

Multi-functional and Environmentally Friendly Rolling Mill: Innovative Application of Waste Heat Recovery Technology and Practice of 'Double Carbon' Target

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Abstract

Rolling system is an important part of metallurgical production. With the production line product development and production gradually improved, the requirements for the finished rolled products are further improved, but the existing after-roll cooling capacity is poor, poor stability of the equipment and mill before and after the generation of a large number of dust and other issues will lead to the product of the plate shape of the process quality indicators decline. Most of the optimised rolling devices currently available on the market are single, and can only solve the problems of dust removal, cooling or conditioning individually. This work designs a multifunctional optimised sheet metal rolling device, combining semiconductor cooling and vacuum dust extraction technologies, greatly improving the quality of sheet metal and improving the working environment. The multifunctional metal sheet rolling includes the design of four aspects: cooling component, dust-absorbing component, conditioning component and waste heat recovery system. In order to solve the problem of the traditional rolling device cooling effect is not ideal, this paper establishes a cooling mechanism, can be in direct contact with the surface of the workpiece in time, rapid heat transfer, greatly eliminating the product internal temperature difference due to the formation of stress; the use of the blower produces strong suction and pressure to cause the Hoover inside the vacuum produced by the instantaneous vacuum on the collection of dust and debris to achieve the workbench of the dust; set up the regulating components, through the screw Setting up the adjusting component, through the screw driving the rolling rolls to move the rolling rolls to change the distance, so as to meet the different processing needs, and improve the applicability of the rolling device; Finally, combined with the characteristics of the hot rolling process produces a large amount of heat, the design of a waste heat recovery and power generation system to collect the heat energy and convert it into electricity for the rolling device to continue to use. It provides a technical basis for the steel rolling system of steel enterprises, improves the quality and efficiency of rolled plates, promotes the steel enterprises to be green, efficient and energy-saving and emission reduction, and helps our country to move towards the goal of carbon peak and carbon neutrality.

Keywords

Multifunctional Optimization; Semiconductor Cooling; Vacuum Extraction; Waste Heat Recovery; Power Generation.

1. Introduction

The continuous development of society, all walks of life technology is also constantly developing, rolling is a metal processing technology, is a material to reduce the cross-section, the length of the increase in the pressure processing method, can make the metal organisation is more dense, mechanical properties have been improved, through the rolling can make the plate to form a certain specification, easy to carry out subsequent processing. However, in the actual use of the process, the rolling device structure is relatively single, affecting the efficiency of the product into the material; processing, often need to cool the surface temperature of the workpiece, the existing cooling device is mostly used as a heat-absorbing medium for the water spray or spray, the humidity of the cooling environment is also therefore long in the high value of the state, combined with the high temperature of the surface of the workpiece and the conditions of oxygen and so on, resulting in the surface of the rolled workpiece is easy to rust corrosion, the cooling effect is not ideal. Rust and corrosion, the cooling effect is not ideal; and in the sheet metal processing, there will be debris impurities fall, there will be a lot of dust. Due to the construction of the mill did not consider dust removal facilities, these dust and water vapour mixture scattered into the plant to all parts of the plant, seriously affecting the environment near the mill and even inside the plant, put into operation shortly after the brand-new plant and equipment is covered with reddish-brown dust, workers long-term direct contact will be hazardous to physical and mental health [1].

After investigation, every year rolling industry personnel will be due to high temperature and rolling process debris and other reasons induced by a variety of chronic diseases, such as Table 1; and rolled products of the thickness adjustment time-consuming, poor applicability; therefore, this multifunctional metal plate rolling device first designed cooling device, followed by an increase in the adjusting components to regulate the distance between the rolling rolls, increase the applicability of rolling device, design dust-absorbing devices to remove the The design of dust-absorbing device to remove the debris and dust in the process, and finally the use of waste heat recovery system to collect a large amount of thermal energy generated in the rolling process, which greatly promotes the development of the steel rolling industry.

Table 1. Illnesses of examined workers in a steel plant, 2019-2021

Annual	Hypertension			Pneumonia, Influenza			Acute Upper Respiratory Tract Infection		
	Number of persons	Number of cases	Prevalence rate (%)	Number of persons	Number of cases	Prevalence rate (%)	Number of persons	Number of cases	Prevalence rate (%)
2019	2171	1046	48.18	2171	466	21.46	2171	1156	53.25
2020	2156	733	34.00	2156	739	34.28	2156	1103	51.16
2021	1447	355	24.53	1447	424	29.30	1447	714	49.34

1.1 Domestic and Foreign Research Status

Since the founding of the country 43 years ago, especially in 1980, China's steel rolling technology and equipment with other industries, like the rapid progress of the development of China has developed from the introduction and digestion of foreign advanced technology and equipment, the development of independent innovation, self-integration, and basically mastered the independent design and manufacture of complete sets of equipment for the whole line of technology, in recent years, China's steel rolling technology and equipment, productivity and product quality has been greatly improved, and the various consumption indicators Substantial reduction, hot loading and hot delivery, cutting and rolling, online testing and online heat treatment and other technologies with international leading level have been promoted and applied, but the rolling workpiece corrosion

problems, the rolling process of the dust problem, etc. have not been improved substantially, therefore, China's rolling technology has a long-term development prospects [2].

Foreign rolling technology and equipment is more mature than our country. Japan produces HC mill and its various derivatives of the model HCM, HCW, HCMW mill, etc., because it has excellent kun-type control performance, has been in the ferrous and non-ferrous metal strip cold rolling, hot rolling, levelling and thick plate mill put into use, not only to improve the plate type, but also reduces the thickness of the finished product of the thickness of the rolled products to adjust the time-consuming; Germany's rolling mill manufacturers have also developed a cold rolling equipment to match the CSP technology, which is more mature than our country. German mill manufacturers have also developed with the CSP technology to match the cold rolling equipment, can be more economical production of high-quality cold rolled sheet, with high operational flexibility; in the Czech Republic for the first time into production of two-stand longitudinal hearth mill increased laminar flow cooling system to ensure that the product of the plate shape and temperature. It seems that, with the development of the world, the market for steel quality requirements in terms of performance and dimensional accuracy, have been significantly improved.

1.2 Development Significance

Existing rolling device has a cooling effect is not ideal, the structure is relatively single and debris impurities can not be reasonably collected and other issues, not only can not improve the efficiency of rolling technology, but also on the production of workers' health hazards. The new multi-functional optimised sheet metal rolling device reduces the time-consuming thickness adjustment of the rolled product, designs the cooling components and dust-absorbing devices, and increases the waste heat recovery system to absorb the hot air discharged. Greatly improve the efficiency of the rolling process, to ensure the health of workers in the industry, while the development of renewable resources recycling, help to alleviate and ultimately solve the problem of resource scarcity in China.

2. Rolling Device Design Programme

2.1 Overall Programme Design

This rolling device includes the design of rolling table, cooling component system, dust-absorbing component system, regulating component system and waste heat recovery system in five aspects; the specific model diagram is shown in Figure 1, in which ① is the cooling hood, the whole rolling table is placed in the hood, ② semiconductor cooling components, ③ is the rolling table, ④ is the cooling nozzle, ⑤ is the rolling mill, and ⑥ is the dust-absorbing component. Figure 2 shows the specific design structure inside the cooling hood. In the rolling process, the first rolling table to achieve rolling processing, and then the use of cooling components system so that the cooling gas can be directly contact with all the workpiece's internal and external surfaces and timely and rapid heat transfer, reduce the workpiece's temperature difference in all parts of the workpiece can greatly eliminate the product internal stress formed by the temperature difference; and then the use of dust-absorbing components system on the surface of the table to absorb the dust impurities, to achieve automatic de-dusting of the table. Then use the dust-absorbing component system to absorb the dust and impurities on the surface of the workbench to achieve automatic dust removal on the workbench to ensure that the workbench is neat and clean, thus avoiding the impact of impurities and debris on the finished product and the hazards to the body of the workers on the work line; and then use the adjusting component system to process the metal plates according to different processing requirements to meet different processing requirements and improve the applicability of the rolling device; and finally, use the residual heat recovery system to collect the hot air discharged for the conversion of energy for the work of the rolling device. Finally, the waste heat recovery system is used to collect the discharged hot air for energy conversion, which provides energy for the rolling device.

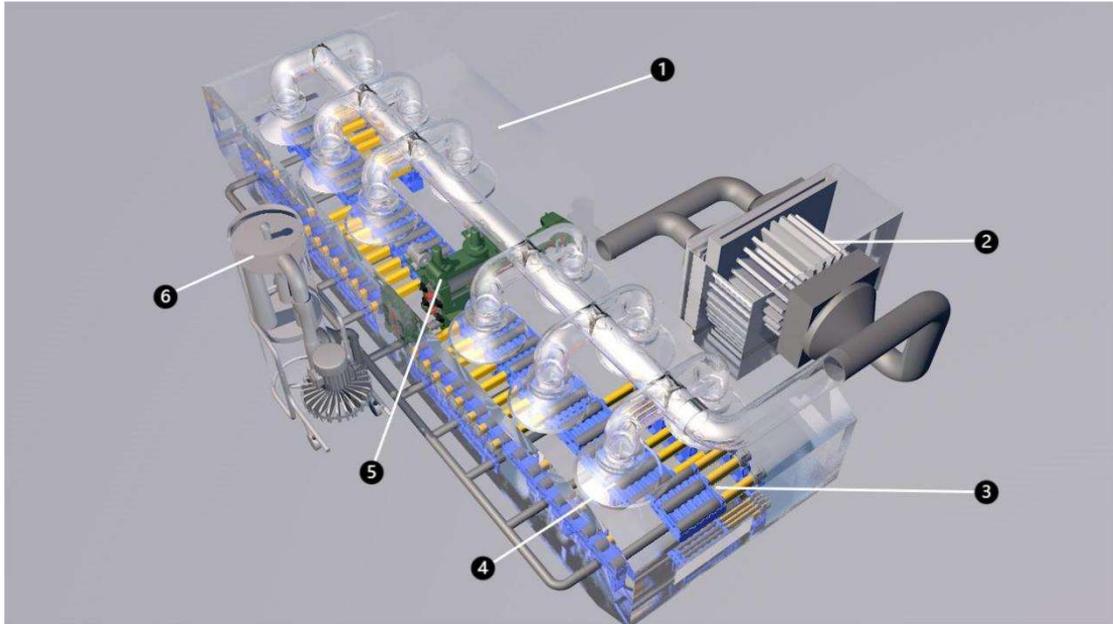


Figure 1. Top view of the general design of rolling unit



Figure 2. Internal structure of the overall design of the rolling unit

2.2 Design of Refrigeration Components

2.2.1 Working Principle

As shown in Figure 3, the cooler works and absorbs the surrounding heat to make the surrounding temperature drop, the heat exchanger vane on the periphery of the cooler also cools down synchronously, the heat-absorbing gas blown into the refrigeration chamber by the return pipe transfers the heat to the heat-carrying gas that flows through the cooler and the heat-exchanging vane and is transported to the cooling chamber through the output pipeline and the cold-air nozzle, and the heat-absorbing gas with low temperature passes through the inner and outer surfaces of the workpieces and takes away the heat of the surfaces it passes through rapidly. The heat-absorbing gas carrying heat is fed into the cooling room through the return pipeline to complete a cycle of flow.

2.2.2 Structure Design

The refrigeration component design system includes a cooling mechanism and a shield in a closed state, with a cooling chamber inside the shield, the cooling mechanism includes a cooler, a refrigeration chamber, an output pipeline, a cold air nozzle, a blower, a moisture absorber and a return pipeline, and the cooler is fixedly assembled inside the refrigeration chamber, which is used to cool heat-absorbing gases that flow through the refrigeration chamber, with the refrigeration chamber, the output pipeline, the cold air nozzle, the refrigeration chamber, and the return pipeline connected in sequence to form a closed cycle. The refrigeration chamber, the output pipe, the cold air blower, the cooling chamber and the return pipe are connected in turn to form a closed circulating circuit, the output pipe and the return pipe are fixedly assembled with a dehumidifier for dehumidifying the heat-absorbing gases flowing through them, and a blower drives the heat-absorbing gases to continuously circulate unidirectionally in the circulating circuit. As shown in Figure 3 refrigeration assembly plan structure diagram, wherein 1 for the rolling table, 2 for the cooling mechanism, 3 for the closed state of the shield, 4 for the cold air blowing nozzle.

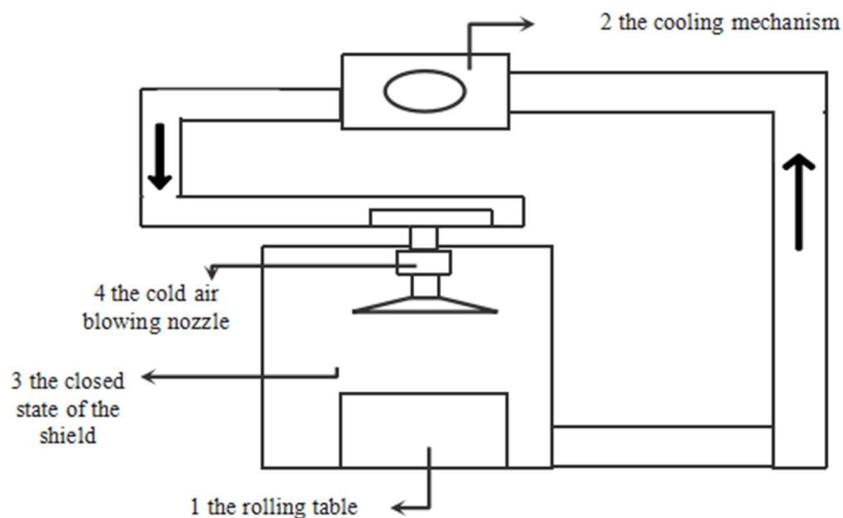


Figure 3. Layout of refrigeration components

2.2.3 Refrigeration Method

The cooler uses semiconductor refrigeration technology to achieve refrigeration effect, semiconductor refrigeration is the use of semiconductor materials to form a P-N junction, refrigeration through the application of direct current at both ends of the direct conversion of electrical energy into thermal energy; semiconductor refrigeration principle of operation as shown in Figure 4, a P-type semiconductor element and an N-type semiconductor element connected to a thermocouple, connected to the DC power supply, the joints will produce temperature differences and heat transfer, at the upper end, the direction of the current is N-P, the temperature drops and absorbs heat, which is the cold end, while at the lower end, the direction of the current is P-N, the temperature rises and exothermic, which is the hot end [4]. After placing the semiconductor refrigeration material in the refrigeration unit and putting it in the refrigeration assembly, the model diagram of the refrigeration unit is shown in Figure 5.

The use of semiconductor refrigeration has a clean, no noise pollution and no emission of harmful substances, long life, robust, high reliability, stability, a series of advantages, in line with the requirements of green environmental protection, compared with other refrigeration methods, the cold and hot end of the conversion is convenient, as long as the direction of the current can be shifted, and its refrigeration device can be made into a variety of shapes, and semiconductor refrigeration sheet thermal inertia is very small, the refrigeration time is short.

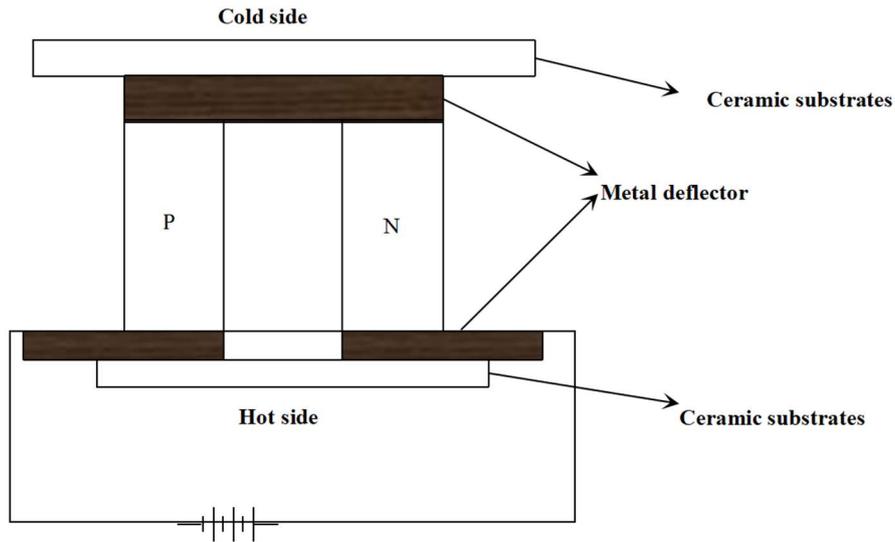


Figure 4. Plan view of semiconductor cooler

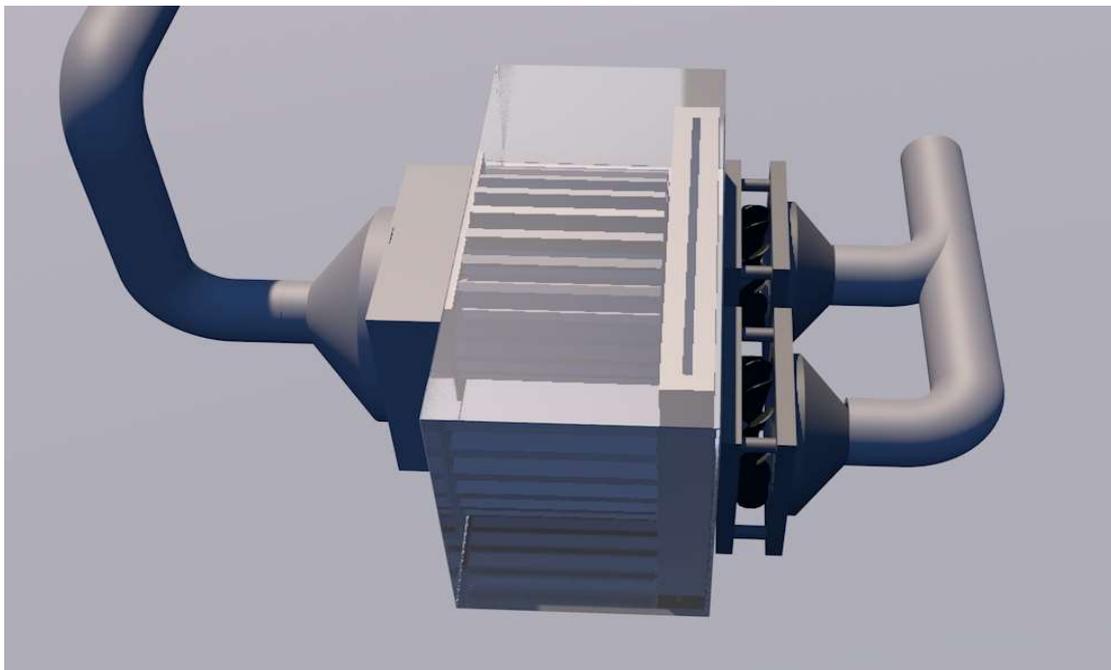


Figure 5. Model diagram of semiconductor cooler

2.3 Dust Extraction Component Design

2.3.1 Structural Necessity

Due to the mill before the construction of the time did not consider the dust removal facilities, these dust and water vapour mixture into the plant spread to all parts of the plant, seriously affecting the environment near the mill and even inside the plant, soon after the commissioning of the brand-new plant and equipment is covered with reddish-brown dust, the workers long-term direct contact will be hazardous to physical and mental health. This design is in order to effectively capture these soot and dust, to ensure the environmental health of the workshop and set up the dust removal system. At the same time, domestic steel mills in smelting cleaning has been mainly manpower cleaning, low efficiency, long time, and cleaning caused by the secondary dust is quite serious, collection and processing of cleaning materials also need manpower and material resources, and seriously endanger the health of workers, so in the preparation of sheet metal mill to improve the function of cleaning dust is very necessary.

2.3.2 Structure Design

The dust-absorbing assembly includes a dust ball twist, a filter cloth tube, a centrifugal separator, an inhalation port, a dust collection drum, and a blower; the inhalation port is in the middle of the dust collection drum and the centrifugal separator, the blower blows the wind through the pipeline into the dust-absorbing assembly, and the filter cloth tube is on the top of the centrifugal separator. The structural model of the dust-absorbing assembly is shown in Figure 6, in which ① is the dust ball twist, ② is the filter cloth tube, which is a dust collection bag with filtering ability, and can realise the filtering work of the dust; ③ is the centrifugal separator, ④ is the dust collection barrel, which can collect the dust and is convenient for cleaning; ⑤ is the blower. Dust removal device through the blower will be vacuumed inside the barrel, high negative pressure so that the air quickly through the air inlet into the barrel inside the barrel, the barrel over the vacuum brush and vacuum pipe, the flow of air with the need to collect and process the solid particles into the barrel, the filter bag and the inlet connected to the solid is attached to the inner surface of the filter bag, the filtered air through the blower or the air pump into the exhaust duct exhaust port.

2.3.3 Working Principle and Effect

The bottom of the dust suction assembly is equipped with a blower, after the power is turned on, the blower produces strong suction and pressure, under the action of suction and pressure, the air is quickly discharged, and the front end of the suction port part of the air is constantly replenished with the air in the blower, resulting in the Hoover to produce an instantaneous vacuum, and the external atmospheric pressure to form a negative pressure difference, under the action of the pressure difference, the impurity dust of the rolling table is sucked in to realise the dedusting of the table, thus ensuring the worktable neat and tidy, and the worktable will be cleaned and tidy. This ensures the neatness of the workbench, thus avoiding the impact of impurities and debris on the rolling.

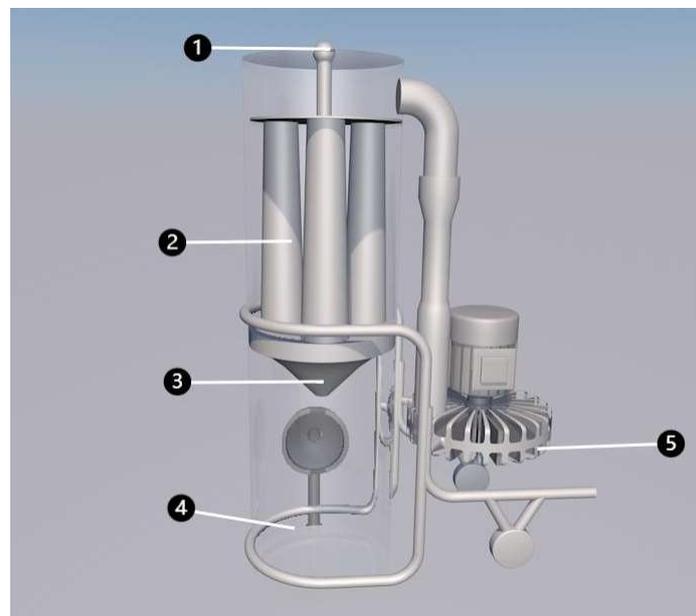


Figure 6. Structural model diagram of dust suction assembly

2.4 Regulating Component Design

2.4.1 Structure Design

As shown in Figure 7, there are pillars fixedly connected on both sides of the top of the rolling device table, two pillars are connected with two rolling rolls through the transmission of the adjusting component, there is a sliding groove on one side of the pillar, the screw holder of the adjusting component is slidingly connected with the sliding groove, there is a first chamber in the screw holder, there is a rotating lever rotating in the sliding groove through the bearings, there is a sleeve rotating

inside the first chamber, the sleeve is connected with the rotating lever, the sleeve has a first bevel gear snap-on on the outer surface, the first bevel gear engages the second bevel gear on one side, the second bevel gear engages the second bevel gear on one side. The outer surface of the sleeve is connected with a first bevel gear, the first bevel gear is engaged with a second bevel gear, the second bevel gear is fixedly connected with a first connecting shaft, one end of the first connecting shaft is fixedly connected with one side of the rolling rollers, and the rotating rod and the inner wall of the sleeve are all hexagonal in cross-section.

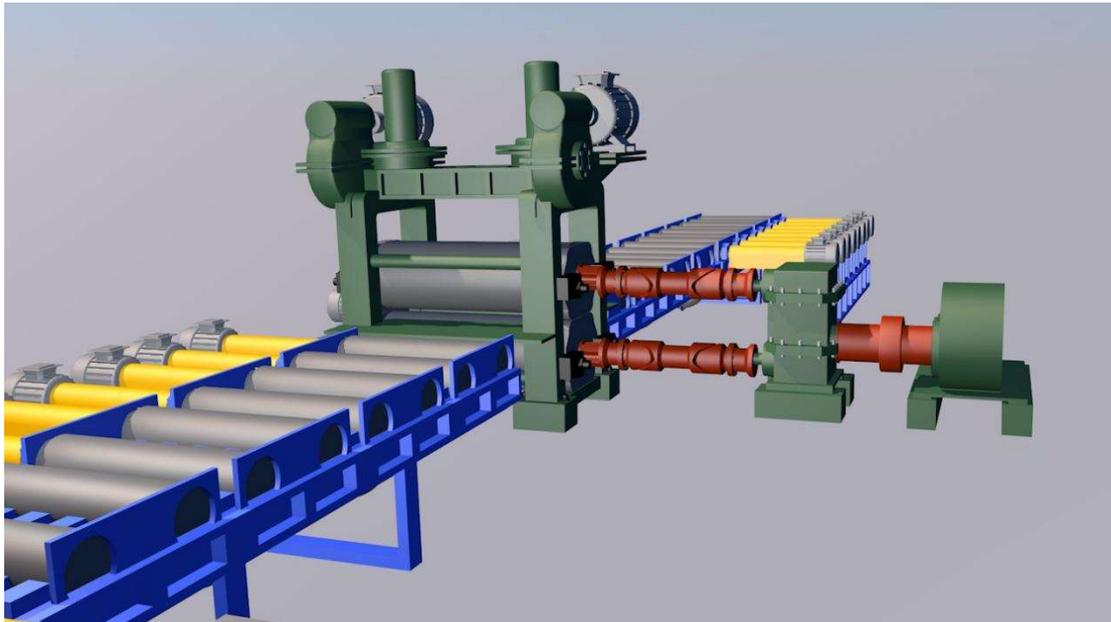


Figure 7. Structural model diagram of the regulating component

2.4.2 Working Principle and Effect

The staff drives the lifting screw to rotate by twisting the knob, and the lifting screw drives the screw holder to slide, and the screw holder drives the rolling roller to move through the first connecting shaft, so that the distance between the two rolling rollers changes, so that the rolling device can process the metal sheet according to different processing requirements, thus meeting different processing needs and improving the applicability of the rolling device.

2.5 Waste Heat Recovery Power Generation System

2.5.1 Structural Design

The components of the waste heat recovery power generation system include cooling machine, dual-channel waste heat collection box, induced draft fan, circulation fan, evacuation device, cooling machine hot airflow recovery tube, air outlet, electric adjustment valve, in which the induced draft fan generates negative pressure to pump the hot air from the cooling machine to the waste heat collection box, and the heat exchanged airflow is formed by the circulation fan to circulate the hot air cycle, and between the circulations, the water will be converted into hot saturated steam, and the hot saturated steam will drive the turbine, which will convert heat energy into electric energy. The hot saturated steam drives the turbine, which converts heat energy into electricity.

2.5.2 Working Principle and Effect

Waste heat recovery power generation system includes hot airflow recovery system, waste heat collection system and turbine generator system, and the system structure diagram is shown in Figure 8; the hot airflow recovery system is generated by the negative pressure of the induced draft fan at the outlet of the waste heat collection system, which sucks the hot exhaust gases in the air hood of the cooling machine of the refrigeration system to the waste heat collection box, and then the low-temperature airflow after the heat exchange is sent to the air box at the bottom of the cooling machine

by the recirculation fan to form the hot air circulation. The airflow pipeline is equipped with corresponding bypass pipes and control valves. Waste heat collection system is to use the heat carried by the airflow, will be arranged in the collection of a series of heated surfaces in the box within the water into superheated saturated steam. The turbine-generator system is driven by steam to a turbine, which converts the heat energy ultimately into electrical energy for continued use by the rolling unit.

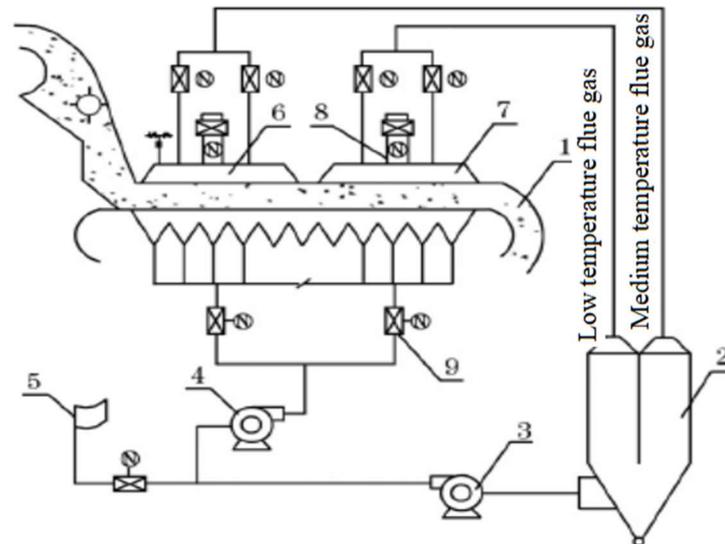


Figure 8. Structure of waste heat recovery system

1-cooler; 2-double-channel double-pressure waste heat collection box; 3-induced draft fan; 4-circulating fan; 5-exhaust device; 6-cooler hot airflow recovery 1 section; 7-cooler hot airflow recovery 2 section; 8-air outlet; 9-electrical adjustment valve.

3. Feasibility Analysis

3.1 Technical Feasibility Analysis

This rolling device includes cooling component design, dust-absorbing component design, regulating component design, waste heat recovery system design, the device design is fully functional, this device alleviates the corrosion of the metal, so that the rolled samples can be better shaped to solve the dust problem in the rolling process, and regulating component design can better adjust the thickness of the rolled workpieces, the use of waste heat recovery system can maximize the realization of resources. The use of waste heat recovery system can maximise the rational use of resources, in line with China's sustainable, green and intelligent development needs.

3.2 Benefit Analysis

3.2.1 Economic Benefits

(1) Optimisation of human resources

At present, domestic steel mills still use manual dust cleaning in the smelting process. The design of the dust-absorbing components of this device reduces the dust and impurities generated during the manufacturing of metal sheets from the source, so that the steel mills do not have to use human resources to clean up the dust during the actual production process, which reduces the expenditure by 10,000-20,000 yuan per month and achieves the purpose of human resources optimisation.

(2) Improvement of working efficiency and reduction of raw material cost

Most of the optimised rolling devices that have been developed nowadays have a single structure, containing only one of the dust-absorbing device or cooling system. And this work combines the optimisation devices. Manpower cleaning is mainly low efficiency and long time, this device can

replace manpower cleaning and improve rolling efficiency; the adjustment component meets the needs of different rolling workpieces by adjusting the change of the distance between the rolling rolls, which improves the rolling efficiency.

3.2.2 Social Benefits

(1) Employee physical safety

Using the dust-absorbing component system to absorb dust and impurities on the surface of the worktable, it realises automatic dust removal on the worktable and ensures the tidiness of the worktable, so as to avoid the influence of impurity debris on the rolled workpieces and the hazards to the body of the workers in the working assembly line.

(2) Improvement of ecological environment

This product increases the waste heat recovery system to absorb the discharged hot air, recycle the heat energy, realise the reuse of resources, and can achieve the role of energy saving and efficiency after promotion and application.

4. Innovative Points and Technological Keys

4.1 Innovation Points

The main innovation points of this work are:

- (1) Incorporating four structural designs that can be improved to optimise the rolling device in all aspects.
- (2) Solve the problems of unsatisfactory cooling effect of traditional cooling device and easy corrosion and rust of rolling mill surface.
- (3) Dust-absorbing components use the formation of an instantaneous vacuum to form a pressure difference with the outside world to absorb the dust and impurities in the metal rolling process, reducing the hazards of dust on workers, in line with the concept of green development.
- (4) Adjustment components by adjusting the distance between the rolling rolls to meet the needs of different rolling workpieces; waste heat recovery system to achieve the conversion of heat to electricity, maximising the use of energy.

4.2 Technical Key

The technical key of this work is:

- (1) Refrigeration components are designed in combination with semiconductor refrigeration technology.
- (2) The dust-absorbing component uses a blower to generate great pressure and suction to create an instantaneous vacuum to form a pressure difference, thus absorbing dust as well as impurities during metal rolling and processing.
- (3) Waste heat recovery power generation system based on the principle of hot air circulation.

5. Application Prospects

This rolling device is a multi-functional mill with cooling technology and dust absorption device, which can well meet the needs of different rolling work, improve rolling efficiency, and compared with the existing rolling device, the structure is more complete, the function is more abundant, and it has a competitive advantage, and it has a good application prospect. At the same time, this product increases the waste heat recovery system to absorb the hot air discharged, the heat energy is recovered, to achieve the re-use of resources, after the promotion and application, can achieve the role of energy saving and efficiency. In the 'double carbon' as the main theme of today's society, in response to the national environmental protection call, in the promotion of renewable use of resources and ecological civilisation construction is constantly being attached importance to the background has a good prospect, put into production and use will produce significant economic and social benefits.

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