SCIENTIFIC WORKS ON THE GEAR FORMING-GRINDING

成形磨齿论文集

Authors Liang Xichang etc. 梁锡昌 等著

Trawslator Fang Fengzhou 房丰洲 译英

Proofreader Du Chengnan 杜承南 校英

Chongqing University

重 庆 大 学

1 9 8 4

Address Chongqing university
Chongqing China
Telephone 661185
Telex 6234

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Gear Forming-Grinding and the Design of Dresser

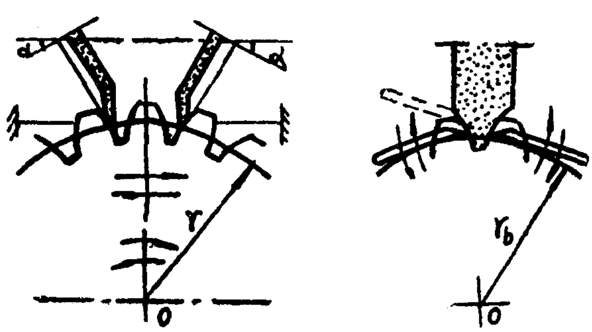
Liang-Xichang Fang-Fengzhou Wang-Xujin

Abstract

Gear grinding is the main process on the quenched gear. From the efficiency, a new gear forming-grinding process is presented in this paper. And the optimum design of the key set, that is, the dresser, on the gear forming-grinding is made. The test shows that the gear forming-grinding process used the new dressed may increase efficiency and decrease cost remarkably.

1. Development of gear grinding scheme

Gear grinding is the main machining means of quenched gear. It has many advantages as compared with the gear razoring and gear honing processes. In the generating method used widely, gear grinder MAAG is used mainly in quenched gear for the advantages of short transmission and high precision. But, because the movement part has big mass and inertia, the movement speed is not large lest the force borne and change of deformation are too long. Besides, the rigidity on grinding wheel of dish form is no better and cutting quantity is not too large, hence the efficiency is very low. And the machine construction is complicated and the cost is very high, therefore every workpiece's cost is very high. In order to keep



a) b)

Fig 1

the advantages of gear grinder MAAG and eliminate its shortcomings, we assume that the movement of rolling round is changed into the movement of rolling rod (Fig 1, b). Because the rolling rod is very light, the movement speed produced involuted profile may be increased very much and the efficiency is also increased. And generating grinding at very point is changed into forming-grinding in the whole tooth slot. It increases also gear grinding efficiency remarkably. Because the movement of the machine is simplified into to and fro movement and division movement, the cost of machine would be much lower. Since the transmission set that forms involute profile is not changed, new grinding method still has a similar precision.

Taken together, gear forming-grinding has high efficiency, high precision and low cost.

2. Work principle and Construction Scheme of New Dresser

Now in our country, the dresser on involute forming grinding wheel of whole rod is used in some factories. The main problems of this dresser

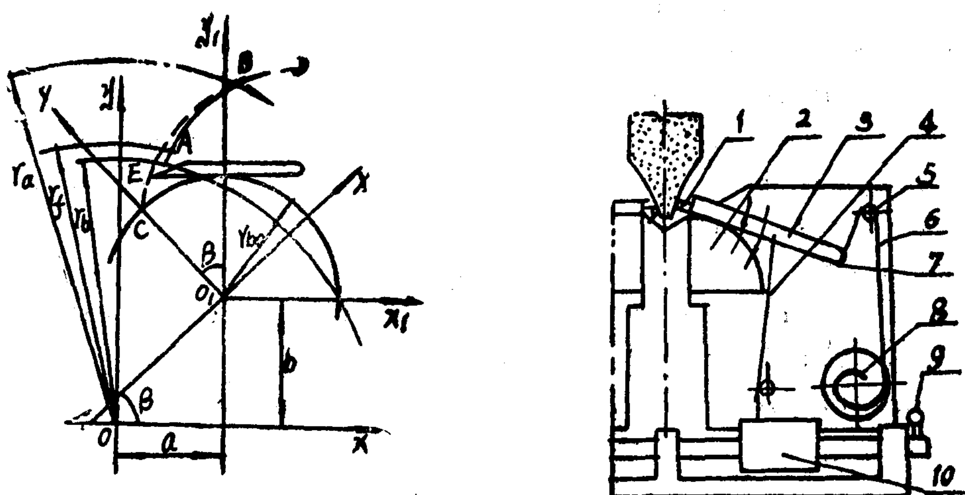


Fig 2

are, 1) when right diamond point is rotated clockwise to the wheel, the position of left diamond point is as shown in the figure and left surface of the wheel would be dressed off. Therfore only after the right surface of the wheel is dressed by using right diamond point, the diamont point is replaced to left side to dress the wheel. The efficiency and stableness lower. 2) non-involute part can not be used in gear production.

In order to solve the problems above mentioned, our university presented

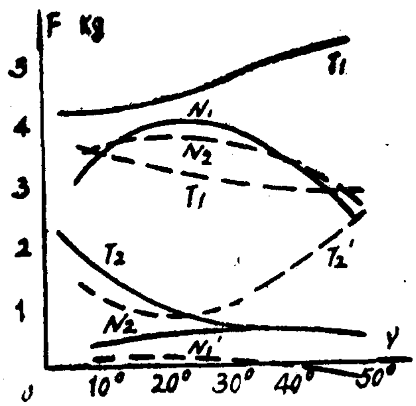


Fig 3

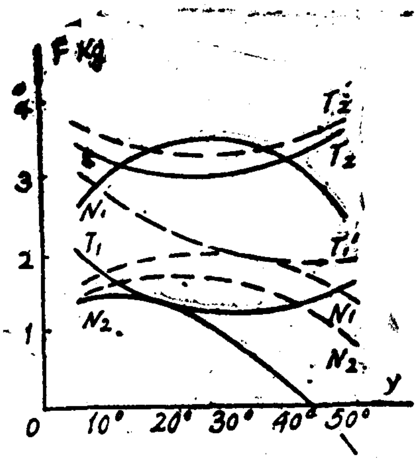


Fig 4

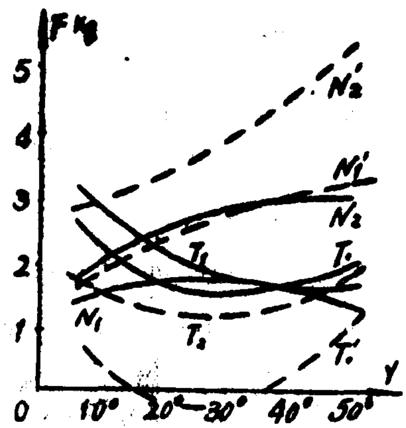


Fig 5

the gear grinding of replacement involute curve. Its fundamental idea is, since the wheel would grind off base round, we assume to make round be somewhat small. The smaller base round is used to replace original base round of the gear (Fig 2, a). Assuming that involute curve of gear is AB and the involute curve on replacement base round is CD, we can make CD to approach AB by means of regulating the position a, b of centre O_1 of replacement base round. The calculation on a, b has been stated in [1]. Left and right diamond points are used to dress two forming surface of grinding wheel by using a new work method at same time. And non-involute part may be dressed also. The grinding wheel would not cut off base round.

After this new work method is found, the revelant set must be designed to make the rolling rod do simple movement on base round. We set a steel belt between both. The end is fixed on the base round, and the other end is fixed on rolling rod 3. Rolling rod 3 is moved clockwise down from steel string 4. Plane spring 8 is used through pulley 5 to pull rolling rod to move counter clockwise. The aim used plane spring is to make rolling rod end to be pulled at a similar constant force in movement. The action of pulley is to make rolling rod to have a certain pressure N and pull T to base round in any position. When handle 9 is rotated, two wheels 10 on horizontal shaft pull two steel string to make two diamond points dress grinding wheel at same time.

In order to make rolling rod do ideal simple movement, while it rotates, pressure N of rolling rod to base round is required to have a suitable value and remain constant. Pull 7 of steel belt to pull rolling rod should have also a suitable value and remain constant. The test shows that change scope of the pressure N and the pull T had beter not exceed 30 per cent. When rolling rod is rotated on base round, because force direction of steel string 4 and fulcrum position of base round are always changed, forces N and T calculated change with rotation angle γ of rolling rod changed as shown in Fig 3 to 5.

3. Construction Optimum of the Dresser

After construction scheme of the dresser is decided, revelant parameters should be selected correctly to keep pressure N and pull T of rolling rod to be constant fundamentally. For this reason the force figure of machanism is made. From the figure, rolling rod is acted by base round N, steel belt pull T, steel string pull P and spring action Q. The calculation shows that the constance of the two forces is affected by the rolling rod length S, the support length t, the position x_1, y_1 of pulley o_1 and the position x_2, y_2 of pulley o_2.

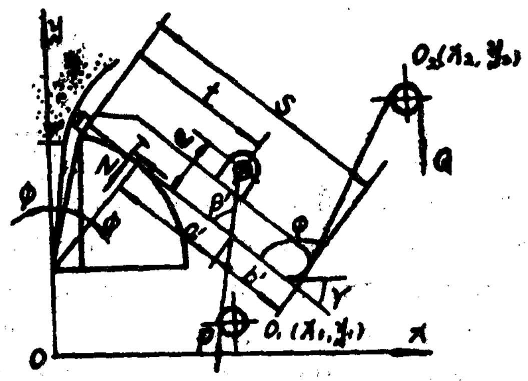


Fig 6

In Fig 3 real lines show, when rolling rod length $s_1 = 69$ mm and $s_2 = 109$ mm, the two forces are changed with rolling rod rotated. The dot lines show change of the two forces when support length $t_1 = 35$ mm and $t_2 = 75$ mm. In Fig 4 real lines show change of the two forces when pulley o_1 position $x_{11} = 45$ mm, $x_{12} = 65$ mm and dot lines show when $y_{11} = 65$ mm, $y_{12} = 105$ mm…, Besides, the constance of the two forces is affected also by the gear parameters. In Fig 5 real lines show $m_1 = 4$, $m_2 = 6$ and dot lines show change on $z_1 = 60$ and $z_2 = 90$. Taken together, factors that affect constance of two forces are many. And we may infer that there is an optimum scheme on object.

First of all, we find the statics relation of any position on rolling rod.

$$\begin{cases} P = \dfrac{(a+b)Q\sin\beta}{[t - r_b(\phi - \phi_0)]\sin\beta + e\cos\beta} \\ N = \dfrac{b}{a} Q\sin\phi \\ T = P\cos\beta - Q\cos\phi \end{cases}$$

In the formula, Q is pull of plane spring and the unit is kilogram, r_b is base circle radius of gear and the unit is millimeter, e is the rising distance of a point among rolling rod. When rolling rod is rotated, it may change the pulling point of the steel string to increase the constance of the two forces.

After the ideal value T* of pull and the ideal value N* of pressure are selected, objective function may be established.

$$F(s,\ t,\ x_1,\ y_1\ x_2) = \left(\frac{N_i}{N^*} - 1\right)^2 + \left(\frac{T_i}{T^*} - 1\right)^2$$

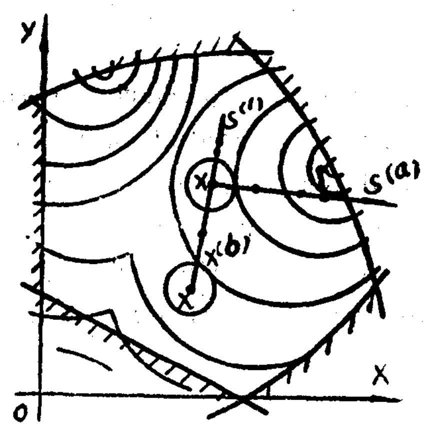


Fig 7

The meaning of right part $\left(\frac{N_i}{N^*} - 1\right)$ on above formula is that pressure N_i at any rotation angle is desired to approach the ideal value N^*. In this case, $\frac{N_i}{N^*}$ is similar to 1 and this item is minimumized.

Stochastic direction seeking is used to find optimum value on computer. The principle of this method is as shown in Fig 7. First of all, beginning point $X^{(0)}$ is selected and feasibility conditions are tested. Then N stochastic unit vectors $s^{(j)}$ $(j = 1, 2, \cdots, N)$ are made. After seeking direction

$s^{(1)}$ is found by minimum function value, new point $X^{(1)}$ is decided to replace beginning point $X^{(0)}$. Every item is repeated by this till satisfactory construction parameters s, t, o_1, o_2 are found.

4. Reasonable Use of the Dresser

After optimum means is used to design the dresser, the problem of production must still be solved. Because of this, the construction optimum of various cylinder gears is made (m=1.5~8, pitch circle diameter d = 30~310 mm). Fig 8 shows the effect of gear pitch circle diameter to optimum construction parameters. From the figure, reasonable construction parameters of the dresser are changed as the pitch circle diameter is changed. This is because when the pitch circle diameter is changed, the change of rolling point and the size of rotation angle of rolling rod have to be changed. Because the effect of y_2 is very small and the construction is restricted, it is designed to be constant.

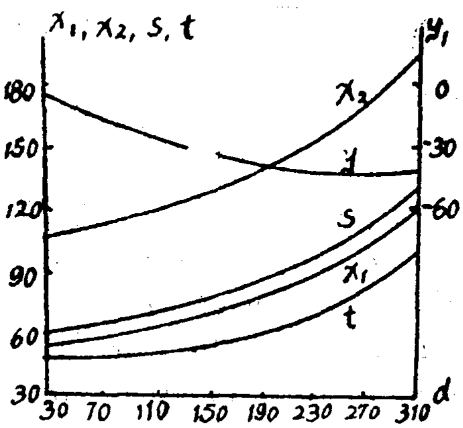


Fig 8

In order that the use is convenient, after the optimum parameters of various gears are calculated, by this change the construction parameters are divided into four groups. Different position parameters are arranged by the hole is drilled on the base (Fig 8). New integer values are used for testing. The change of the two forces and regulation table 1 of the dresser are obtained. Therefore the regulation of the dresser is simplified greatly.

Conclusion

Nowadays gears are being developed to large power, small volume and long life, quenched gear is used widely. But now the precision of gear is lowed 1 to 3 degrees after heat treatment. The accurate generation of quenched gear become a key problem of the machine industry.

Grinder MAAG is the high precision gear grinding equipment used widely. From its shortcomings, a new gear forming-grinding is developed,

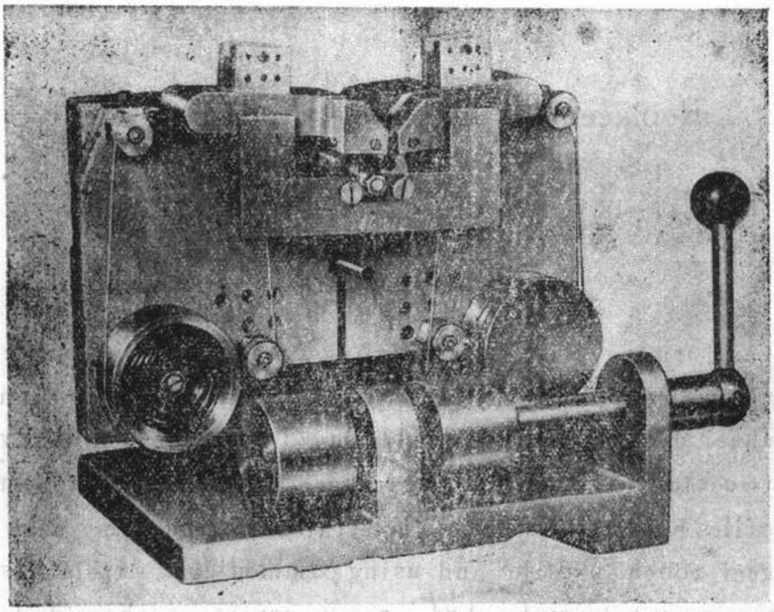


Fig 9

Table 1

NR	gear parameters			dresser parameters				
	pitch circle diameter d	pressure angle α	profile shift coefficent ξ	s	t	x_1	y_1	x_2
1	30～120	20°	0	70	50	60	0	120
2	121～200	20°	0	90	65	75	−15	140
3	201～260	20°	0	115	80	90	−30	160
4	261～310	20°	0	140	100	115	−45	190

After relevant dressing principle is advanced, the construction design of the dresser and the parameter optimum of the construction is discussed and optimum working condition of the dresser is found. For the use of factories, a regulation is put forward in this paper

The test shows that gear grinding precision of this new gear grinding method can be obtained as 6 degrees and efficiency can be increased several times, cost decreased several times. To middle and small factories, the dresser of low cost is needed to provide and quenched gear may be produced. It is economical.

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Replacement Involute Grinding of Gear

Liang xichang

Abstract

The gear forming-grinding principle on which replacement involute curve is used to approach the gear profile is presented and the new grinding wheel dresser is developed. The dresser has the advantages of dressing two sides of the grinding wheel as well as the non-involute part of the profile beneath the base circle at the same time and of grinding modified gear tooth profile and using common base circle disks. Besides, its structure is quite simple. And a new prospect is showed for forming-grinding of gears more efficiently and more economically.

Gear grinding is the main machining means of quenched gears. Gear grinding is divided in two groups, forming grinding and generating grinding. The precision which the generating grinding method can get is not so high because this kind of grinder's transmission is long, the rigidity low, and the generating structure heavy. And the weight of the machined gears changes greatly. But forming grinding dresser is simple in construction and small in size. And its precision is higher [1—3]. Besides, the forming grinding method can increased the productivity many times and reduce the cost greatly.

Nowadays, almost only generating grinding method is used in production in our country, but not so widely for its high cost. It is necessary to develop a new gear grinding method with high efficiency and low cost. In recent years, a lot of researches have been done on this problem[1, 2, 4], but the practical method has not been found yet. A dresser coming from the involute principle is discribed in Fig 1. When the rolling rod (4) with a diamond (3) is rolled on the base circle disk (1) by the steel belt (2), the involute profile of the wheel is dressed. The diameter of the root circle must be bigger than that of the base circle to prevent wearing off the base circle disk and the belt. If it is 2 *mm* bigger for the gears which modulus are 4 *mm*, the number of teeth must be bigger than 58, which losts the practicality.

Nowadays, the involute dresser used in production in our country has a two layer construction that a base circle plate seperates with grinding wheel in space. It can not dress two involute forming surface at the same time and can not dress non-involute part beneath base circle. Its construction is complicated. And it can only be used in the tool shop, and can not suit a lot of gears that are produced.

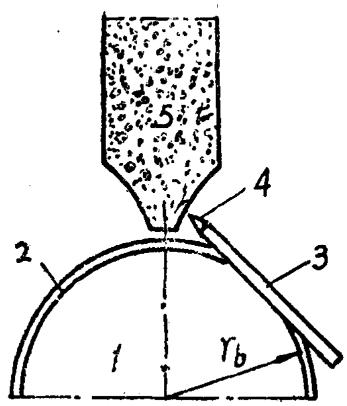

Fig 1

The replacement involute grinding method of gears is developed in this paper. The method can overcome the short comings as discribed above and show a prospect for the forming grinding of gears.

I. Method

In the coordinate axes oxy (Fig 2), the centre of gear to grind is o, the addendum circle radius is r_a, the dedendum circle radius is r_f, the base circle radius is r_b, the part of gear involute curve is AB.

The radius of replacement base circle plate of the dresser is r_{b0}. The centre is o_1. In coordinate axes O_1XY, the involute curve which it problems is CED. The beginning C of involute curve is cross point of axis Y and base circle r_{b0}. It is known to us that when the curvature radius of the involute curve CD is increased, the circle increases. The curve AB has the same property also. Assuming that the curve CD slips along the curve AB, a place can be always found to make the curve CD approach the curve AB. Assuming that Fig 2 is the place they are nearest, the replacement base round coordinate O_1XY make a movement

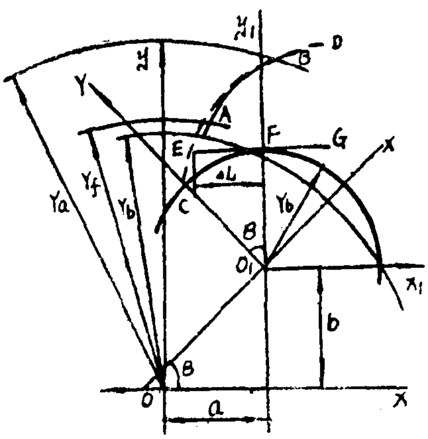

Fig 2

and a rotation in relation to gear coordinate oxy from the figure known. Hence, the horizontal movement is a, the vertical movement is b, the rotation angle is β.

When a given gear is machined, the modulus m, the numbers of teeth z, the pressure angle α, the profile shift coefficient ξ, the gap of teeth side Δs and the part of involute curve AB are known. Assuming that replacement base circle radius r_{b0} has been chosen, the values a, b and β of curve CD are obtained to approach curve AB. Replacement error between curve AB and CD, and the gap between the wheel and base circle plate are obtained to determine if it does exist.

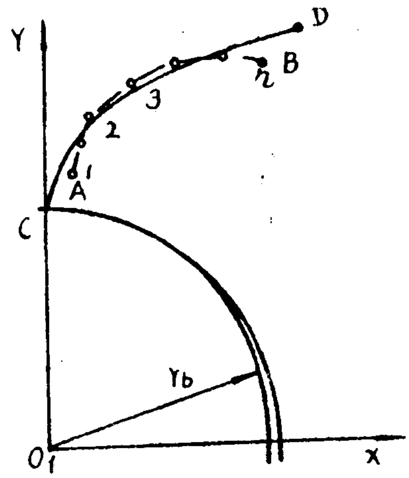

Fig 3

2. Optimum Calculation

When the optimum model is established, first of all, the gear involute curve AB should be changed into a digit group (x_i, y_i) that consist of several coordinate points.

$$\left.\begin{aligned} x_i &= r_b[sin(\phi+\omega_0)-\phi cos(\phi+\omega_0)] \\ y_i &= r_b[cos(\phi+\omega_0)+\phi sin(\phi+\omega_0)] \end{aligned}\right\} \qquad (1)$$

In formula, ϕ is the involute angle of involute curve, ω_0 is half of the centre angle between a tooth and another on base circle.

Assuming that the coordinate movement values and the rotation value a, b, β have been obtained, the coordinate value of involute curve AB can be turned into the coordinate axes O_1XY of replacement base circle. The coordinate digit group $(X_i\ Y_i)$ are obtained

$$\left.\begin{aligned} X_i &= (x_i-a)cos\beta+(y_i-b)sin\beta \\ Y_i &= (y_i-b)cos\beta-(x_i-a)sin\beta \end{aligned}\right\} \qquad (2)$$

In replacement base circle coordinate axes O_1XY (Fig 2), the equation of involute curve CD is

$$\sin\sqrt{\frac{X^2+Y^2}{r_{b0}^2}-1}-\sqrt{\frac{X^2+Y^2}{r_{b0}^2}-1}$$

$$\cdot\cos\sqrt{\frac{X^2+Y^2}{r_{b0}^2}-1}-\frac{X}{r_{b0}}=0 \qquad (3)$$

In this case, gear involute curve AB is expressed in 1, 2,…,n numbers of coordinate point. Assuming that first point $(X_1, Y_1)$is on the curve CD, f $(X_1Y_1)=0$ by formula (3). Assuming that second point $(X_2\ Y_2)$ is not on the curve CD, $f(X_2, Y_2)\neq 0$ by formula (3). Its value $\varepsilon_2=f(X_2, Y_2)$ expresses the error of second point. In this way the errors of n points ε_1, ε_2,……, ε_n are obtained. The whole error ε is the sum after squaring the various point errors,

$$\varepsilon=\sum_{i=1}^{n}\varepsilon_i^2==\sum_{i=1}^{n}\left(\sin\sqrt{\frac{X_i^2+Y_i^2}{r_{b0}^2}-1}\right.$$

$$\left.-\sqrt{\frac{X_i^2+Y_i^2}{r_{b0}^2}-1}\cdot\cos\sqrt{\frac{X_i^2+Y_i^2}{r_{b0}}-1}-\frac{X_i}{r_{b0}}\right)^2 \qquad (4)$$

The value ε changes with the values a, b and β. When the values a, b and β are optimum, the error ε is minimum. In this case, the replacement involute curve approaches the curve AB.

Besides, rolling rod EFG is increased Δl to obtain replacement involute curve CD in coordinate axes $o_1x_1y_1$ by Fig 2. $\Delta l=EF=r_{b0}\beta$, that is, rotation angle β is replaced with the increased length Δl of diamond point. It makes the construction of the dresser simple. And objective function is turned into

$$\varepsilon=f(a,\ b,\ \Delta l) \qquad (5)$$

In an electronic computer, dressing parameters a, b and Δl are found by means of the optimum method.

3. Calculation Results

Table 1 is the calculating results of the dressing parameters and the error on some gears. In the table, base circle ratio $\phi=r_b/r_{b0}$, and error coefficient k is the ratio between calculating error ε and the 6 degree profile tolerance.

Table 1

№	m	z	$\alpha°$	ξ	ΔS	r_b	r_{b0}	ϕ	a	b	Δl	f_f	ε	K
1	2	35	20	0	0	32.889	30	1.10	1.121	2.691	0.153	8	4.76	0.59
2	2	70	20	0	0	65.778	60	1.10	2.097	5.392	1.647	9	0.50	0.05
3	4	35	20	0	0	65.778	67.1	0.98	−0.509	−1.234	−2.488	11	2.54	0.23
4	4	75	20	0	0	131.557	120	1.10	4.194	10.785	3.295	11	1.01	0.09
5	4	50	20	0.1	0.05	92.388	84	1.10	3.437	7.667	2.749	11	1.13	0.10
6	6	35	20	0	0	98.667	97	1.02	0.639	1.557	−2.308	11	2.93	0.26
7	4	50	20	0	0	93.969	96.9	0.97	−1.088	−2.730	−2.663	11	0.89	0.08
8	4	50	20	0	0	93.969	85.4	1.10	3.180	7.984	1.696	11	2.52	0.23
9	2	17	20	0	0	15.975	14.5	1.10	0.639	1.348	−0.584	8	3.90	0.48
10	2	25	20	0	0	23.492	21.4	1.10	0.848	1.939	−0.262	8	5.60	0.70
11	2	50	20	0	0	46.985	42.7	1.10	1.590	3.992	0.848	8	1.26	0.15
12	2	100	20	0	0	93.969	85.7	1.10	3.058	8.010	3.050	9	0.23	0.02
13	4	100	20	0	0	187.938	170.8	1.10	6. 17	16.020	6.100	11	0.45	0.04
14	4	50	20	0	0	93.969	78.3	1.10	5.805	14.901	4.377	11	4.46	0.40
15	6	50	20	0	0	140.954	128.1	1.10	4.770	11.976	2.543	11	3.78	0.34
16	6	70	20	0	0	197.335	179.4	1.10	6.509	16.737	5.165	12	1.57	0.13
17	6	100	20	0	0	281.908	256.3	1.10	9.140	23.937	9.113	12	0.68	0.05

Fig 4 shows the relation between the error coefficient k of gear m4 and base circle ratio ϕ. The approached error would be increased with the difference between replacement base circle and design base circle. Therefore, with a certain gap between the grinding wheel and the base circle, replacement base circle should come close to design base circle. By the figure, the fewer the numbers of teeth, the larger the replacement error. Besides, sometimes the larger base circle is used to replace design base circle.

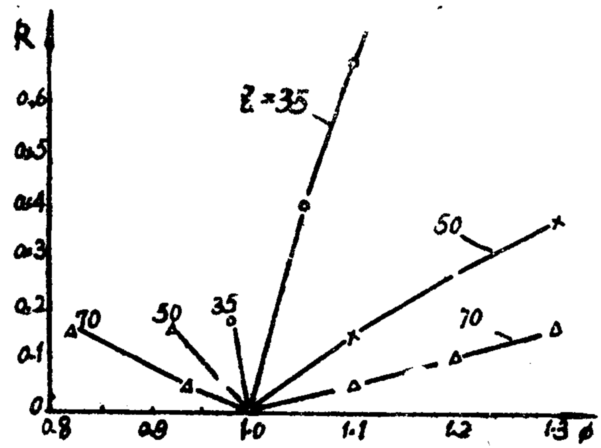

Fig 4

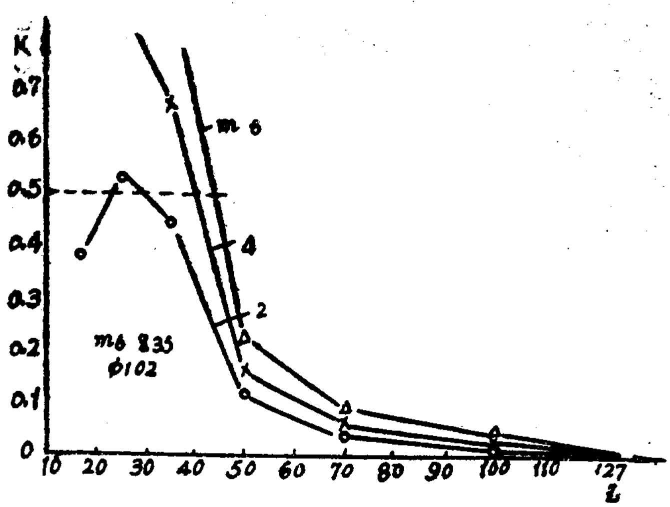

Fig 5

The influence of the numbers of gear teeth and the modulus on the calculating error is presented in Fig 5. The curves are illustrated by