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# Micro scale design and experimental research of rolling interface[①]

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**[Abstract]** Aimed at some central issues of general interest and odd phenomena, an experimental research analysis and simulation of rolling interface was presented. Some root causes or originations of these issues were found. It is shown clearly that, surface roughness of working roll, a certain vibration mode of roll gap, material types of roll sleeve and lubrication state of rolling interface are the key factors determining rolling material quality and are sensitive to dynamic stability of rolling interface.

**[Key words]** interface; dynamic stability; temperature field
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## 1 INTRODUCTION

Rolling interface is of complicated and sensitive link, also is the key of various problem existing in rolling system. As we know, a lot of factors have influence on performance of rolling interface, some of them are recognized by researchers, others, especially some micro parameter or weak coupling, are not. Based on experiment researches and analyses, this work realizes or finds the mechanism of some kinds of micro parameter or weak coupling and its influence on performance of rolling interface, and some understanding about design of material processing interface and processing technology are put forward in this paper.

## 2 DYNAMIC STABILITY OF ROLLING INTERFACE

The requirement of material surface quality is very high at present time, for instance surface defect of high grade car plate can not goes up to $10^{-3}$mm in thickness. However material surface quality depends on working state of interface completely, and it is determined by many factors such as rolling velocity, rolling pressure, thermodynamic process, elasticity of operation mechanism, plasticity of workpiece, dynamic behavior of interface sticking-sliding and partial hydrodynamic lubrication etc. The mechanisms of interaction and effect of these factors on interface are still gray-fields. For instance, "spectre chatter", which will produce chatter marks on strip surface or make thickness error, is a typical problem which attracted world-wide attention in the rolling fields. The following points are part of results of experimental researches and findings of our recent research work.

### 2.1 Influence of working roll roughness

Research results indicate that rolling mill chatter which produces $10^{-2}$ ~ $10^{-3}$mm thickness error on material surface is closely related to interface state. Fig. 1 and Fig. 2 are power spectra of vertical vibration of working roll of a certain steel strip rolling mill.

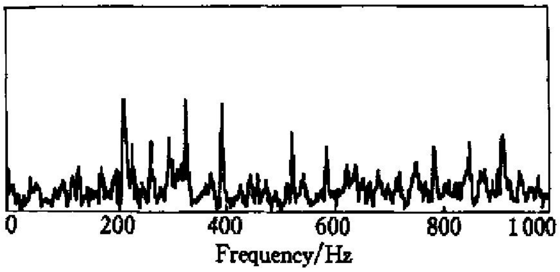


**Fig. 1** Spectrum of vertical vibration of rougher roller

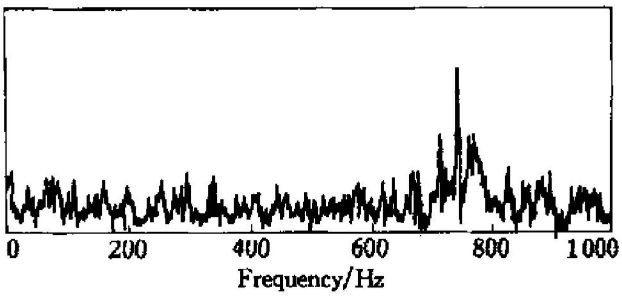


**Fig. 2** Spectrum of vertical vibration of smoother roller

Obviously, the frequency distribution of rough roller is more evenly and more scattered than that of the smooth roller which has aggregation frequency distribution at 735Hz which is detrimental to mill stability and material surface quality. Preliminary ex-

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periment and analysis indicates that, under the same condition, the smoother the roller is, the more unstable the friction force is, thus provides hot bed for producing of self-excited vibration.

## 2.2 Chatter mark producing

The surface chatter marks produced by so-called "spectre chatter" is closely related with vertical vibration frequency of working roll. Fig. 3 is surface chatter marks of the rolled material sample of a certain temper mill, the brightness streak spacing $L = 29\sim 30$ mm, rolling speed $V = 1\,000$ m/min $= 16\,600$ mm/s, so frequency $f = V/L = 16\,600/(29\sim 30) = 572\sim 593$ Hz. On the other hand, power spectra of vertical vibration of working roll corresponding to rolled steel strip material sample have center frequency at 584 Hz as shown in Fig. 4. Therefore we can infer that 584 Hz vertical vibration of working roll is the key condition that leads to chatter marks on surface of steel strips. Indeed, further analyses show that the 584 Hz frequency vibration is related closely to a certain vibration mode of working roll.

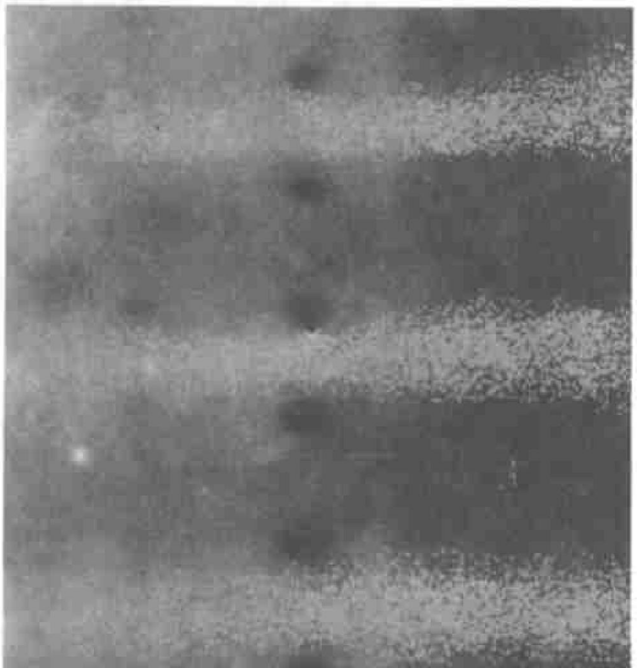

**Fig. 3** Shape of chatter marks on surface of steel strips

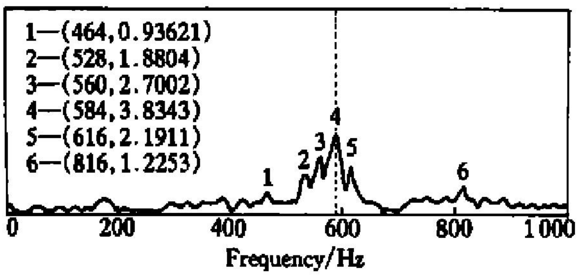


**Fig. 4** Spectrum of vertical vibration of upper working roller

## 2.3 Electromechanical couplings

There are a lot of electromechanical couplings in rolling mill systems, such as the coupling between armature current and twist vibration of main drive shaft as shown in Fig. 5 and Fig. 6. Comparing the two figures, we can see that, both of them have distinct peak value frequency distribution at 300, 600, 900 Hz, and almost no frequency difference, except power spectrum of twist vibration of main drive shaft has more background noise. Since it is a typical strong electromechanical coupling, a great importance will be easy to be attached to it.

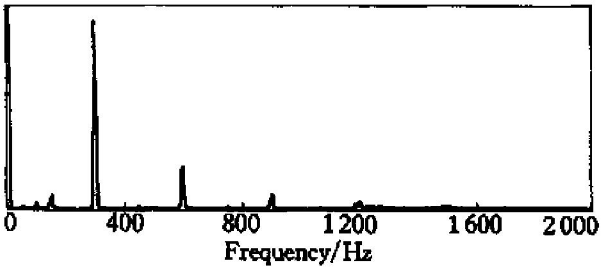


**Fig. 5** Power spectrum of armature current

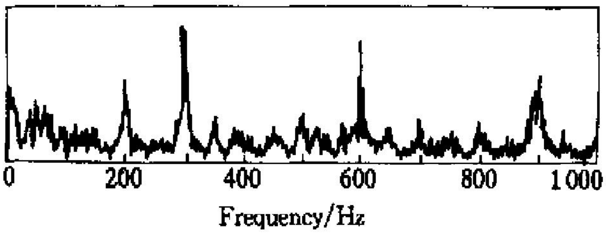


**Fig. 6** Power spectrum of twist vibration of main drive shaft

Indeed, traditional material processing systems generally emphasize the strong electromechanical coupling design, which decide the fundamental functions of processing systems. But alongside increasing of rolling speed and rolling pressure day by day, some weak coupling become very significant. For instance, weak electromechanical coupling is also found between armature current and vertical vibration of working roll and theoretical analyses show that it is transmitted through coupling chain as following: armature current $\rightarrow$ twist vibration of main drive shaft $\rightarrow$ processing interface in roll gap $\rightarrow$ working roll. Harmonic vibration of working roll found in test record is illustrated in Fig. 7.

## 3 TEMPERATURE DROP RATE DESIGN OF ROLL-CASTING INTERFACE

Experimental research makes it clear that if the roll-casting process from solidification to plastic deformation was made under the circumstance of high gra-

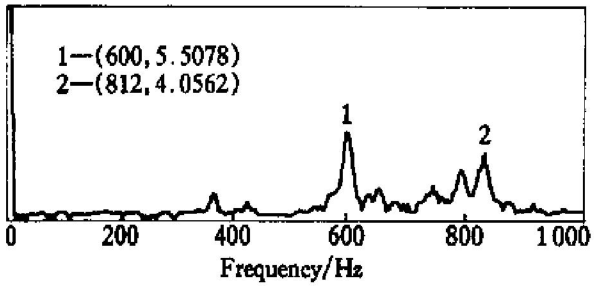


**Fig. 7** Power spectrum of harmonic vibration of working roll

dient temperature field, the properties of materials would be much better and power loss much less than processing operation now available.

For instance, comparing converter-continous cast-hot rolling with electric furnace-continuous roll-casting of thin plate, the work period of the latter is 1/8~ 1/9 as the former, power consumption 1/3, capital input 1/8 ~ 1/10. In addition, when aluminum thickness is reduced to 2 ~ 3 mm, working speed may increase greatly and uniform equiaxed fine-grain structure can be obtained. Therefore, realization of high temperature molten material crystallization and solid plastic formation under the condition of high temperature gradient is one of the important developing directions in materials processing domain. The key for realization of the strengthened processing technology is to produce a working interface, which has a strong bearing capacity and makes rolling material to possess super high temperature drop rate and roll sleeve to possess suitable temperature gradient.

Our recent research works include:

1) The relation between temperature gradient and sleeve thickness.

2) The heat conduction rate in the same direction of different materials.

3) The relation between the ability of heat conduction of interface and factors such as the roughness of working surface, surface pressure and surface affinity.

4) The relation between interface lubrication state and the ability of heat conduction.

For instance, the comprehensive research shows: there is a high density heat flow layer at point $A$ in roll-casting interface of aluminium as shown in Fig. 8, and Fig. 9 is temperature distribution in the direction of roll sleeve thickness and circumference of roll outside surface. That is, after entering the rolling-cast area, the roll temperature increase rapidly and reaches extreme value at point $A$, then it decreases rapidly. Fig. 10 is the cut-away view of the summit point (i. e. point $A$). Roll-casting area in the thickness direction of temperature field could be divided into high density heat flow area $a$ and low density heat flow area $b$. The temperature peak value area (i. e. area $a$) is corresponding to extraordinary

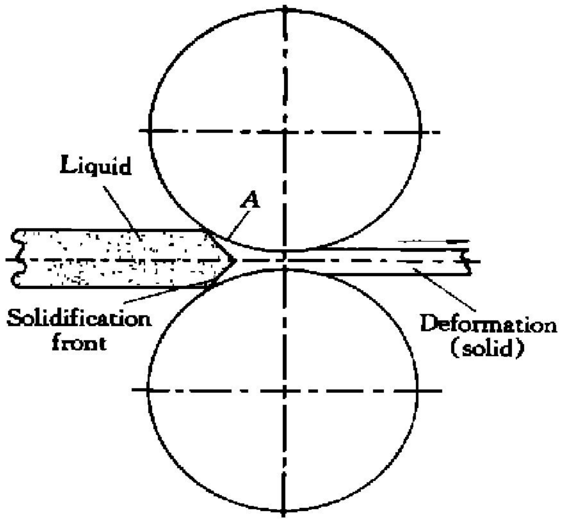


**Fig. 8** Schematic diagram of roll-casting process of aluminium

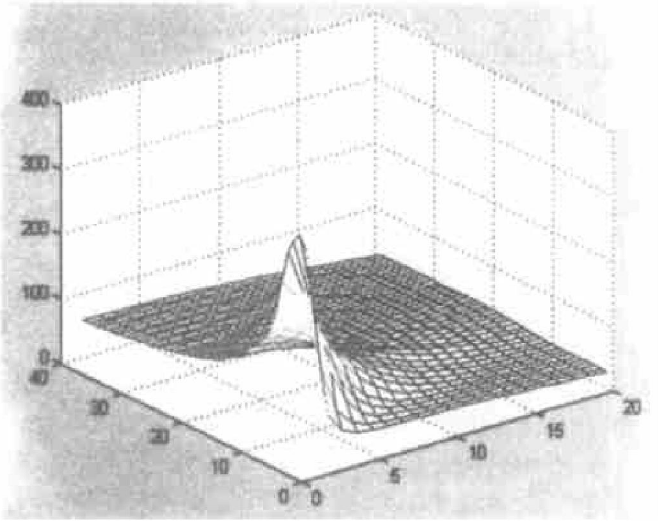

**Fig. 9** Temperature distribution in direction of roll sleeve thickness and circumference of roll outside surface

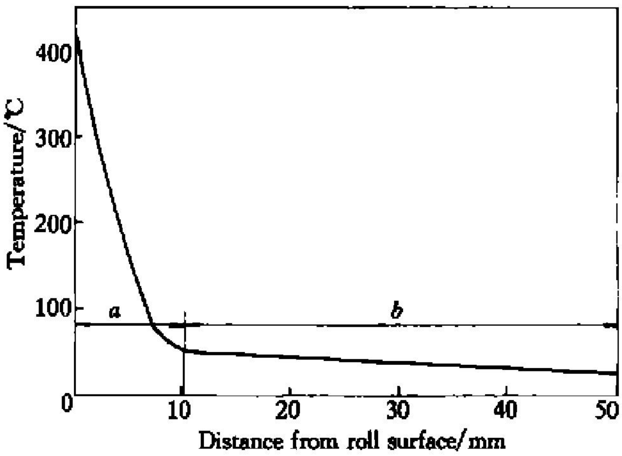


**Fig. 10** Temperature distribution in direction of roll sleeve thickness

physical circumstance of the fast solidifying of molten aluminum.

Obviously, the wider the area $a$ is, the better the fast solidification circumstance is, and the width of area $a$ is closely related to roll sleeve radial temperature gradient curve. The experimental research shows, material types, surface roughness, surface lubrication state and contact stress and so on, will have influence on the feature of curve in Fig. 10.

### 3.1 Material comparison experiment

Fig. 11 shows the influence of different materials on temperature field in the direction of roll sleeve thickness.

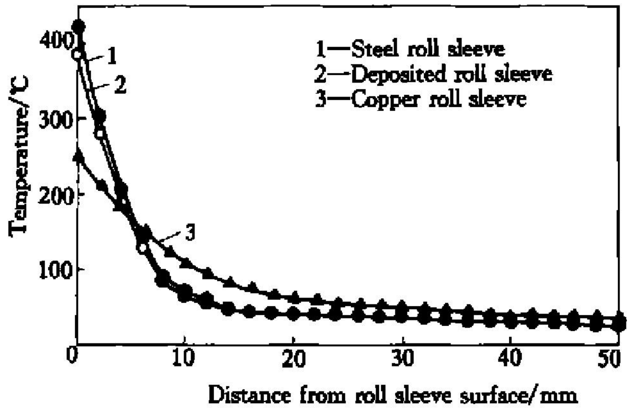


**Fig. 11** Influence of different materials on temperature field in direction of roll sleeve thickness

Apparently, the heat conduction coefficient of the copper sleeve is quite large, therefore not only the interface temperature is the lowest, but also area $a$ is the widest. However, the normal steel sleeve has a contrary situation, so its fast solidification condition is much worse than that of the copper one, and the coefficient of heat conduction of deposited roll sleeve is between the two values. From this aspect, the adoption of the material with strong ability of heat conduction will improve the temperature drop circumstance, but at the same time the strength of material should be considered.

### 3.2 Roll surface roughness comparison

Experimental results also indicate that under general liquid-solid condition, relatively rough surface has less heat resistance, lower interface temperature and wider area $a$ (Fig. 12), therefore, is naturally advantageous to form fast solidification circumstance.

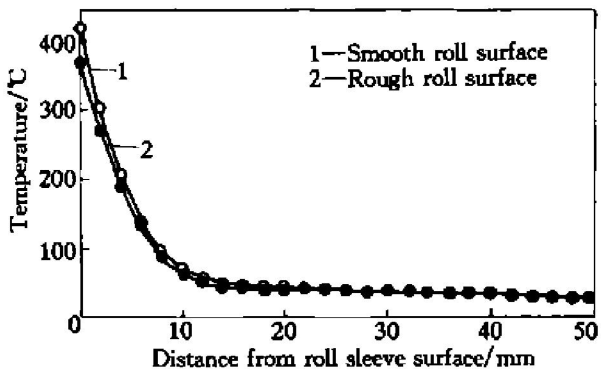


**Fig. 12** Influence of surface roughness

For this reason, relatively rough roll sleeve is better than the relatively smooth one.

### 3.3 Lubrication comparison

Experimental results also show that the fast solidification circumstance is influenced by lubricating state of rolling interface. Fig. 13 illustrates a comparison between under-lubrication interface and over-lubrication interface. Clearly, for under-lubrication circumstance, there is very little heat-resistance, therefore, heat can transfer from interface to sleeve, and causes high temperature on the sleeve surface as curve 1 in Fig. 13. Therefore, molten aluminum is apt to stick to rolls, as a result, the process of roll-casting can not run continuously. But for the circumstance of over-lubrication, because of the high contact heat-resistance, the ability of heat conduction is very low, and the heat in molten aluminum liquid cannot transmit to sleeve efficiently and quickly. Therefore molten aluminum cannot be solidified efficiently (as curve 3 in Fig. 13). It is shown that a better and compromising radial temperature gradient of rolls is curve 2 in Fig. 13. Under the working condition corresponding to curve 2, the sticking of aluminum to rolls can be avoided, and molten aluminum can be solidified more efficiently. Therefore the process will proceed continuously and efficiently.

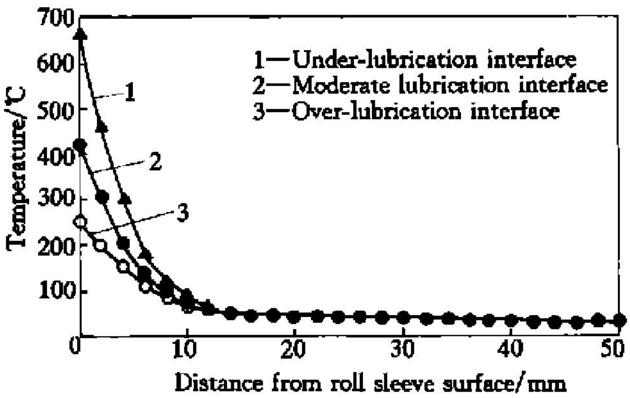


**Fig. 13** Comparison between under-lubrication interface and over-lubrication interface

Considering Fig. 11, Fig. 12 and Fig. 13, the effect difference produced by different factors on sleeve radial temperature gradient is mainly reflected in area $a$. From this point of view, one of benefit of widening area $a$ is that the roll sleeve thickness could be made full use of in heat conduction. Thus two extreme roll sleeve radial temperature gradient curves have to be designed as shown in Fig. 14. Under the condition of proper contact heat-resistance, curve 2 is the best and curve 1 should be avoided.

## 4 CONCLUSION

The analyses as above mentioned show that ma-

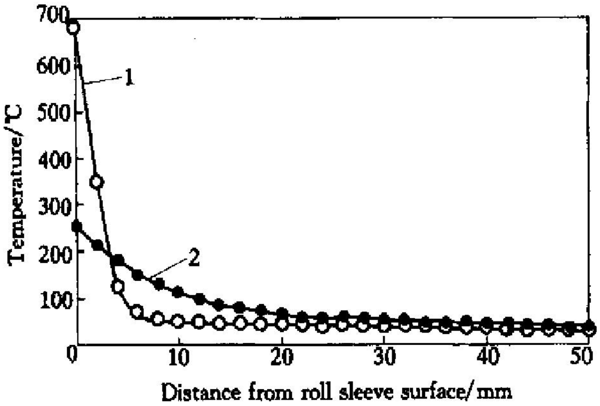


**Fig. 14** Design comparison between two extreme roll sleeve radial temperature gradient curves

terial processing machine is a complex, sensitive system. Many factors, such as vibration, roller-sticking etc can be very serious problems with rolling mill equipment and mainly depend on working condition of rolling interface. In order to identify various influence on rolling interface, experiment investigation and analyses have been performed. The results show that working performance of rolling interface is sensitive to surface roughness of roller, material types, interface lubrication, harmonic component of motor etc. For instance, as to roll-casting process, to solidify efficiently and avoid roll-sticking, both under-lubrication interface and over-lubrication interface can not be chosen, and yet a compromised, carefully designed lubrication interface will lead to high quality of roll-casting products.

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