On Measuring of Rolling Pressure and Rolling Torque of Roughing Stands in a Full-Continuous Wire Rod Mill*

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Synopsis

The rolling pressure and the rolling torque are measured with the roughing stands of a full-continuous wire rod mill. When four billets of mild steel are rolled at the same time, the range of the rolling pressure of each stand is between about 9 and 37 tons per billet. Generally speaking, the rolling pressure of the oval rolling stands is considerably higher than that of the square rolling stands. And it is found that front or back tension between the two stands has some effects on the rolling pressure on threading or delivery of billets.

The measured torque is considerably higher than the one calculated from the measured pressure. The rolling efficiency of the roughing stands is about 71%, which is obtained from the measured rolling torque and the motor torque. The load distribution of each stand to the main motor is also discussed.

At the end of this paper, the relationship between the mean specific pressure and some rolling factors is discussed.

I. Introduction

A full-continuous wire rod mill designed by the SIEMAG in Germany was installed at the Hikari Works of Yawata Iron & Steel Co., Ltd. in May 1955.

Since then, the mill has been working continuously with good results. Commercial and special wire rods can be rolled with this mill. The diametric range of the rods is from 5.0 mm to 16.0 mm. The main features of this mill are: 1) the rolling speed is 24 m/sec at its maximum, and is much faster than the conventional one, 2) the diametric clearance of the rolled wire rod is small, and 3) its appearance and quality are excellent.

Fig. 1, which represents schematically the layout of a full-continuous wire rod mill, may help the reader to understand the rolling procedure of this mill.¹⁻²⁾ Dimensions of a rolling billet are 70 mm square and 9,000 mm long, and its weight is about 335 kg. A three-zone type conventional furnace is used, of which the fuel is heavy oil.

Fig. 1. Layout of an all-continuous wire rod mill

Each billet is heated for 1½ hours, and then it is pushed out and fed to the mill. The mill is able to roll four billets at the same time.

This continuous mill consists of twenty-one stands in series. Nine of them are roughing mills in series, and are separated into three groups. Six stands (No. 4-No. 9 stands of these nine roughers) are driven by a 1,800 HP motor through reduction gears. After rough rolling, rolled rods go through the down looper into the first intermediate stand group. The second intermediate stands are separated into two lines, so that two wires can be rolled at the same time. Each of the two rolled wires passed through the second intermediate stands is fed into one of the four finishing stand lines. One finishing line consists of three groups, each consisting of a vertical type roll stand and a horizontal-type roll stand. The rolled wire lines are lastly wound up by wire rod coilers after passing through water cooling pipes.

One of the characteristics of the second intermediate stands and the finishing stands is that only their bottom rolls are driven by the main motor, and the top rolls follow them by friction. This is the so-called "Schleppwalzen" method. The friction driven rolling as well as the combined installation of a vertical type roll and a horizontal type roll, is effective in prevention of rolling defects and in the improvement of gauge accuracy.

The rolling pressure and the rolling torque are measured in order to analyze the rolling characteristics of the No. 4—No. 9 roughing stands. From the results of this measurement, distributions of rolling load at each stand are studied. Many fully studied reports on measurement and calculation of the rolling pressure as well as the mean specific pressure for plate and sheet rolling have been presented. However, the analysis of grooved rolling is very complicated and has been left unstudied.

Therefore, the relationship between the mean specific pressure and the grooved rolling shapes of the wire rod is studied herein.

II. Measuring Procedures

1. Measuring Method of Rolling Pressure

Rolling pressure is measured by use of load cells, which are inserted between an upper bearing chock and a screw down spindle on both sides of each stand, as shown in Fig. 2. The load cells are made of SF 55 forged steel (JIS G3201), on which the resistance wire strain gauges, type K 22, are attached.

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Fig. 2. Insertion of the load cell into the stand
① Housing screw ② Load cell

Prior to the measuring of rolling pressure, the load cells are calibrated statically by a compression testing machine. The rolling pressure measured for two stands at the same time is recorded on an electromagnetic oscillograph with a strain amplifier.

2. Measuring Method of Rolling Torque

For the purpose of measuring of rolling torque, four sets of resistance wire strain gauges of type KB 9 are attached in a direction of forty-five degrees on the grind-finished surface of the roll spindles, which connect the rolls to the pinions. The rolling torque is measured through slip-rings by using the same amplifier in measuring the rolling pressure. Torque calibration is made before-

hand up to maximum of 3,000 kg-m by steps of 500 kg-m intervals. The motor load is measured at the same time.

An optical pyrometer is used to measure the temperature of rolling materials between the two stands. The sectional areas of the rolled materials at each stand are measured directly by a sudden stop of the rolling.

3. Rolling Materials

Four kinds of mild steels for wire rods were tested, their chemical composition is shown in Table 1. Rimmed steel SWRM 3 (JIS G3501) was used for measuring the rolling pressure, and rimmed steel, killed steel SWRM 4, and rimmed steel SWRY 11 (JIS G3523) were used for measuring the rolling torque.

4. Rolling Conditions

On rolling procedure which is shown in Table 2, the rolling of Nos. 4, 6 and 8 roughing stands is called an oval rolling procedure, and that of Nos. 5, 7 and roughing stands is called a square rolling procedure. Rolled steel rods are passed successively from an oval rolling stand to a square rolling stand.

For example, in the case of passing from No. 4 stand to No. 5 stand, rolled materials are turned over ninety degrees, from No. 5 stand to No. 6 stand zero degrees, from No. 6 stand to No. 7 stand ninety degrees, from No. 7 stand to No. 8 stand forty-five degrees, and from No. 8 stand to No. 9 stand ninety degrees again.

The temperature of billets just after they are pushed out of furnace is 1,240°C and the speed of the main motor is 300 r.p.m. In this experiment,

Table 1. Chemical composition of rolled steels

Specification	C	Si	Mn	P	S	Remarks
SWRM 3	0.12	0.01	0.43	0.041	0.031	For measuring of rolling load For measuring of rolling torque
SWRM 4 (killed)	0.13	0.24	0.44	0.014	0.023	
SWRM 4 (rimmed)	0.20	0.01	0.30	0.014	0.030	
SWRY 11	0.08	0.01	0.60	0.009	0.015	

Table 2. Rolling conditions of roughing stands for wire rod of 5 mm ϕ

Stand No.	4	5	6	7	8	9
Section of rolled steel	●	■	—	◆	●	◆
Roll diameter (Dmm)	30.8×59.9	37.1×35.6	18.8×43.2	23.2×23.4	11.8×28.5	17.2×17.2
Roll diameter (Dmm)	417.5	417.5	382	383	384	384.5
Rolling speed (V _u m/s)	0.24	0.34	0.43	0.76	1.16	1.62
Section area of rolled steel (A mm ²)	1820	1287	829	550	350	191
Reduction of section area ($\Delta A/A \times 100\%$)	28.4	29.4	35.6	36.7	36.4	23.0
Strain of section area ($\ln A_{n-1}/A_n \times 100\%$)	24.9	25.7	30.3	31.2	31.0	20.7

the number of billets which are passed at the same time to the mill is increased successively from one to four.

III. Results of Measurement

1. Rolling Pressure

When the billets are rolled according to rolling conditions of Table 2, the temperature of the rolled materials in each roughing stand is higher on the top side of billets than at the bottom side, as shown in Fig. 3. The temperature difference is about 20°C.

In the case of rolling four billets at the same time, the measured rolling pressure is higher at the entry and the delivery rolling of the billets than at the middle position, as indicated in Fig. 4 (a). The average of the pressure difference is about five tons between the entry and the middle position, and about 11 tons between the delivery and the middle position. The causes of the higher rolling pressure, as abovementioned, presumably come from the facts that it is only the back tension and not the front tension which acts on the entry side, and it is vice versa on the delivery side, and also from the fact that the delivery end rolling temperature is lower than at the middle position.

The rolling pressure is increased proportionally with the increase of the number of billets which are rolled simultaneously. In the case of oval rolling stands the pressure is a little less, and in the case of square rolling stands a little more.

The rolling pressure of No. 6 stand shows the highest value among all the roughing stands. Generally speaking, the rolling pressure of oval rolling stands has a tendency to be higher than that of square rolling stands.

Fig. 3. Temperature of a billet at each stand

2. Rolling Torque

i) Measured Rolling Torque

As shown in Fig. 4 (b), the difference of the measured rolling torque among three kinds of steel is not significant. Similar to the case of rolling pressure, the rolling torque has a tendency to be decreased as the rolling goes on. However the rolling torque of No. 6 stand shows the highest value among all the roughing stands. The rolling torque is calculated from the measured rolling pressure as indicated in Fig. 4 (b), this calculated torque is, however, about 20-40% smaller than the measured torque. Even if the bearing efficiency is taken into account, the calculated rolling torque seems to be rather small. This difference presumably comes from the difficulty of consuming the correct length of the contact arc and the torque arm, especially in the case of grooved rolling. In this case, the torque arm obtained by the Trinks' method³⁾ is used for the calculation of rolling torque.

The rolling torque is larger (about 380 kg-m) at the roll entry than at the middle position of billets.

Fig. 4. (a) Rolling pressure of roughing stands
(b) Rolling torque of roughing stands

This may be due to the back tension action. The rolling pressure is higher at the roll delivery than at the middle position, whereas the rolling torque of the former is somewhat lower than that of the latter. This is presumably due to the front tension action, as mentioned above. In the case of rough rolling in the continuous wire rod mill, some tensions may considerably influence the rolling torque as well as the rolling pressure.

ii) Distributions of the Rolling Torque at Each Stand

The rolling torque of each stand, which contributes to a main motor through the reduction gears, is calculated from the results of the measured maximum rolling torque, and is indicated in Table 3. No. 6 stand shows the highest distribution of rolling torque among all the roughing stands, and it covers about 25% of the total.

iii) Rolling Efficiency

The rolling efficiency η is defined as follows:
$$\eta = (\text{total rolling torque}) / (\text{motor torque}) \times 100$$

The average rolling efficiency for maximum rolling torque is about 71%, the value indicated in Table 3. As shown in Fig. 5, rolling efficiency for calculated torque is somewhat smaller than that for the measured torque. Furthermore, as the number of the simultaneous rolling of billets is increased, the rolling efficiency is increased, but gradually it begins to saturate.

IV. Consideration on Mean Specific Pressure

1. Mean Specific Pressure at the Roughing Stands of the Wire Rod Mill

In order to calculate the mean specific pressure from the measured rolling pressure, the projected

Fig. 5. Rolling efficiency of roughing stands

contact area which is obtained from the Trinks' method, is adopted. The range of the mean specific pressure of roughing stands is about 9.8 and 18.2 kg/mm², and is shown in Fig. 4. The mean specific pressure tends to be increased as the rolling goes on, and that of the oval rolling is, to some extent, larger than that of the square rolling.

Table 3. Contribution of the rolling torque at each stand to the motor and rolling efficiency

Steels (JIS G)	Specification	Stand No.						Total rolling torque (kg-m)	Motor torque (kg-m)	Rolling efficiency (%)
		4	5	6	7	8	9			
SWRM 4 (killed)	Max. rolling torque (kg-m)	6867	6118	9000	4165	3828	1960			
	Contributed torque to the motor (kg-m)	264	339	813	567	789	527	3299	4510	73
	Contribution of each stand to the motor (%)	8.0	10.3	24.6	17.2	23.9	16.0			
SWRM 4 (rimmed)	Max. rolling torque (kg-m)	7620	6365	9220	4920	3580	2030			
	Contributed torque to the motor (kg-m)	292	353	832	669	734	546	3426	4670	73
	Contribution of each stand to the motor	8.5	10.3	24.3	19.5	21.4	16.0			
SWRY 11	Max. rolling torque (kg-m)	6738	5590	8480	4510	2590	1940			
	Contributed torque to the motor (kg-m)	259	310	766	613	533	523	3004	4440	68
	Contribution of each stand to the motor	8.6	10.3	25.5	20.4	17.7	17.4			

2. Relationship between the Mean Specific Pressure and the Rolled Shapes

As some different tendencies of rolling pressure and rolling torque are found in the oval and the square rollings, further investigations into the relationship between the mean specific pressure and the size of rolled materials or some factors of the rolled shapes are made. They are:

$hm/bm = (\text{mean thickness of rolled steel}) / (\text{mean width of rolled steel}),$
 $hm/Dm = (\text{mean thickness of rolled steel}) / (\text{mean roll diameter}),$
 $L/\sqrt{A} = (\text{half length of section periphery of rolled steel}) / (\text{root of section area of rolled steel}).^{(4)}$

i) Relationship between the Mean Specific Pressure and hm/bm

As indicated in Fig. 6 (a), the mean specific pressure is increased at different rates in oval rolling and in square rolling when hm/bm is increased. In other words the former is increased faster than the latter.

ii) Relationship between the Mean Specific Pressure and hm/Dm

As indicated in Fig. 6 (b), the relationship between the mean specific pressure and hm/Dm is similar to that in the case of hm/bm .

iii) Relationship between the Mean Specific Pressure and $L/\sqrt{A}$

A factor of $L/\sqrt{A}$ represents the nondimensional expression of grooved rolling shapes. Relationship between the mean specific pressure and $L/\sqrt{A}$, as indicated in Fig. 6 (c), changes at different rates in the case of oval and square rolling.

(hm : mean thickness of Rolled steel, bm : mean width of rolled steel, Dm : mean diameter of roll, L : half length of section periphery, A : section area of rolled steel)
Fig. 6 Relation between the specific pressure and some factors of rolled shapes

3. Relationship between the Mean Specific Pressure and the Mean Strain Rate $\dot{\phi}_m$, or the Rolling Temperature T

The mean strain rate $\dot{\phi}_m$ of rolling is calculated from Sims' equation⁵⁾ of (1), shown in Table 4,

$\dot{\phi}_m = Vu/ld \times \ln A_n/A_{n-1} \dots \dots \dots (1)$

where, Vu is the peripheral speed of the roll, ld is the projected contact length, and A_{n-1} and A_n are the sectional areas of the rolled material before and after the rolling.

As the range of rolling speed is between 0.24 and 1.62 m/sec, the range of the mean strain rate is between 1.2 and 11.4/sec. The mean specific pressure tends to be increased with the increase of the mean strain rate, as shown in Fig. 7. However, the mean specific pressure of the oval rolling is increased more abruptly than that of the square rolling. The relationship between the mean specific pressure and the rolling temperature is shown in Fig. 8, and the mean specific pressure of the oval rolling is higher than that of the square rolling. It should be noted that the relationships which are shown in Figs. 7 and 8, contain both the factors of the strain rate and the rolling temperature.

Table 4. Mean specific pressure of roughing stands

Stand No.		4	5	6	7	8	9
Rolling temperature ($T^{\circ}\text{C}$)		1075	1060	1040	1015	1000	980
Mean strain rate ($\dot{\phi}_m \text{ sec}^{-1}$)		1.2	1.6	3.9	5.5	11.4	7.1
Projected contact area (mm^2)		3016	1964	1972	1040	949	749
Projected contact length ($ld \text{ mm}$)		67	72	48	63	46	60
Mean rolling pressure ($P \text{ ton}$)		30.6	20.0	36.5	15.0	22.5	9.0
Mean specific pressure ($K_f \text{ kg/mm}^2$)		9.8	10.9	15.8	12.5	18.2	12.3
Velocity-modified temperature ($T_m \text{ K}$)		1324	1291	1221	1179	1125	1133
Resistance of deformation by tensile test $S \text{ (kg/mm}^2\text{)}$		8.4	9.0	11.9	13.5	16.3	14.1
K_f/S	Oval rolling	1.165	—	1.330	—	1.115	—
	Square rolling	—	1.203	—	0.925	—	0.873

Fig. 7. Relation between the mean specific pressure and the mean strain rate

Fig. 8. Relation between the mean specific pressure and the rolling temperature (T_k : absolute temp.)

4. Relationship between the Mean Specific Pressure and the Velocity Modified Temperature T_m

On the basis of the theories of viscous flow, the relationship between the strain rate $\dot{\varphi}$ and the temperature T_k of steady state creep is expressed as (2):

$$T_m = T_k(1 - K \ln \dot{\varphi} / \dot{\varphi}_0) \dots\dots\dots(2)$$

where T_m is the velocity-modified temperature, and K and φ_0 are constants.

Macgregor and Fisher⁶⁾ verified from Manjoine's data⁷⁾, that the resistance of deformation K_f in tensile test can be expressed as the function of two factors of the velocity-modified temperature T_m and the strain φ :

$$K_f = f(T_m \cdot \varphi) \dots\dots\dots(3)$$

And Inoue⁸⁾ also confirmed the above-mentioned relationship at even higher temperatures. Therefore, by using Inoue's data for high temperature and high speed tensile tests of low-carbon rimmed steel, constants of K and $\dot{\varphi}_0$ in the equation (2) are obtained as K is 0.044 and $\dot{\varphi}_0$ is 0.8/sec.

The relationship between the velocity-modified temperature T_m and the mean specific pressure of rolling, or the resistance of deformation in the

tensile test, is shown in Fig. 9. Regardless of the same value of the velocity-modified temperature, the mean specific pressure of the oval rolling is higher than that of the square rolling.

The mean specific pressure K_f of rolling is compared with the resistance deformation S obtained by the tensile test at the same values of T_m and φ as in Fig. 9. The mean specific pressure of the oval rolling is about 1.20 times greater than the resistance of deformation obtained by the tensile test, and that of square rolling is about 1.00 times.

Comparison of the ratio of R_f/S with a factor of the grooved rolling shapes $L/\sqrt{A}$ reveals that the ratio of K_f/S tends to increase with the increase of $L/\sqrt{A}$ as shown in Fig. 10.

With the subsequent study of the rolling of rails,⁹⁾ it is found that the ratio of K_f/S is closely connected with the factor $L/\sqrt{A}$. By using the information of the ratio K_f/S of the particular rolling, the mean specific pressure and rolling pressure of the grooved rolling can be inversely calculated.

Generally, it is very difficult to calculate the mean specific pressure of very complicated grooved rolling, because of the rolling procedures, the grooved rolling shapes, and the tension during the rolling effect on frictional force, on width widening, and on rolling pressure, etc.

Consequently, it is presumably necessary in future to obtain the ratio K_f/S in many complicated grooved rollings.

Fig. 9. Relation between the mean specific pressure and the velocity-modified temperature

Fig. 10. Relation between the K_f/S and the factor of rolled shapes ($L/\sqrt{A}$)

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V. Conclusions

The rolling pressure and the rolling torque of the roughing stands of the full-continuous wire rod mill are measured, and the following results are obtained:

- (1) The rolling load of the oval rolling stands has a tendency to be higher than that of the square rolling stands.
- (2) It is observed that some tension effects on the rolling load occur at the entry part and the delivery part of rolling.
- (3) The ratio of the mean specific pressure of rolling to the resistance of deformation in the tensile test, K_f/S , of the roughing stands is considered under the same conditions as the strain rate, the temperature and the strain. The average values of the ratio K_f/S are about 1.20 at the oval rolling and about 1.00 on the square rolling.
- (4) It is noticed that there are some relationships between the ratio K_f/S and the value $L/\sqrt{A}$.

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