Gear Hot-Rolling Machine

By Takeo TUTIKAWA**

In order to investigate the structure of the gear rolling machine which is suitable for manufacturing practical gears, the author made experimentally various gear rolling machines, and compared their performances. The results reveal that the most accurate gears are rolled by using a double-side-pressing type hydraulic rolling machine. Referring to these results, the author made a full automatic gear rolling machine, and examined the performance of the gear rolling machine. The results show that the performance of the gear rolling machine is stable, and the accuracy and the size of the hot-rolled gears hold uniformity during mass production.

1. Introduction

The gear hot rolling equipment consists of an equipment heating a gear blank up to a rolling temperature and a rolling machine forming teeth by pressing die-rollers against the periphery of a heated gear blank. The rolling machine should have two structural elements: in the first a device pressing die-rollers against a gear blank, and a device forming teeth by dividing the periphery of a gear blank into a given number of teeth.

In the rolling machine the die-rollers approach to a gear blank or withdraw from it; the distance between the shaft on which a gear blank is mounted and the shaft on which a die-roller is mounted varies. Even though the distance varies, these shafts are required to be rotated at a constant ratio of rotation by using a special method in the device of transmission element coupling these shafts.

In pressing the die-rollers against a gear blank, the following two methods can be adopted: one by the screws or cams, and the other by the springs or hydraulic devices. Mr. Naruse and Mr. Inoue made a comparative investigation on a cam-type and a hydraulic one in cold rolling(1). And at “Красный Металлист” Factory in Soviet a screw-type hot rolling machine was manufactured for trial(2).

The author made experimentally three kinds of rolling machines different in the methods of pressing the die-rollers, and examined the relation between the pressing method of the die-rollers and the accuracies of the rolled gears. On the basis of the results the author made a full automatic gear rolling machine for the purpose of mass-producing gears for a practical use. Further, the author carried out a trial of mass-production by using this full automatic gear rolling machine, and made an experiment on the faculties of this rolling equipment and the stability of its accuracy.

* Received 14th September, 1960.
** Lecturer, Faculty of Engineering, University of Tohoku, Sendai.
2. Indexing of gear teeth

There are two methods of driving the gear blank and the die-rollers in the gear rolling equipment; one is called a “free-driving system” and the other a “forced-driving system”. In the former, only either of the die-rollers or the blank is given a forced rotation, and while one is making the other rotate by their engaging, a gear is rolled. In the latter, both of the die-rollers and the blank are given a rotation corresponding to their respective gear ratios. In the case of cold rolling, when notches which index the periphery of a blank are made, the die-rollers bite into the blank at the points of these notches, and thus a gear can be rolled by a “free-driving system”, too. In the case of hot-rolling, as the rim of the blank becomes soft, the die-roller skid or bite without pressing into the blank at the points of these notches, when the die-rollers are pressed by a “free-driving system”. And consequently an intended gear is not obtained. A “forced-driving system” should be adopted for manufacturing a gear having a required number of teeth by hot-rolling.

3. Relation between the method of pressing die-rollers and the accuracy of rolled gears

To have a heating device which was easy in the regulation of power output and the change of frequency, and increase the heating efficiency, the author used a vacuum tube type high-frequency induction-heating apparatus (output 85 kW, frequency 200 kc) for this research.

3-1 The single-side-screw-pressing gear rolling machine

As Fig. 1 shows, this rolling machine is provided with only one die-roller which works on the gear blank from only one direction. To press the die-roller a screw is used, and on a gear blank shaft and on a die-roller shaft their respective timing gears are set. These timing gears are ones which are the same in the gear ratio and the size of a pitch circle diameter.

The diameter of a gear blank is smaller than the outside diameter of a finished rolled gear. So, when a sliding head is made to go forward, first the timing gear begins to engage, and then the rotation of a gear blank shaft transmits to a die-roller shaft by the timing gear, and the gear blank and the die-roller rotate at the proper speed ratio. When the die-roller

![Image of gear rolling machine](image-url)

Fig. 1 Structure of the single-side-screw-pressing gear rolling machine

![Graph of gear accuracy](image-url)

Fig. 2 Accuracy of a gear hot-rolled by using the single-side-screw-pressing gear rolling machine

m = 3, α = 20°, z1 = 32,
spur gear, Cr-Mo steel
is made to move forward, it touches a gear blank and bites into the rim of the gear blank, and here rolling is worked.

When such structural elements are adopted, the structure of the rolling machine becomes comparatively simple, and satisfies the necessary fundamental elements of a rolling machine, and can roll gears. At the "Stalin" Motor-car Factory in Soviet Russia an equipment resembling this was manufactured by rebuilding a milling machine[4].

Fig. 2 shows the measured results of the accuracy of the spur gear of module \( m = 3 \) (Cr-Mo Steel) as an example of the gears hot-rolled by this rolling machine. To roll this gear, it takes 25 sec for heating and 10 sec for rolling.

3-2 The double-side-screw-pressing gear rolling machine

As Fig. 3 shows, this rolling machine is provided with two die-rollers which work on the gear blank from mutually opposite directions.

The author adopted the transmission device coupling the gear blank shaft with the die-roller shaft whose structure gives the two shafts a constant ratio of rotation, the gears contained in the transmission device meshing in the normal state in either case of die-rollers' going forward or backward.

When two die-rollers are used, the phases of their respective teeth must be adjusted to a gear which is rolled. As the method of adjusting the phases of a die-roller's teeth, the author adopted the method to make one of the intermeshing helical gears slide along a shaft and to use the rotating movement caused there. By the experiment it was affirmed that it was possible by this method to make continuously fine adjustment and that this rolling machine was of a sufficiently rigid phase adjusting device.

To press two die-rollers screws are used. They can be rotated either manually or by an electric motor.

Fig. 4 shows the measured result of the accuracy of a cam shaft gear (Carbon Steel) for a light vehicle as an example of a gear rolled by using this rolling machine.

To roll this kind of gears (to roll them, two blanks being piled at one time) it takes 20 sec for heating and 8 sec for rolling.

3-3 The double-side-hydraulic gear rolling machine

The structure of this rolling machine, as shown in Fig. 5, is the same as that of the above-mentioned

1: Round tool
2: Pitch error
3: Pitch variation
4: Index error

Fig. 3 Structure of the double-side-screw-pressing gear rolling machine

Fig. 4 Accuracy of a gear hot-rolled by using the double-side-screw-pressing gear rolling machine

\( m = 2.25 \), \( \alpha = 20^\circ \), \( \beta = 13.5^\circ \), \( z_1 = 38 \), 0.48C steel
double-side-screw-pressing gear rolling machine in the transmission device coupling a gear blank shaft with a die-roller shaft. Giving equally hydraulic pressure to the right and left sliding heads causes the die-rollers to be pressed into the blank.

When sliding heads are moved by only hydraulic pressure, both of die-rollers keep pressing into a blank, carrying on deformation under so much pressure given, as a deformation resistance is working in the course of it being rolled. But the deformation resistance does not work till the die-rollers bite into the periphery of the gear blank, and the forward speed of right and left sliding heads are not equal to each other because of the difference of hydraulic circuit resistance or that of resistance on the sliding surface of the sliding head. Consequently the right and left die-rollers make some difference in biting time, and the difference of their first biting time is unstable, and so it is difficult to check exactly their first biting time. In the case of hot rolling, it is necessary to check exactly die-rollers’ biting time as heating time is exactly determined, and in this point it is not the same as in the case of cold rolling. For this reason, in this rolling machine a coupling device making use of racks and a pinion is used, and the author adopted the method of coupling mechanically the forward motion till the time when both of die-rollers touch the periphery of a gear blank. While the gear blank is being rolled, this coupling device is not to work.

As an example of a gear rolled using this rolling machine, Fig. 6 shows the measured result of the accuracy of a crank shaft gear (Carbon Steel) for a motor truck. It takes 25 sec for heating and 8 sec for rolling.

3-4 Considerations on the experimental results

From the results of these experiments the followings are considered:

1) The machine whose structure is as simple as a gear rolling machine is a single-side gear rolling machine using one die-roller. Even in the case of using a rolling machine of this structure a gear having an accuracy near to the 6th quality in JIS can be rolled.

![Fig. 6 Accuracy of a gear hot-rolled by using the double-side-hydraulic gear rolling machine](Image)

1: Runout  2: Pitch error  3: Pitch variation  4: Index error

m=3, α=20°, β=25°, z=35, 0.48C steel

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Fig. 5 Structure of the double-side-hydraulic gear rolling machine

1: gear blank 2, 2': die-rollers 3: indexing gear box 4, 4': hydraulic cylinders 5, 5': supports of piston 6, 6': micro-stopper 7: chucking device 8: gear blank shaft 9: coupling device of sliding heads
(2) When the accuracy of a gear rolled by a single-side gear rolling machine is compared with that of a gear rolled by a double-side gear rolling machine, the latter is found to have fewer runouts than the former. The reason for this is considered as follows: In a single-side gear rolling machine, the very pressing force of a die-roller acts on a gear blank shaft and the inside diameter surface, and the fact is apt to cause eccentricities to appear on the gear blank shaft and the inside diameter surface be deformed or injured. Consequently, the runout of the gear rolled is apt to become large.

On the contrary, in a double-side gear rolling machine with two die-rollers pressing against a gear blank from the opposite positions the pressing force which acts on a gear blank and a gear blank shaft can be balanced and the fact causes a gear blank shaft to have few eccentricities and the inside diameter to be a little deformed or injured. Therefore, a gear rolled on a double-side gear rolling machine has fewer runouts than a gear rolled on a single-side gear rolling machine.

In the point of the balance of pressing forces in a rolling machine, one with three die-rollers has more stability than one with two die-rollers. In cold rolling, a rolling machine whose three die-rollers are arranged in the form of Y is made for trial(15), but, in hot-rolling, the larger number of die-rollers becomes, the smaller becomes the surface of a blank which can be used for heating, and it is remarkably difficult to heat a blank, and so one with more than three die-rollers cannot be used.

(3) Even in the case of a double-side gear rolling machine, when a rolling machine using screws in pressing die-rollers is compared with one using hydraulic pressure, the latter can roll a gear which has fewer runouts than the former. The reason for this is considered as follows: As a screw-pressing rolling machine gives mechanically a forward movement to the die-rollers, and by doing so makes the die-rollers be bitten, the two die-rollers' positions of going forward, in relation to a gear blank, must be equally adjusted, for, otherwise, rolling is worked by only one die-roller, or a gear blank is bent, and so eccentricities are apt to be caused. But it is difficult to adjust exactly the two die-rollers' positions of going forward. Sometimes the fact causes a gear blank shaft to be bent. On the other hand, a hydraulic rolling machine gives only a pressing force to the die-rollers and does not check their positions going forward. The die-rollers keep biting a gear blank, and working deformation in accordance with given force, and consequently, if the pressure is equally given to the two die-rollers, they keep biting a blank, and working deformation with an equal pressing force. Then the pressing force acting on a gear blank shaft is perfectly balanced, and here eccentricities are not caused. The author considers that is why the gear rolled on the hydraulic rolling machine has fewer runouts than one rolled on the screw-pressing rolling machine.

(4) When a gear rolled by a hydraulic rolling machine is compared with one rolled by a screw-pressing rolling machine, the former has not only fewer runouts than the latter, but also has better accuracy of pitch. The reason for this is considered as follows: The method of giving only a pressing force to the die-rollers by hydraulic pressure without checking the positions of going forward is better than the method of pressing which gives mechanically a forward movement to the die-rollers by using screws, for in the former method the die-rollers keep biting in accordance with the given pressing force and naturally carries on rolling.

4. The full automatic gear rolling machine

On the basis of these results, the author made experimentally a full automatic gear rolling machine which was intended for mass-production. In manufacturing this rolling machine, the author specially paid attention to the following points:

(1) The net operating time required for hot-rolling is within 30 sec even including the heating time, and consequently to shorten the time of chucking a gear blank is an important factor governing the operating efficiency in rolling. So the author adopted an automatic chucking device to chuck a gear blank quickly.

(2) To mass-produce gears, it is important that the rolled gears have uniformity in size and accuracy. In hot-rolling, the rolling conditions have influence on the size and accuracy of the rolled gears. Therefore, to uniformalize the size and accuracy of the rolled gears, the author considered that the rolling conditions should be constant and the whole process from setting on a gear blank till setting off a rolled gear be automatized.

(3) The author considered that the changing of the die-rollers, the exchanging of the timing gears and the phase adjusting of the two die-rollers' teeth should be facilitated, and the rolling machine be made so as to be easily operated.

Fig. 7 shows the structure of the rolling machine which was experimentally made in accordance with these considerations. In this rolling machine the method of hydraulic pressing is adopted to press the die-rollers, and the whole process from setting on a
gear blank till setting off a rolled gear is automatically carried out.

Fig. 8 shows the measured result of the accuracy of a helical gear of module $m=2.25$ (Carbon Steel) as an example of a gear rolled by using this rolling machine.

To roll this kind of gears (they are rolled, two blanks being piled at one time) it takes 10 sec for heating and 8.5 sec for rolling. It takes 34 sec for the whole operation from setting on a gear blank till setting off a rolled gear.

5. The faculties and the stability of accuracy in the hot rolling machine

In the mass-production of gears it is an important problem what degree of accuracy each gear has and also what degree of uniformity in its accuracy and size it has, when its practicality is taken into consideration.

It is feared that in hot-rolling the heat while a gear blank is heated might be transmitted to the die-rollers or the rolling machine in the course of mass-production, and the fact would cause variations in the size and accuracy of the rolled gears.

And as the rolling machine is a machine resembling the press for plastic deformation and is required to be as accurate as a cutting machine, it is another problem in what degree of uniformity its accuracy should be kept.

So the author tried mass-production by using about 1000 gear blanks and tested the maintenance of the accuracy of the rolling machine, the temperature rise, the durability of the die-rollers, the accuracy of rolled gears and the uniformity of their size.

The dimensions of a gear and the die-rollers used in the test are as follows:

- Gear to be rolled: normal module $m_n=2.25$, number of teeth $z_2=37$, normal pressure angle $\alpha_s=20^\circ$, helical angle $\beta=13.5^\circ$, Carbon Steel ($C=0.48$).
- Die-roller: normal module $m_n=2.25$, number of teeth $z_1=110$, normal pressure angle $\alpha_s=20^\circ$, helical angle $\beta=13.5^\circ$, Cr-Mo Steel, case-hardened.

The experiment was made by using the full automatic gear rolling machine.
Fig. 9 shows the measured results of the stability of the rolling machine's automatic motion. Fig. 10 shows the measured results on the eccentricities of the gear blank shaft and the die-roller shafts.

Fig. 11 shows the results obtained by taking some gears in order which were rolled at intervals of about ten times, and measuring arc teeth thickness across profiles, runout, pitch variation and profile error.

From the results of this test the following conclusions can be reached:

1. Under constant values of the rolling pressure, the current of a driving motor and the rolling time, it is considered that the rolling temperature is constant and deformation resistance is not varied.

2. The stopping positions of the right and left sliding heads and the time of the whole process have constant values. And the eccentricities of the die-roller shafts and the gear blank are not varied before and after the test. This fact is interpreted to show that the motion of the rolling machine is stable and its accuracy is not varied.

3. As a result of measuring the accuracy and size of rolled gears, in every item and in the course of mass-production they are found to have uniformity without showing variations which have any tendency.

This fact is considered to mean that the rolling machine is stable and the temperature of the die-rollers is kept at the temperature about 20~30°C higher than the room temperature by pouring cooling water and consequently their accuracy is not varied.

4. The accuracy of the rolled gears conforms to the 4th or the 5th quality (JIS) in runout, the 3rd quality in pitch variation, the 6th or the 7th quality in profile error and the 4th or the 5th quality in the error of arc teeth thickness across profiles.
6. Conclusions

To sum up the results of these experiments:

(1) In hot-rolling, to index the periphery of a blank into a given number of teeth and to form teeth, it is necessary to adopt the method of "forced-driving system".

(2) A rolling machine whose structure is simple is the single-side-screw type rolling machine. The rolling machine of this structure can be made by rebuilding a lathe or a milling machine and gears can be rolled by it.

(3) In point of the accuracy of a rolled gear, the double-side type rolling machine can roll a gear which has fewer runouts than the single-side type rolling machine can do. In the double-side type rolling machine, one by hydraulic pressure can roll a gear which has fewer runouts and whose accuracy of pitch is higher than one by pressing with screws.

(4) As a result of the trial of mass-production by using the experimentally made full automatic gear rolling machine, the motion of the rolling machine is stable, and the uniformity of its accuracy is satisfactory.

(5) In mass-production the temperature of the die-rollers is kept at the temperature about 20~30°C higher than the room temperature and their accuracy is not varied and their durability is satisfactory.

(6) The accuracy and size of a rolled gear do not vary with any tendency even in the case of mass-production and have uniformity. It can be used as a practical gear having an accuracy near to the 5th quality.

References

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