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Materials

Force Parameter Model of 3-Roll Mills for Continuous Cold Rolling Wires

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Abstract: Based on experimental data, the mathematical model of rolling force parameters of 3-roll mills was studied. The structure of the model was theoretically set up and the coefficients were determined by static analysis of the data. The torque in continuous rolling was measured, and the characteristics and efficiency of 3-roll mills are investigated.

Key words: 3-roll mill; force; mathematical model; cold rolling; wire

From the time when 3-roll mills are invented to the end of 1970's, they had been used in hot rolling of wire rods, especially in producing of non-ferrous metals. It is estimated that approximately 90% of the wire rods made from aluminum and aluminum alloys were produced on the 3-roll mills at that time [1]. In 1980's, many plants began to use the technology to substitute for cold drawing in production of wire rods [2], and now the mills have been widely applied to cold rolling of steel wires as its high-performance of compact structure, simple operation, various products, closer tolerance and better surface quality of products than 2-high mills.

It is necessary to analyze the force parameters of the 3-roll mills in order to make the technology more efficient. However, in this field, no more complete and practical research results have been reported until now, especially on cold rolling of rods and bars made from alloy steel. In addition, it is not accurate and inconvenient directly to apply the theory for 2-high rolling to the 3-roll rolling. Based on the experimental results of the rolling force, torque and input power in rolling of alloy steel wires, this paper studied the model of rolling force and analyzed the deformation characteristics of 3-roll mills.

1 Experimental

The rods with 8.0 mm in diameter, made of alloy steel, were rolled into wire rods with about 6.0 mm in diameter though oval and round passes on a 4-stand continuous rolling mill [3]. The ratio of every stand is fixed and the layout of the mill is shown in **figure 1**. The arrangement of rolls is shown in **figure 2**.

2 Model of Rolling Force

Based on the solution of rolling force for cold rolling of strips, a model of rolling force for the 3-roll mill can

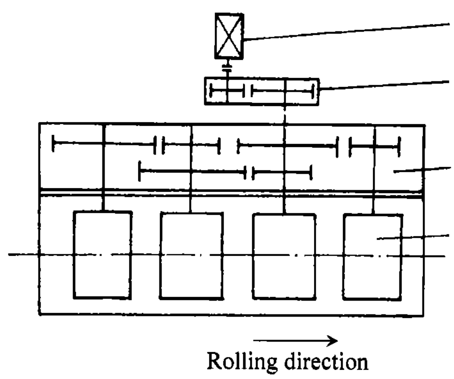


Figure 1 Layout of the mill.

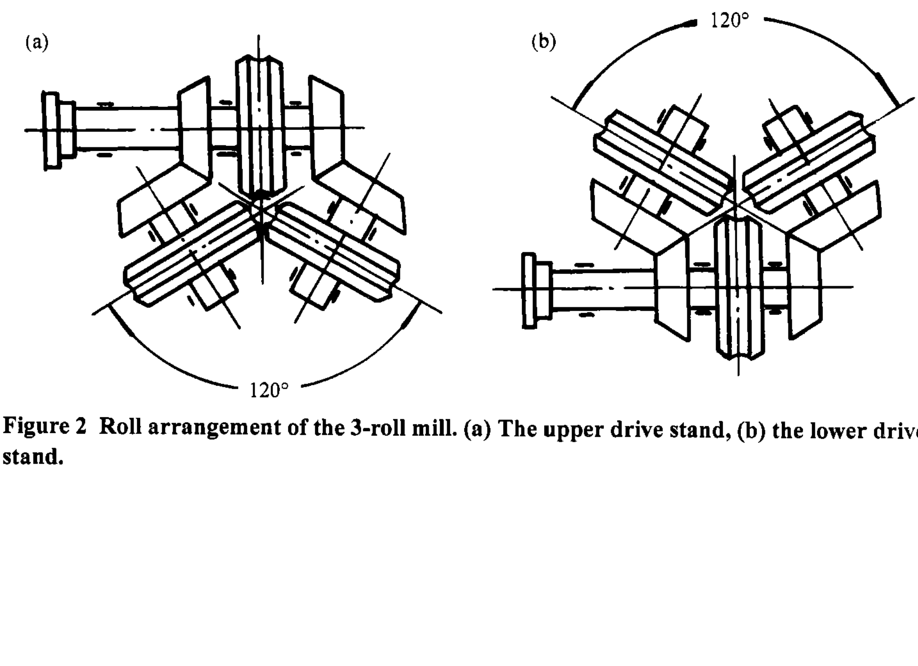


Figure 2 Roll arrangement of the 3-roll mill. (a) The upper drive stand, (b) the lower drive stand.

be proposed by introducing a roll pass coefficient α. The coefficient is determined by statistical analysis of the experimental data. The model of rolling force is

$$P=\alpha K_m Q_p Q_q F_d \quad (1)$$

where α is the roll pass coefficient, K_m is the average resistance of deformation, Q_p is the model of stress state factor, Q_q is the factor revealing the effect of tension [4] on rolling force (in experiments, the specimen were rolled on only one stand, so $Q_q = 1$), and F_d is the area of contact.

2.1 Stress state factor

The generally accepted concept for the rolling force of cold rolling strips, Band-Ford theory, is introduced to set up the model of Q_p. In order to simplify calculation, the equation without tension is adopted, which is simplified by Hill [4]:

$$Q_p=1.08+1.79\varepsilon' f\sqrt{\frac{R'}{H}}-1.02\varepsilon' \quad (2)$$

where ε' is the reduction in %, f is the friction factor, R' is the radius of the flattened roll, and H is the height of work pieces.

In order to make this equation suitable for the 3-roll mill, the reduction $\varepsilon'=\Delta h/H$ is calculated by assigning $\Delta h=d_0-d$ and $H=d_0$. Here, d_0 and d stand for the diameters of inscribed circles on the cross-sections of inset and outlet work pieces respectively, and R' presents the radius of the flattened roll. Because the roll flattening is quite small for cold rolling of wires and bars and R' is difficult to calculate accurately, R' is considered to be R [6], the radius of the roll in this paper. f stands for the friction factor. According to the statistical data [5] in cold rolling with lubrication, f is about 0.096. In calculation, let $f = 0.096$. The error caused by doing so can be corrected because of the introduction of α.

2.2 Area of contact

The area of contact

$$F_d=b\cdot l \quad (3)$$

where b is the width of contact and l is the length of contact.

In calculation of b for 2-high bar rolling, the rectangle method is routinely applied to transfer shape rolling to plate rolling. But in 3-roll mills, rolling force is acted in three directions, which is obviously different from 2-high one. Therefore, geometry is applied to calculate b. As shown in **figure 3**, it is approximately presented by

$$b=\sqrt{d_0^2-d^2} \quad (4)$$

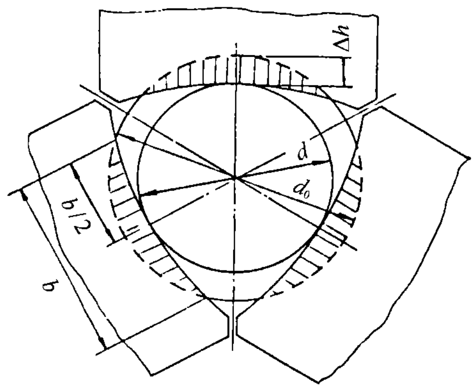


Figure 3 Roll pass and work piece.

2.3 Average resistance of deformation

The average resistance of deformation is

$$K_m=1.15(\sigma_0+a\varepsilon^n) \quad (5)$$

where σ_0 is the first yield stress, a is the strain-hardening coefficient, n is the strain-hardening index, and ε is the strain. The values of σ_0, a, n for the materials studied in this paper are shown in **table 1**.

Table 1 Mechanical properties of materials.

Material	σ_0 / MPa	a / MPa	n
Brass	171.5	28.42	0.64
Carbon Steel	294.0	28.91	0.64
Stainless Steel	294.0	91.14	0.62
Fe-Cr-Al	490.0	69.58	0.58

2.4 Roll pass coefficient

The roll pass coefficient presents the effect of the roll pass on rolling force. It is an amendment to applying the Bland-Ford-Hill theory for 2-high mills to 3-roll mills. After a roll pass is designed and regulated, mill spring is the only one factor, which affects the roll pass. Therefore, it will cause α to change. When equipment and the size of work piece are unchanged, material is the only one factor that influences rolling force and mill spring. So α is mainly dependent on K_m for a certain roll pass. By substituting the experimental data and the calculated values of the parameters into equation (1), α is obtained. Analyzing the relationship of α and K_m shown in **figure 4**,

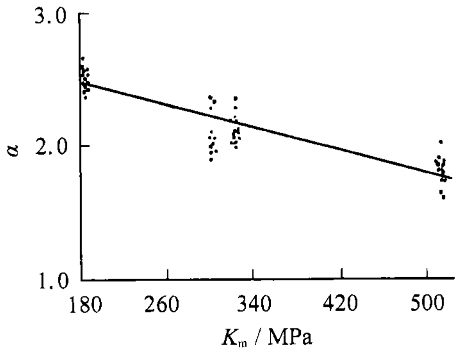


Figure 4 Relationship between α and K_m.

$$\alpha = 0.002\,173\,6 K_m + 2.886\,6 \quad (6)$$

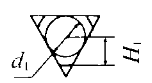
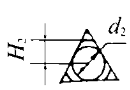
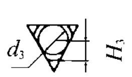
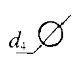
The correlation coefficient is $r = -0.83$, so the relationship of α and K_m is approximately linear. The square root variance between the measured values of force and the predicted by equation (6) is 0.32 kN.

3 Rolling Torque and Characteristic Analysis of Deformation

In order to study the characteristics of the mill in continuous rolling process, the torque of every stand is measured in a continuous rolling process of 4 stands. Before the experiment, 4 strain gauges are mounted on the main driveshaft of every stand and arranged in a Wheatstone bridge. In rolling process, the electric signals provoked by the rolling torque are transmitted through the slip-rings designed especially, amplified and recorded. In addition, the voltage and current along with the rotate velocity of the motor are measured. Active power can be calculated too.

There were 4 specimens for each of four materials, which were 0Cr25Al5, GCr15, 1Cr18Ni9 and Cr21Ni10. The specimens were rolled at two speeds: speed I and II, with and without lubrication individually. Flat and round passes were applied. The sizes of the roll pass and the work pieces, and the elongation for each pass are shown in **table 2** (where δ_n is the elongation). The typical wavy curve and the measure torque are as shown in **figure 5**. The input power of the motor, the average of active power of the mill and efficiency factor under the normal rolling condition (with lubrication) are shown in **table 3**.

Table 2 Roll passes, work pieces and percentage of elongation.

Number n	Cross section	d_n / mm	H_n / mm	δ_n / %
0		8.00	4.00	–
1		6.92	3.92	43.9
2		6.48	3.82	32.1
3		5.78	3.05	40.0
4		5.18	2.59	22.6

There are two kinds of wavelets on the typical wavy curve. One kind is small and weak, and exists before a work piece enters the roll pass. It is because the machining precision of the mill is not high enough so that some part is eccentric and the mesh of gears is not steadied. However, the another kind, obvious and strong, is provoked by inhomogeneity of sizes and properties of work pieces.

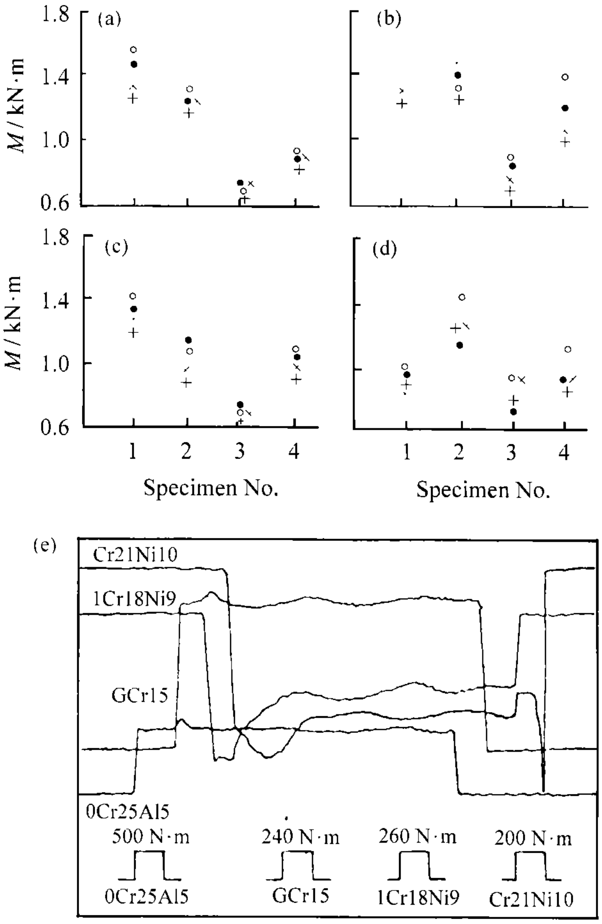


Figure 5 Results of the measured torque. (a) 0Cr25Al5, (b) GCr15, (c) 1Cr18Ni9, (d) Cr21Ni10 and (e) schematic diagram of the measured torque. • Speed I, without lubrication; + Speed I, with lubrication; ○ Speed II, without lubrication; × Speed II, with lubrication.

When a work piece enters every stand, the wavy curve of torque appears a small peak, which presents the impulse of work pieces to the stand. Furthermore, when a work piece enter stand 4, the torque of stand 3 drops sharply. It is reasonable that there is great tension between the two stands. It is verified by the sharp decrease of the torque of stand 4 when the work piece is thrown from stand 3. The sharp tip is the result when it leaves the guide. According to the experimental results, it is known that the tension between the stand 3 and stand 4 is very large. This causes the difference of the loads between the two stands and makes the roll wear rapid and inhomogeneous.

Based on the experimental results, it is concluded that rolling torque has not obvious difference when the speed changes from seed I (about 60–70 r/min) to speed II (about 120–130 r/min). At one of the speeds the

Table 3 Power of the mill.

Condition	Material	Input power / kW	Active power / kW	Efficiency / %
Speed I	GCr15	7.50	5.28	70.4
	1Cr18Ni9	6.25	4.35	72.5
	Cr21Ni10	6.40	4.69	73.3
Speed II	GCr15	11.63	8.28	71.2
	1Cr18Ni9	10.24	7.93	77.4
	Cr21Ni10	10.80	7.81	72.3

change of rolling torque is little with or without lubrication.

With respect to efficiency, the efficiency factor of the mill is about 75%. It is because that the drive system of the mill is complex and has many gears so that the number of friction faces is increased greatly. This situation can be improved by making the design better and raising the lubrication quantity [3].

4 Conclusions

(1) It is feasible and simple setting up the model of rolling process on 3-roll mills by identifying the structure of the model theoretically and determining the coefficients of the model by statistical analysis of experimental data. The model of rolling force can be used for predicting rolling force accurately or applied to control rolling process.

(2) The measurement of rolling torque of each stand in continuous rolling can be used to analyze the deformation characteristics of metals on 3-roll mill and evaluate the technological process, which supplies guidance for improvement of the technology and equipment.

(3) Although this kind mill is very compact, the efficiency is not very high owing to the complication of the drive system.

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