed in Grinding the Spring End

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***Abstract*—As a case study of vertical shaft spring grinder, this paper analyses the process of spring end grinding and establishes geometric model of spring face grinding, then calculates the formula of grinding force by the formula of surface grinding machine with vertical spindle and rotary table. Meanwhile, the paper also analyses the relation of grinding feed and depth, and applies controlled-force grinding to spring end grinding. In order to guarantee the grinding force with a fixed value, the grinding feed will be changed with the grinding depth. Considering the spring as an elastomeric, the wheel's feed is composed of grinding feed and compensating feed when the spring end is grinded.**

Keywords-Spring End Grinding Machine; Spring; Face Grinding; Grinding Force; Feed

I. INTRODUCTION

The purpose of spring end grinding is to correct the verticality of spring and the parallelism of both spring ends, and to make spring ends and other components in close contact, and to improve the service life of compression spring by uniform pressure. [1] The requirements of the spring end grinding describe as follows :①the grinding angle is at least 270 °; ②the thickness of the end needs to be not less than 1/8 of the spring wire diameter(1/4 is the best).[2]

Spring end grinding belongs to face grinding, and the characteristic of the spring determines unique grinding process. With the change of grinding depth, grinding area and positive pressure between spring and wheel change in the spring end grinding process. In this way, if the pressure grinding is adopted, the grinding force will be inconstant and grinding efficiency must be low. To improve grinding efficiency and grinding accuracy, the control force grinding is applied with constant grinding force. This grinding method is good for the low-rigidity grinding system. According to the spring grinding process, this paper deduces the grinding force of spring end grinding theoretically, and analyses the relationship of the grinding force with the grinding feed and depth.

II. ANALYSIS OF THE FORMULA OF GRINDING FORCE FOR FACE GRINDER

At present, because of the lack of the formula of grinding force at home and abroad, it is difficult to show grinding performance and potential load of grinder.[4] The study for grinding force of face grinder are few, especially for the spring. This paper deduces the grinding force of spring end grinding which are based on the grinding force formula of vertical axis surface grinder with round table.

The grinding force formula of vertical axis surface grinder with round table [5]:

$$Fa = 9.81[C_F \cdot \pi \cdot \mathrm{n} \cdot f_a \cdot R^2 / v_2] \tan \beta \tag{1}$$

Where Fa is vertical grinding force, N; n is the speed of spring, m/s; v2 is the speed of wheel, m/s; fa is axial feed, mm; CF is the energy which are required to remove unit volume of abrasive dust, kgf/mm2; β is the half-angle of abrasive cone, 61°~69°35′; R is the radius of workbench, mm.

Where [π·n·fa·R2] is the volume of abrasive dust in unit time. V is the volume of abrasive dust of single spring in unit time; N is the number of grinding spring in unit time. So the formula of axial grinding force of spring end grinder is:

$$F_a = 9.81[C_F \cdot N \cdot V / v_2] \tan \beta \tag{2}$$

III. GEOMETRY MODEL OF SPRING GRINDING

V, the volume of abrasive dust of single spring in unit time, will be derived by selecting single spring for research object. According to the grinding features of the helical cylindrical compression spring, get spring end ring straightened out, as showed in fig.1. Fig.2 shows sectional view of spring end ring when end grinding. In the picture, α is spring spiral angle (typically 5°~ 9°). OB is total grinding height, which is typically 3/4 wire diameter. h is arbitrary grinding height, make a line to parallel AC ,which line through the point P and intersects with the lines AB、BC at M、N (see Fig.1).

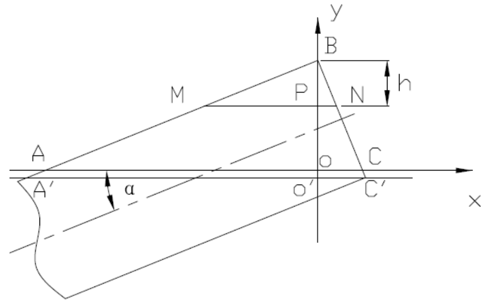

Fig.1. Geometry model of spring end ring

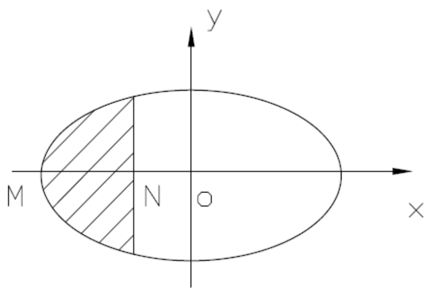

Fig.2. Cross section of spring end ring

As showed in Fig.2, the area of shaded parts is grinding area in arbitrary grinding height. Known form geometrical relationship, grinding area is always an ellipse that d/sinα is major axis and d is minor axis, where d is wire diameter.

With grinding area which lines in grinding depth h increase, line MN will increase and point N will gradually close to another elliptic endpoint, so area of shaded parts will increase. Order a=d/sinα, b=d,

$$l=MN=h(\tan\alpha+\cot\alpha) \tag{3}$$

So the area of shaded parts is :

$$\begin{aligned} S &= \int_{-a}^{l-a} \frac{2b}{a}\sqrt{a^2-x^2}\,dx \\ &= b(\frac{l}{a}-1)\sqrt{2al-l^2}+ab\arcsin\frac{l-a}{a}+\frac{1}{2}\pi ab \end{aligned} \tag{4}$$

Because grinding depth is very small when spring is grinded, the grinding volume of single spring can be worked out, as follow.

$$\begin{aligned} V &= \int_{h}^{h+ap} S dh \approx S\cdot a_p \\ &= [b(\frac{l}{a}-1)\sqrt{2al-l^2}+ab\arcsin\frac{l-a}{a}+\frac{1}{2}\pi ab]\cdot a_p \end{aligned} \tag{5}$$

IV. SOLUTION OF THE NUMBER OF GRINDING SPRING IN UNIT TIME

The number of grinding spring in unit time has a relationship with the center distance between tray and wheel、the diameter of trough relative to the center of tray and the speed of tray. As shown in Fig.3.

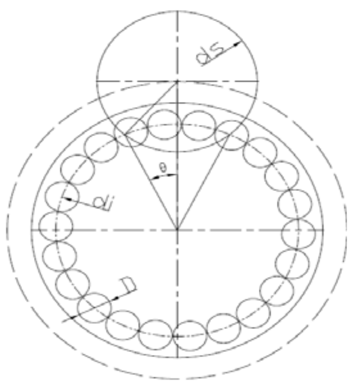

Fig.3. Shows position between tray and wheel

$$N=\sum_{i=1}^{m}\left(\frac{v_i}{D}+\frac{1}{D}\cdot\frac{\pi\cdot d_i}{180}\cdot\arccos\frac{d_i^{\,2}+4L^2-d_s^{\,2}}{4L\cdot d_i}\right) \tag{6}$$

Where m is the number of turns of spring trough in tray, typically is 1~3; i is the i-th ring of spring trough; vi is the speed of the i-th trough relative to the center of tray, m/s; d_i is the diameter of trough relative to the center of tray, mm; d_s is the diameter of wheel, mm; D is the diameter of trough, mm.

V. SOLUTION OF THE GRINDING FORCE AND FEED

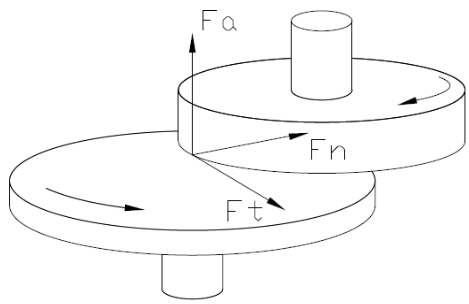

Fig.4. Schemes to the decomposition of grinding force in face grinding

Grinding force between wheel and spring in grinding can decompose into three component force: tangential force F_t which follows tangential direction of rotate wheel; radial force F_n; axial force F_a. According to some theories in the literature, because wheel is composed of abrasive grains, radial force Fn and axial force Fa are very small. Therefore , the two force are out of account in this paper. From Eqs.(2) and (5), we can get grinding force's formula, as following equation:

$$\begin{aligned} F_a &= 9.81\cdot a_p\{C_F\cdot[b(\frac{l}{a}-1)\sqrt{2al-l^2} \\ &+ab\arcsin\frac{l-a}{a}+\frac{1}{2}\pi ab]\cdot N/v_2\}\tan\beta \end{aligned} \tag{7}$$

Wheel cutting-in of face grinding is equal to wheel down feed, and grinding depth of surface grinding is typically 10~50μm. We can assume that springs are grinded with a minimum depth when grinded to max grinding height, that is h=3/4d, a_p=10μm,

$$\begin{aligned} F_{a(\mathrm{ap}=0.01)} &= 0.0981\{C_F\cdot[b(\frac{l}{a}-1)\sqrt{2al-l^2} \\ &+ab\arcsin\frac{l-a}{a}+\frac{1}{2}\pi ab]\cdot N/v_2\}\tan\beta \end{aligned} \tag{8}$$

The grinding force $F_a(a_p=0.01)$ will be maintained in the whole grinding process, by this way, it can achieve controlled-force grinding. Different grinding depth h can correspond to different grinding feed a_p, and we can know the relationship between grinding depth h and grinding feed a_p from Eqs.(7) and (8).

VI. ANALYSIS OF THE TOTAL FEED OF WHEEL

The total feed fa can be found from the formula when spring grinding:

$$f_a = a_p + f_a' \tag{9}$$

Where a_p is grinding feed; f_a' is compensated feed which aims at overcome spring elastic potential energy.

Because spring has certain elasticity, wheel must produce enough positive pressure which applied on spring, by this way, abrasive grains with certain linear speed can cut spring metal matrix. Obviously, grinding feed a_p is based on compensated feed f_a'. When spring is grinded with critical grinding thickness a_{min} of abrasive grains, the positive pressure between wheel and spring is defined as critical positive pressure. The critical grinding thickness a_{min} of abrasive grains can refer to table 1. [6]

TABLE.1. CRITICAL GRINDING THICKNESS $a_{\min}$

Material	r_g	$a_{\min}$	$k_s = a_{\min}/r_g$
Hardened carbon steel	6	1.5	0.25
Cast-iron	6	3	0.5
Annealing carbon steel	6	4	0.67

Where r_g is the radius of micro blade of abrasive grains; k_s is a parameter which can characterize the cutting ability of material.

Grinding demand decides on selection of r_g, different granularity can corresponding to different harshness. In general, we use alumina grains for wheel when spring end grinding, and the keenness of alumina grains can be shown by r_g and tip angle of abrasive grains α, as follow in table 2

TABLE.2. THE KEENNESS OF ALUMINA GRAINS

Granularity	46#	60#	80#	W40	W28
r_g/μm	28	18	13	4	2.7
a/(°)	110	108	106	98	90

When springs are grinded with critical grinding thickness of abrasive grains, the formula of grinding force:

$$\begin{aligned} F_a' &= 9.81 a_{\min}\{C_F \cdot [b(\frac{l}{a}-1)\sqrt{2al-l^2} \\ &+ ab\arcsin\frac{l-a}{a} + \frac{1}{2}\pi ab]\cdot N/v_2\}\tan\beta \\ &= 9.81 r_g \cdot k_s\{C_F \cdot [b(\frac{l}{a}-1)\sqrt{2al-l^2} \\ &+ ab\arcsin\frac{l-a}{a} + \frac{1}{2}\pi ab]\cdot N/v_2\}\tan\beta \end{aligned} \tag{10}$$

Positive pressure from pressure spring should meet the formula:

$$\begin{aligned} F_N &= K \cdot f_a' = F_a'/N \\ f_a' &= F_a'/(K \cdot N) \end{aligned} \tag{11}$$

Where FN is elasticity of single spring; K is spring stiffness; N is the number of spring.

The relationship between total feed and grinding can be found from Eqs.(7) 、 Esq.(9) and Eqs.(11), it plays an important guiding significance in spring end grinding and can vastly improve the grinding efficiency and grinding quality.

VII. CONCLUSIONS

1. The process of spring end grinding is analyzed and the feasibility of controlled-force grinding using for spring end grinding is proved. The grinding force formula by analyzing geometric model of spring grinding is introduced to ensure the power of grinding head motor. These theories are of great help in designing spring grinder and confirming technology.

2. The process of spring grinding must have a constant grinding force. As the grinding depth increase, grinding area will increase and grinding feed will decrease.

3. Spring is considered as an elastomer and the grinding feed can be divided into two parts: one is grinding feed and other is compensated feed. The former is built on the latter, so we must consider both feed in spring end grinding.

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