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Lubrication Pressure Injection System of Hot Rolling Line Valve Controlled Rolling

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The role of rolling lubrication technology in hot rolling production line and composition of rolling lubrication hydraulic injection system are described. Through the analysis of the problems in the practical application of the conventional pump controlled rolling lubrication hydraulic injection system, we proposed the design of valve control system. The characteristics of the pressure injection valve and its characteristics are analyzed. The control problem of the system is analyzed in order to control the strip shape and guarantee the stability of rolling process.

1. Introduction

Rolling lubrication technology in the hot continuous rolling line as a new type of energy conservation technology includes a hydraulic injection system in a core. The working principle of the hydraulic injection system for rolling lubrication, as shown in Fig. 1, is to distribute the uniform and stable lubricants from the system to the lubrication medium spray beams and nozzles of each array of rolling mills via pipelines where they are jetted to the juncture between hot-rolled blank and the work roll surface at preset temperature, pressure, flow, and spray angle. The lubricants can be effective to lubricate the working surface in the high-temperature rolling deformation area, improve the tribological performance during rolling, reduce rolling force and the roll surface wear, and finish the surface of the hot rolled strip. Lubricant is a kind of emulsion formed by fully mixing the traces of base rolling oil and cooling water.

The important functions of this technology are given as follows:

In the presence of lubrication action, the friction coefficient during rolling can be reduced by 30%~50% (Sun, 2010; Sun et al., 2010; Azushima, 2007) more than that in the absence of lubrication action so that the frictional drag in the deformation zone significantly decreases. In this way, the drive current of the main motor in the rolling mill can be effectively lessened, and an evident energy conservation effect can be achieved (Komi, 1998; Keyser et al., 1998; Pellizzari ei al., 2005; Shirizly and Lenard, 2000; Jin et al., 2002).

According to statistics, to trace back to the main motor of the rolling mill, it is deduced that the rolling current declines by about 8% ~ 20%, in other words, power consumption will be saved by about 3 ~ 5 kW·h per ton of steel. In the case of equal rolling load, the working potential of the rolling mill can be further exploited, the rolling pass can be reduced, or a thinner strip steel product can be rolled out, thus the capacity of the rolling line can be significantly improved, while the roll force of the rolling mill can be increased by 10%~15% (Shi et al., 2006).

Roll wear may lessen to extend roll service life and save roll changing time, thus to improve the operating rate of overall production line. As lubrication rolling runs after introducing the hot rolling process, the roller and the rolling piece are detached by a layer of rolling oil film at the boundary, in order to avoid black skin produced on the surface of the roller, relieve the roll wear, and prolong the working cycle and the rolling kilometers of the work roll as scheduled, also save the roller changing time and increase the operating rate of the rolling mills on the whole production line. According to statistics, the consumption of roller can be reduced by 30% ~ 50%, and with the same roller, the rolling kilometers can be extended by more than 5% at the cost of equivalent consumption. Each roll of 10,000 tons of steel can save more than 50 minutes of roller change time.

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The surface finish of the strip steel can be significantly improved, thus reducing the iron oxide scales rolled in blank surface during rolling. Today, users raise the bar for the surface quality of strip steel so that companies all compete to develop new rolling technologies that can improve surface finish. The hot rolling process lubrication technology can well fit the bill. While reducing the roll wear, the small particle scale that attaches to the steel surface can be purged by the injection pressure to directly improve the surface finish after rolling. Additional, the friction regulation effect that process lubricant is applied to the deformation area may help strip shape quality after rolling. For hot-rolled products that require pickling, cold-rolling and other subsequent processes, the improvement of the surface finish after rolling can also speed up the pickling of the hot-rolled strips, rebate the acid consumption, and diminish the loss of pickling metal. According to statistics, the acid consumption per ton of steel is reduced by 0.3-1.0kg.

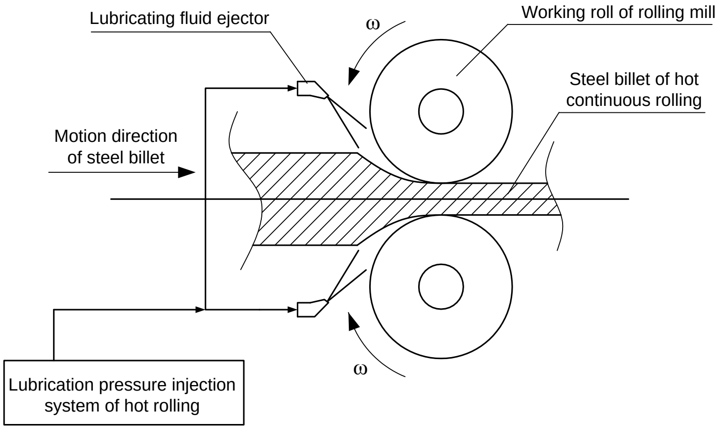


Figure 1: Sketch Map of Lubrication pressure injection system in the Hot continuous rolling

This technology has now been applied in the country. At that, there is something that we have accomplished with this technology, mainly focusing on the large-scale wide-thin plate rolling line, in particular more stainless steel rolling line (He and Yang, 1999; Wang, 2013) has been applied. However, there are still some gaps in the technology in the practical application of the system, which need to be improved and explored extensively. The following discusses this system in conjunction with system analysis.

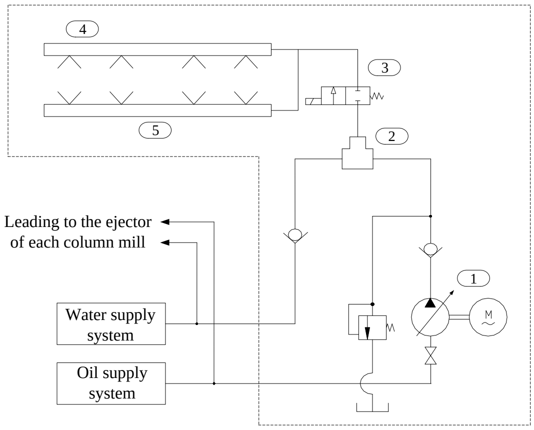
2. Design and composition of valve control system

The conventional hydraulic injection system for rolling lubrication gives the principle of the pump control system, as shown in Fig. 2. The oil supply system feeds the base lube, which is mixed with the cooling water provided by the water system in the static mixer 2 via the metering pump 1 to form a stable emulsion and flow into the upper and lower work roll headers (elements 4 and 5) from the high speed shut-off valve 3. These emulsions will be jetted onto the rolling deformation zone from nozzles installed at equal intervals on the header. The injection control unit composed of parts 1 ~ 5 must be installed with at least one set on each train of finishing mill, however there is also an instance that the upper and lower work rolls are equipped with one set of it respectively.

The following technical problems will occur on the pump control system in practical application:

(1) Since the nozzles on the injection header are easily clogged, coupled with the impact of the injection pressure, the unstable rolling lubrication may be caused. This problem has been highlighted in Literature [4]. There are some measures taken against it, such as the replacement of pipeline and parts made of stainless steel material, and the isolation of the lubrication system from the roll cooling water system, by which the independent water system is constructed for the rolling lubrication system to allow fresh water that has been softened only. These measures have substantially increased the application costs, so that it is imperative for us to study the other new solutions.

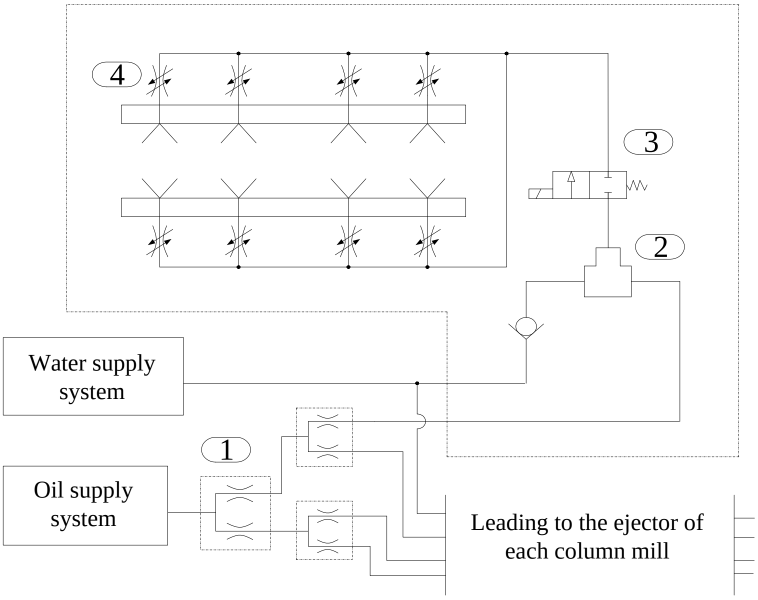
(2) Literature argues the control effect of the rolling lubrication technology on the strip shape. From the perspective of practical application of the conventional pump control system, on each train of finishing mills, after the lubricant is dispensed by a metering pump and is fully mixed by a static mixer, it is jetted onto the rolling zone from a nozzle via a header. The injection flow parameter in the system is constant and basically nonadjustable. There is no control effect over the shape of the rolling pieces, which is worth improving.



1.Metering pump; 2. Static mixer; 3. High speed cut-off valve; 4. Top work roll collecting pipe and nozzle; 5. Lower work roll collecting pipe and nozzle

Figure 2: Conventional schematic diagram of pump control system

(3) The structure of the conventional pump control system is relatively complex. The metering pump is driven by a variable frequency motor, which has high costs, poor reliability. There is a room for improvement.
Based on the technical problems in the above applications, the study proposes a new type of valve-controlled hydraulic injection system for rolling lubrication and its principle is shown in Fig. 3.

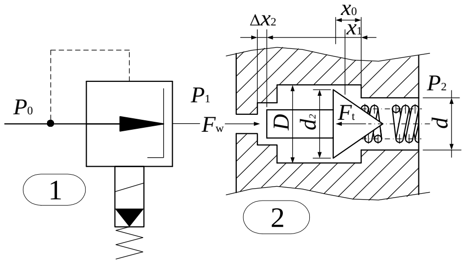


1. Diverter valve 2. Static mixer 3. High-speed shut-off valve 4. Pressure regulator injection valve

Figure 3: Schematic diagram of valve control system

Compare the valve control system with the pump control system, there are some differences as follows:
1) The metering pump is replaced by a diverter valve which can distribute the flow by a preset ratio. Take a finishing mill unit 8 as an example, six diverter valves can help finish the system construction that requires eight metering pump units, which not only simplifies the system but also improves system reliability.
2) The self-designed pressure regulator injection valve replaces the simple jet nozzle structure. The purpose of the design is to make the pressure regulator injection valve achieve the adjustment for the flow and opening by pressure, as shown in Fig. 4. The structure and steady-state characteristics of pressure regulator injection valves are analyzed below.

3. Structure and steady-state characteristics of pressure regulator injection valve



1. Pressure regulator valve；2. Injection valve

Figure 4: Structure diagram of pressure regulating injection valve

The pressure regulator injection valve is composed of two valves, i.e. a pressure regulator valve and an injection valve, in series. The front is the pressure regulator valve, which is implemented by a standard thread cartridge proportional decompression valve, easy to be integrated and installed on the spray manifold. The rear is the injection valve which adopts a self-designed poppet valve structure. In order to explain the control principle of the injection valve, the following analyzes the steady state characteristics of the injection valve.

For the valve core of the injection valve, take the fluid micro element above the valve port. Using equation (1) of the fluid momentum theorem, solve the steady-state hydrodynamic force to obtain formula (2):

$$\sum F = \frac{\Delta(mv)}{\Delta t} \tag{1}$$

$$\begin{aligned} & p\frac{\pi}{4}(D^2 - d_2^2) - p\frac{\pi}{4}(D^2 - d^2) - F_w = \\ & \rho q(v_2 \cos\theta - v_1) \end{aligned} \tag{2}$$

Where, F_w—Steady-state hydraulic power

p—Injection valve pressure drop, $p_1 - p_2$

q—Injection valve flow

ρ—Lubricant medium density

v_2—Valve port flow rate

v_1—Flow rate before valve

θ—Valve core tip angle

D—Diameter of the valve front-cavity

d—Diameter of the valve rear-cavity

d_2—Valve core feed end effect area

The relationship between steady-state hydraulic power and pressure, flow rate, throughput and valve body geometry is derived by Eq. (2), see Eq. (3):

$$\begin{aligned} F = {} & p\frac{\pi}{4}(D^2 - d_2^2) - p\frac{\pi}{4}(D^2 - d^2) \\ & - \rho q(v_2 \cos\theta_2 - v_1) \end{aligned} \tag{3}$$

The steady-state hydraulic power is balanced by the spring force of the injection valve, and it follows Eq. (4):

$$\begin{cases} F_w = F_t = K_s \cdot (\Delta x_1 + \Delta x_2) \\ \Delta x_2 = x_0 - x_1 \end{cases} \tag{4}$$

Where, F_t—the spring force of the injection valve

K_s—The stiffness factor of the spring

Δx_1—Valve core spring pre-compression

Δx_2—Additional spring compression for maintaining valve opening

x_0—Maximum opening of the injection valve at the no-load

x_1—Steady-state opening of injection valve
Eq. (5) may be derived from the formula of flow and pressure via the valve port:

$$q = C_0 A \sqrt{\frac{2\Delta p}{\rho}} \tag{5}$$

Where, C_0—pressure flow coefficient determined by the injection valve structure
A—the through-flow section area determined by the steady-state opening x_1 of the injection valve;
Δ_P—Pressure drop *p* before and after valve
Joint-stereoscopic Eq. (3), (4), (5) can determine the function relationship (6) between injection valve flow q and valve opening degree x_1

$$\begin{cases} q = f_1(p, H, \rho) \\ x_1 = f_2(p, H, \rho) \end{cases} \tag{6}$$

In Eq. (6), *H* is a parameter determined by the injection valve structure, and it represents the structure and dimension parameters determined by the injection valve structure, such as the spring force F_t, the valve chamber size, and the like. The Eq. (6) can solely determine a function expression for calculating the steady state flow and opening of the injection valve which are determined only by the valve pressure *p*, the valve structure parameter *H*, and the lubricant medium density *ρ* as *H* and *ρ* are constant. The valve pressure *p* is adjustable and controllable by the proportional equalizer valve before the injection valve. Therefore, only control pressure *p* can conveniently control the steady state opening. In this way, large particle impurities can be purged easily to eliminate the problem that the nozzle in the pump control system is often clogged; the pressure control using a pressure regulator valve can address lubrication instability caused by the injection pressure of the pump control system; and the pressure regulator injection valve achieve the control of the coolant flow along the axial direction of the roll body, which can provide a solution to the strip shape control. Below is the analysis of its control principle.

4. Fault in system control

There are some control faults occurred in the hydraulic injection system for rolling lubrication that we should study for the purpose of furnishing the line with a well-established, reasonable and stable control system in order to achieve the control and stable lubrication rolling with trip shape.

4.1 Analysis of trip shape control application

The control effect of the hydraulic injection system for rolling lubrication on the strip shape is shown in Fig. 5.

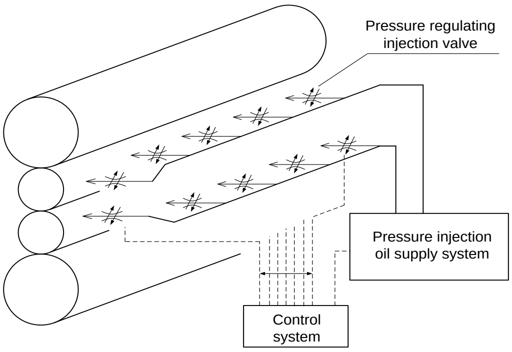


Figure 5: Control effect of lubrication system in strip shape control

The pressure regulator and injection valves are installed on the header in the sections along the length of the roll body. The divided sections should keep consistent with that of the outlet trip shape detector on the finishing mill. The signal received from the trip shape detector is treated and sent to the hydraulic injection control system for rolling lubrication. A flow distribution model preset by the control system dynamically changes the flows of the pressure regulator and injection valves with the thermal roll profile in order to achieve the strip shape control of the strip steel.

4.2 Process control that matches the rolling rhythm

Due to the effect of hot-rolled lubricant, improper control will lead to slippage of the strip steel when it is nipped into the finishing mill unit. If the strip steel cannot be nipped into it, the accident of strip jam will occur since hot-rolled oil residual remains on the work roll and is partly burned so that the following piece of strip steel does not satisfy the condition for nipping due to too low friction force when being nipped.

The control system must be able to achieve a process control that matches the rolling rhythm. The specific control strategy is taken as follows: a photoelectric switch is set up on the roller path before the strip tail accesses the rolling mill. Control system captures this position signal and break the jetting of the first rack lubricant medium in advance with the high-speed shut-off valve. Hot-rolled oil that adheres to the roller is burned out at the high temperature of hot-rolled strip tail; based on the lag time Δt_1 consumed by billets passing through each tandem mill, the subsequent racks are in turn delayed by Δt_1. Jet of the lubricant stops before the trip tail passes through it. After the next strip head is nipped into the first rack, jet of the rolling lubricant medium does not start until Δt_2 later. The subsequent rack jets are in turn started again based on the time lag of the billet passing through each rolling mill. With this control strategy, the lubrication rolling process can be ensured to be stable by field commissioning and adjustment of the delay time.

5. Conclusion

By exploring existing pump-controlled rolling lubrication and hydraulic injection system, we independently design a type of pressure regulator and injection valves based on a valve-controlled system design in attempt to eliminate the faults such as unstable pressure of injection system, easy-to-block nozzles, and complex system configuration. The new valve-controlled rolling lubrication and hydraulic injection system integrated with the control system can play a function of strip shape control. The control strategy that matches with the rolling rhythm can help the rolling lubrication and hydraulic injection system smooth lubricate the rolling process.

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