International Journal of Mineral Processing and Extractive Metallurgy
2019; 4(1): 7-13
http://www.sciencepublishinggroup.com/j/ijmpem
doi: 10.11648/j.ijmpem.20190401.12
ISSN: 2575-1840 (Print); ISSN: 2575-1859 (Online)

SciencePG
Science Publishing Group

Methodology Article

Exploration of Pipeline Filling Methods for High-pressure Water Descaling System

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To cite this article:
Yang Dezheng, Ao Feng, Yang Yiguang. Exploration of Pipeline Filling Methods for High-pressure Water Descaling System. *International Journal of Mineral Processing and Extractive Metallurgy*. Vol. 4, No. 1, 2019, pp. 7-13. doi: 10.11648/j.ijmpem.20190401.12

Received: December 23, 2018; **Accepted**: March 5, 2019; **Published**: March 28, 2019

Abstract: High-pressure water descaling is an important equipment in hot rolling of steel plant. Filling post pipelines of descaling valve during the interval of descaling operation can effectively protect the system equipment. Pipeline filling can prevent water loss from becoming empty pipe and forming air collection, thus to eliminate pipeline impact and vibration caused by descaling operation, and to avoid damage of pipeline equipment. There are two methods of water filling: low-pressure filling and high-pressure filling. Non-energy-saving descaling system, i.e. the system of mixed water supply of descaling pump and accumulator, and the descaling system of direct water supply of descaling pump, should choose high-pressure filling, which consumes little energy of good reliability and safety; while the energy-saving descaling system, i.e. the system of mixed water supply of descaling pump and accumulator, should choose low-pressure filling, which has lower energy consumption and remarkable energy-saving effect, but with relatively poor system safety.

Keywords: Descaling System, Accumulator, Pipeline Filling, Descaling Valve, Water Filling Valve

1. Introduction

In the high-pressure water descaling system of steel hot rolling line, the descaling valve is used to control the high-pressure water, which sprays to the billet surface for descaling operation by means of opening and closing. When the billet reaches the descaling point, the descaling valve opens and the high-pressure water flows to the descaling nozzle through the descaling valve. The high-pressure water sprays on the surface of billet through the nozzle under the combined action of cooling, cracking, blasting and scouring [1]. The oxide scale on the surface is thus removed, the billet passes through the descaling point completely, and the descaling valve closes to complete a full descaling operation.

After the descaling valve closes, the residual water in the post pipeline of the descaling valve overflows through nozzle of the lower descaling header, which causes the air collection in the post pipeline of the descaling valve and the upper descaling header due to water loss. When the descaling valve opens, the high-pressure water compresses the air in the pipeline, which causes impact and vibration on pipeline instantly, and the long-time operation will cause rupture of pipeline and header. Especially at the descaling point of the rolling mill, the upper header is installed on the rolling mill, and the header is installed in a high position with a long pipe, meanwhile equipped with a high-pressure hose for the purpose of header lifting and lowering [2], which is more likely to vibrate and rupture. The post pipeline of the descaling valve is filled during descaling interval (at time of no descaling), so that the pipeline and descaling header are fully filled with water, which prevents pipeline from impact and vibration effectively, thus extending the service life of the pipeline and header.

2. Overview & Classification of Pipeline Filling in Descaling System

The filling method of high-pressure water descaling system is controlled by a water filling valve. The pressurized water enters the post pipeline of the descaling valve fully filled with water, preventing occurrence of water loss, empty pipe and air collection. The filling methods can be divided into

low-pressure filling and high-pressure filling according to the pressure of water supply.

2.1. Low-pressure Filling

The water filling with low-pressure source is often called low-pressure filling, which can be filled with a line of low-pressure water led from the descaling pump room or the rolling line to the descaling valve and the descaling header. The operation principle is shown in Figure 1.

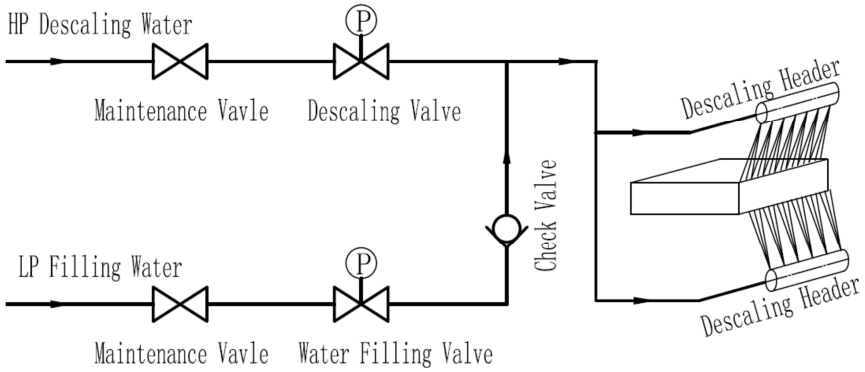

Figure 1. *Schematic Diagram of Low-pressure Filling.*

The operation mode of low-pressure filling is that the water filling valve opens in advance before the billet reaches the descaling point, so that the low-pressure water enters the post pipeline of the descaling valve for filling. The purpose of the water filling valve opening in advance is to ensure that the post pipeline of the descaling valve and the header are fully filled; when the billet reaches the descaling point, the descaling valve opens, and the nozzle sprays high-pressure water to the billet for descaling; the descaling valve and the filling valve close after completion of descaling. When descaling, the high-pressure water enters the post pipeline of descaling valve, the pipeline pressure rising, the check valve closing due to the pressure difference formed between front and back, and the high-pressure water is cut off by check valve and not able to enter the low-pressure pipeline. For every descaling operation, the check valve closes and opens once, the working frequency is fast, the pressure difference between front and back of the valve being large, the check valve easy to form mechanical damage and failure, making high-pressure water channeling into low-pressure pipeline, and resulting in such potential safety risks as equipment damage on low-pressure pipeline, and pipeline breaking. In order to prevent potential safety hazards, double check valves are used in low-pressure filling in many projects, further adding relief valves and pressure monitor between the two check valves for purpose of protecting and monitoring.

When the descaling valve closes, the high-pressure water is completely cut off by the descaling valve, and its flow rate drops rapidly from 4-6 m/s to 0 in 1-2S. It then forms an impact at the descaling valve, causing poor control of opening and closing of the descaling valve, and water hammer is generated in serious cases [3]. When the descaling valve opens, its flow rate rises rapidly from 0 to 4-6m/S in 1-2S, which is prone to cause impact and vibration to the pipeline. The check valve then closes instantly, causing impact and vibration on the low-pressure pipeline to some extent.

The water pressure is low in the mode of low-pressure filling, and there is no pressure loss and of low energy consumption, but it has potential risks of high-pressure water penetrating into low-pressure pipeline, making large impact to pipeline easy to produce vibration.

2.2. High-pressure Filling

The water filling with high-pressure source is often called high-pressure filling. After the high-pressure water is diverted to the descaling valve behind overhaul valve and in front of descaling valve, the post pipeline of the descaling valve is filled through the throttling device, reducing the pressure to 0.5-1 MPa. The principle is shown in Figure 2.

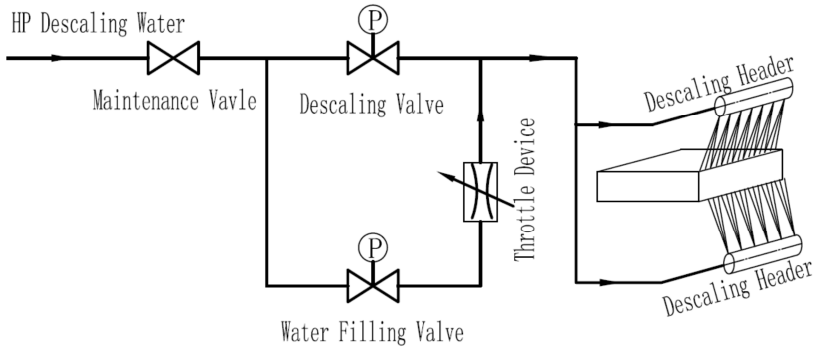

Figure 2. *Schematic Diagram of High-pressure Filling.*

The operation mode of high-pressure filling is that the water filling valve opens in advance before the billet reaches the descaling point. After the high-pressure water reduces to 0.5-1.0 MPa through the throttling device, it enters the post pipeline of the descaling valve for filling. The water filling valve opens in advance to ensure that the pipeline of descaling valve and the header are fully filled with water. When the billet reaches the descaling point, the descaling valve opens and the nozzle sprays high-pressure water for descaling operation. The descaling valve closes after completion of the descaling, and the water filling valve closes in a delay of 2-4S.

The pressure at the descaling point is generally 20-30 MPa, while the filling water pressure is only 0.5-1mpa. The calculation formula of nozzle flow under different pressures shall be $q_1 = \sqrt{p_1 / P_0} \times q_0$ [4], among the formula q_1 and p_1 refers to flow and pressure at filling, q_0 and P_0 referes to flow and pressure at normal descaling. It is thus calculated out that the nozzle flow outward is 15-20% of that of the descaling flow. At the opening moment of the descaling valve, 15-20% of descaling flow passes through the water filling valve, which reduces the flow through the descaling valve at the opening moment, meanwhile decreasing the water impact on the pipeline during the descaling valve opening. When the descaling valve closes, also 15-20% of descaling flow passes through the water filling valve, reducing the cut-off flow of the descaling valve, decreasing the impact on the descaling valve from the water. No matter that the descaling valve opens or closes, 15-20% of descaling flow will pass through the water filling valve, and the flow direction is the same as the direction of descaling, so there is only flow change in the pipeline system and with little impact on pipeline from water.

The high-pressure filling reduces the water pressure from 20-30 MPa to 0.5-1.0 MPa through the throttling device. The pressure difference at front and back of the throttling device is large with serious pressure loss, the energy consumption being high. It produces little impact on the pipeline, and causes little pipeline vibration, therefore of adequate safety and reliability.

3. Descaling Operation of Hot Rolling Strip

The high-pressure water descaling pump station for hot rolling strip usually consists of below parts: low-pressure water intake pipeline, descaling pump, overhaul valve at pump suction, check valve at pump discharge, overhaul valve, minimum flow valve of pump bypass, throttling device, accumulator system and its overhaul valve, minimum liquid level valve, etc. The system PID diagram is shown in Figure 3.

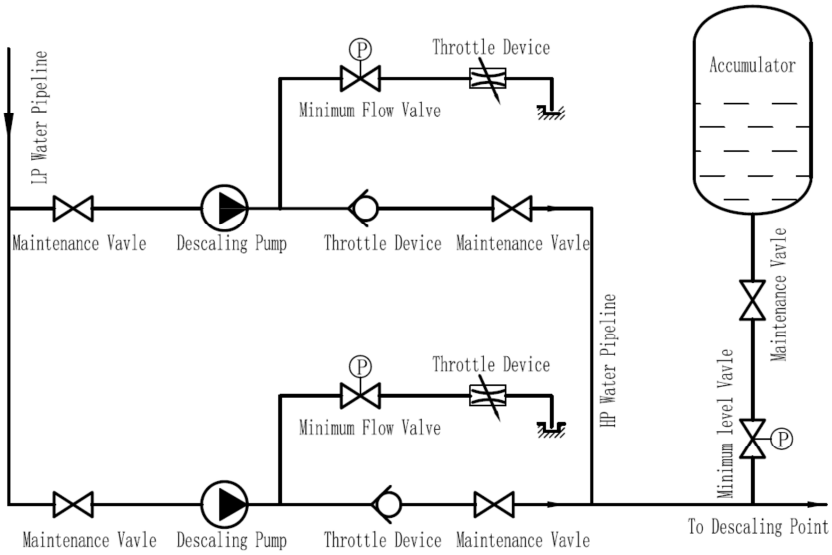

Figure 3. *Schematic Diagram of High-pressure Water Descaling Pump Station System.*

According to the water supply mode of descaling machine (header) in high-pressure water descaling pump station of hot rolling strip, the descaling system can be divided into two types: the mixed water supply system of descaling pump and accumulator, and the direct water supply system of descaling pump.

3.1. Descaling System with Mixed Water of Descaling Pump & Accumulator

In the hot rolling line of medium & wide plate, the high-pressure water descaling point lies in 3 places: pre-descaling behind furnace, descaling in rough mill and descaling in finish mill [5]. The descaling flow of each descaling point is large, the descaling time being short, and there are multiple overlapping descaling points. In hot rolling strip production line, there exists three descaling points: initial descaling (HSB-descaling machine behind heating furnace and in front of rough mill), medium descaling (E1/R1, E2/R2 inlet /outlet descaling header) and finish descaling (FSB - descaling machine in front of finish mill) [6]. The descaling time of initial descaling and medium descaling is short, with large descaling flow; while the finish descaling is long

timewise with relatively small descaling flow as well as with multiple overlapping points for descaling. Whether in medium/thick plate or in hot rolling strip, the descaling flow is large when the descaling overlaps. If the pump is directly supplied with water, the flow of descaling pump will be strong, short descaling time and less effective working time of pump, and the energy consumption is high in the end. Therefore, the descaling system is normally equipped with a big volume accumulator. At time of descaling, the accumulator alone supplies water to the descaling point, or the accumulator and pump with mixed supply water to the descaling point jointly [7], and the descaling pump replenishes water to the accumulator during the descaling intermittent, so that the high-pressure water is stored in the accumulator, ready for consumption of descaling operation. Many projects of this kind of descaling system are generally equipped with frequency converter [8] or hydraulic coupling [9] for energy-saving running. In this sense the mixed water supply system of descaling pump and accumulator can be divided into two types: energy-saving descaling system, and non-energy-saving descaling system.

3.1.1. Filling Method of Non-Energy-Saving Descaling System

The operation mode of non-energy-saving descaling system is that the descaling valve opens, the minimum flow valve closes, the descaling pump and accumulator supply water to the descaling point at the same time. After completion of descaling, the descaling valve closes, the descaling pump replenishes water to the accumulator. When the water level and pressure of the accumulator reach the set value, the minimum flow valve opens. Because the descaling system uses centrifugal pump with low specific speed or extremely low specific speed, it cannot operate in the mode of no-flow output, so when the accumulator fills up water, the system needs to open the minimum flow valve to make the pump keeping a certain flow output, so as to prevent cavitation and vibration of the pump. At this time, the pressure of accumulator system is the minimum flow pressure of descaling pump.

When the descaling system chooses low-pressure filling, it will not consume the output flow of the descaling pump or the water stored in the accumulator, and will not increase the energy consumption of the system. When the descaling system operates under mode of high-pressure filling, the filling water is provided by the accumulator and the descaling pump after the water filling valve opens. During the descaling interval, the minimum flow valve of the system opens and the output flow is emptied. If the system operates under mode of high-pressure filling, the output flow of the pump is combination of the discharge of the minimum flow valve and that of the water filled, and the output flow of system will increase in this case. According to the characteristics of centrifugal pump, the discharge pressure decreases as well as the release of the minimum flow valve. From the performance curve of the descaling pump shown in Figure 4, it can be seen that the pump power increase is very small. Therefore, in order to ensure the safe and stable operation of the system, it is more appropriate to choose high-pressure filling for the non-energy-saving descaling system with mixed water supply of descaling pump and accumulator.

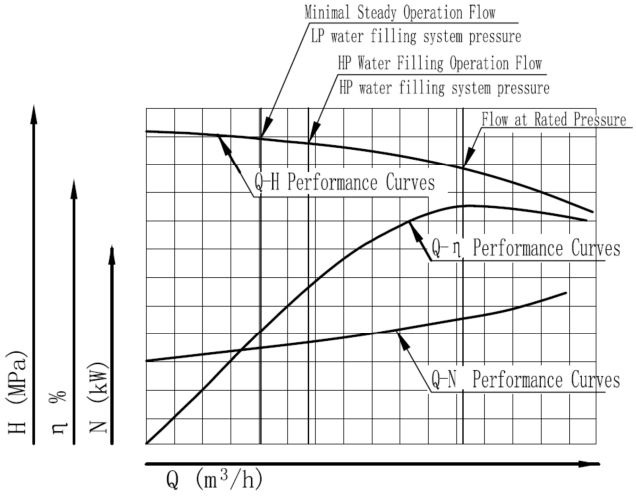

Figure 4. *Performance Curve of Descaling Pump.*

3.1.2. Filling Method of Energy-Saving Descaling System

The operation mode of energy-saving descaling system is that the descaling valve opens during descaling, and the accumulator supplies water to the descaling point. With the descaling operation, the accumulator storage capacity decreases gradually as well as the system pressure. When the accumulator pressure drops to the set value, the speed of the descaling pump increases to the set value through the frequency converter or hydraulic coupling, and the pump discharge pressure climbs with the pump speed increase. When the pump discharge pressure is bigger than that of the high-pressure pipeline system (closing the minimum flow valve at this time), the check valve opens. At the same time, the pump and accumulator supply water to the descaling point. After completion of descaling, the descaling valve closes and the pump replenishes the water to the accumulator. When the water level and pressure of the accumulator reach the set value, the replenishment is completed. The descaling pump speed decreases to a set value [10] through frequency converter or hydraulic coupling, and the pump discharge pressure decreases with its speed drop. When the pump discharge pressure is less than that of the high-pressure pipeline system (when the minimum flow valve opens), the check valve closes, and the pump does not convey the flow to the high-pressure pipeline system. Its output flow is discharged through the minimum flow valve, and the pump starts to operate in the low-speed mode for energy saving.

When the system chooses low-pressure filling, it will not consume the output flow of descaling pump or the water stored by accumulator, no increase of system energy consumption. When the system chooses high-pressure filling, the water filling valve is supplied by the accumulator after opening, which directly consumes water stored in the accumulator, reducing the water supply of the accumulator to

the descaling point, shortening the running time of the pump at low speed and saving energy, increasing system energy consumption. Therefore, in order to ensure the energy-saving effect of the system, the low-pressure filling is more suitable for the energy-saving descaling system with mixed water supply of descaling pump and accumulator.

3.2. Descaling System with Direct Water Supply of Pump

With the increase of market demand for surface quality of steel plate, in order to ensure the performance of steel plate and to solve the problem of inconsistency of descaling effect and difference of mechanical properties of products, many hot strip lines divide high-pressure descaling system into two pump stations: rough rolling descaling pump station and finish rolling descaling pump station. Rough rolling pump station is HSB, E1/R1, E2/R2 descaling point through high-pressure water. The finish rolling descaling pump station only provides high-pressure water for the descaling point of FSB. Because the descaling point of FSB takes a long time and the flow rate is relatively small, the system adopts the descaling pump to supply water directly. The direct water supply of descaling pump station is equipped with only one accumulator of 5-8m3, which acts as a buffer. It provides little water when the descaling valve opens, with its water supply function weakened. The descaling pump can save energy by adjusting the speed of frequency converter or hydraulic coupling. Similarly, the descaling system of direct water supply of pump is also divided into two types: energy-saving, and non-energy-saving.

3.2.1. Filling Method of Non-Energy-Saving Descaling System

The operation mode of non-energy-saving descaling system is that the descaling valve opens when the descaling is operated, the minimum flow valve closes, and the descaling pump supplies water directly to the descaling point. When the descaling is completed, the descaling valve closes, the minimum flow valve opens, and part of the water output from the pump is replenished to the accumulator, and part of the water is discharged out after decompression by the minimum flow valve and throttling device of the bypass system, and all pump flow passes through the bypass.

When the system chooses low-pressure filling, it will not consume the output flow of the descaling pump or the water stored by the accumulator, not increasing system energy consumption. When the system chooses high-pressure r filling, the water filling valve opens and the filling water is supplied by the descaling pump, increasing the energy consumption. When the system operates under high-pressure mode, the output flow of the pump is the discharge of the minimum flow valve and the water filled in the filling system. The output flow of the pump increases by 15%-20% in a short time (about 5S). According to the characteristics of centrifugal pump, the discharge pressure decreases and with of discharge drop of the minimum flow valve. From the performance curve of the descaling pump in Figure 5, it can be seen that the pump power increase is small, and the running time being short, with low increase of energy consumption. Therefore , in order to ensure the safe and stable operation of the system, it is more appropriate to choose high-pressure filling for the non-energy-saving descaling system with direct water supply of descaling pump.

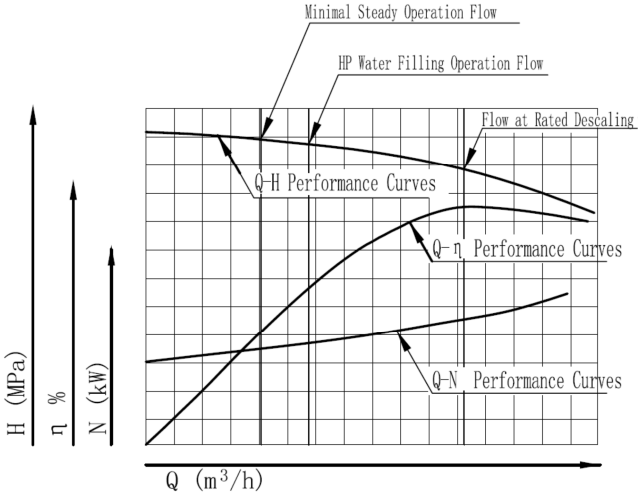

Figure 5. *Performance Curve of Descaling Pump.*

3.2.2. Filling Method of Energy-saving Descaling System

The operation mode of energy-saving descaling system is that before the billet reaches the descaling point, the speed of descaling pump increases to the set speed in advance through frequency converter or hydraulic coupling, and the water filling valve opens ahead of time. When the billet reaches the descaling point, the descaling valve opens, the minimum flow valve closes, and the descaling pump directly supplies water to the descaling point for descaling operation; when the descaling completes, the descaling valve closes and the minimum flow valve opens, the water filling valve closes in delayed time. After the water filling valve closes, part of the output water of pump replenishes to the accumulator, part vents out through the bypass system of the minimum flow valve and the throttle device after decompression. After filling, all pump flow through the bypass, while the descaling pump speed reaches the set value through the frequency converter or hydraulic coupling, starting energy-saving operation.

When the system chooses low-pressure filling, it will not consume the output flow of the descaling pump or the water stored by the accumulator, no increase of system energy consumption. When the system chooses high-pressure r filling, the water filling valve opens. The filling water is provided by the descaling pump, with increase of the energy consumption. The increased energy consumption is consistent with the operation of 3.2.1. Therefore, in order to ensure the safe and stable system operation, it is more appropriate to choose high-pressure filling for the energy-saving descaling system of direct water supply of descaling pump.

3.3. Non-accumulator High-pressure Water Descaling System

With the improvement of control system protection and

pipeline system design optimization, no accumulator is installed in the descaling system with direct water supply of descaling pump, and no bypass minimum flow valve and throttling device are installed at the pump discharge. The system design is very simple. The descaling system without accumulator for water supply includes descaling pump station and descaling valve station. The descaling pump station consists of below parts: low-pressure water intake pipeline, descaling pump, overhaul valve at pump suction, check valve and overhaul valve at pump discharge. The descaling valve station only contains descaling valve and throttling device. The system PID diagram is shown in Figure 6.

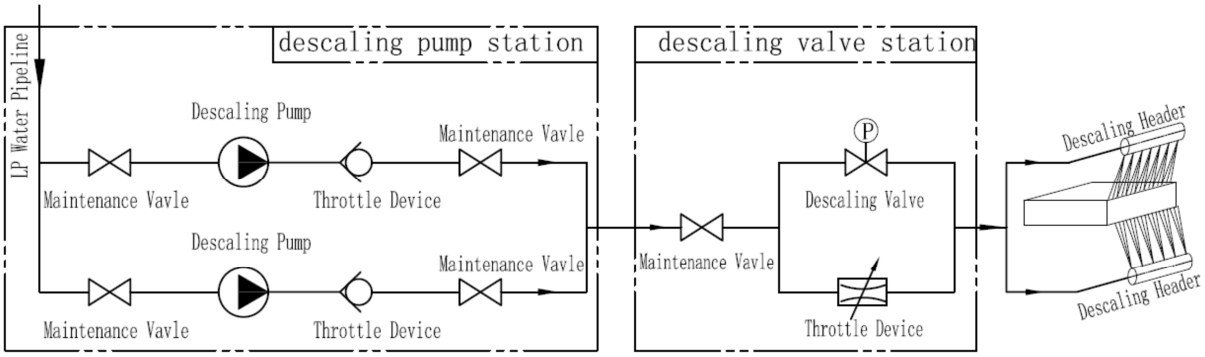

Figure 6. *Schematic Diagram of Non-accumulator High-pressure Water Descaling System.*

The operation mode of non-accumulator descaling system is still divided into two types: non-energy-saving, and energy-saving. There is only one method for water filling: high-pressure filling.

The operation of non-energy-saving descaling system is that the descaling valve opens during descaling operation, and the descaling pump directly supplies water to the descaling point for descaling operation. After completion of descaling, the descaling valve closes. During the descaling operation and the descaling interval, there is always a flow from the pump discharge to the descaling header through the bypass throttling device of the descaling valve, which fills the pipeline behind the descaling valve with water. During the descaling interval, when the spray valve closes, the output flow of the pump flows out through the descaling valve bypass, which is equivalent to the minimum steady flow of the descaling pump. This can not only fill the post pipeline of descaling valve, but also protect the descaling pump. The control is relatively simple, no energy consumption increase.

The operation of energy-saving descaling system is that before the billet reaches the descaling point, the speed of descaling pump increases to the set speed ahead of time through frequency converter or hydraulic coupling. When the billet reaches the descaling point, the descaling valve opens，and the descaling pump directly supplies water to the descaling point for descaling operation; when the descaling completes, the descaling valve closes, and the speed of the descaling pump decreases to the set value through frequency converter or hydraulic coupling, starting energy-saving operation. During the descaling interval, the water filling operation is consistent with the non-energy-saving descaling system. When the speed of the pump decreases, the discharge pressure also decreases as well as the filling flow through the throttle device, which does not fully meet the filling flow. However, in the process of pump speed increase, the pump discharge pressure increases gradually, with the flow increase through the throttle device to meet the filling flow in the end.

4. Conclusion

1. Low energy consumption of low-pressure filling system can easily cause impact and vibration of low-pressure pipeline. There are potential risks of high-pressure water penetrating into low-pressure pipelines. The high-pressure filling system has certain loss of energy consumption, and of small pipeline impact. It will not cause pipeline impact and vibration, and it runs smoothly and of reliable safely.
2. For non-energy-saving descaling system with mixed water supply of descaling pump and accumulator, the high-pressure filling is under recommendation. The system energy consumption is small, and the system operation is relatively safer and more reliable. For energy-saving descaling system with mixed water supply of descaling pump and accumulator, the low-pressure filling is recommended with more remarkable energy-saving effect.
3. The descaling system with direct water supply of descaling pump should choose high-pressure filling. The system energy consumption increases little, and the system runs more smooth and safer. The non-accumulator descaling system r can only choose high-pressure filling, which can simplify the system configuration, reducing investment and occupied area, while increasing the stability of the system operation.

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