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Innovative design of stop mechanism and zinc stripping device integrating TRIZ tools

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Abstract

In order to solve the engineering problems of zinc stripping machines in the process of stripping zinc plates, such as shaking cathode plates, frequent jamming, and low success rate of stripping plates, this paper innovatively adopts the method of integrating TRIZ tools for problem-solving. Based on the TRIZ analysis problem theory, the innovative fusion of the triaxial analysis tool and the functional model analysis module is used to establish a systematic process and model for analyzing the problem, so that the analysis tools can be linked to each other and the analysis results can be avoided in isolation, thus identifying the problem efficiently and accurately. Finally, a stopping mechanism and a zinc stripping device are proposed. The stopping mechanism realizes the fixation of aluminum plates, which not only solves the engineering problems of shaking cathode plates, frequent jamming, and low success rate of stripping plates but also realizes the purpose of operation automation and reduces labor costs. The research results provide a reference for reducing the shaking frequency of the cathode plate and improving the success rate of the stripping plate in the zinc stripping machine, and further provide the improvement direction and ideas for the existing workshop management.

Keywords: TRIZ, Triaxial analysis, Functional model, Zinc stripping Device

1. Introduction

In China, with the continuous expansion of the mining speed and scale of mineral resources, the grade content of useful minerals gradually decreases. The mineral resources show the characteristics of poor, fine, and miscellaneous, which further aggravates the difficulty and complexity of metallurgical equipment and puts forward higher requirements for the design of metallurgical equipment flow and the development and optimization of metallurgical equipment. S., Yao. (2020) put forward for the processing and manufacturing enterprises of mineral processing equipment, it is more and more important to deeply understand the characteristics of discipline attributes, give full play to the technical advantages of interdisciplinary integration, and learn to use innovative theoretical methods and technical means, to better promote the overall rapid development of metallurgical equipment. In this case, TRIZ theory has successfully overcome the inertia of traditional thinking with its unique and systematic innovative thinking advantages, which is helpful to realize the high-quality leapfrog development of the metallurgical equipment manufacturing industry.

TRIZ theory is a solution to the invention problem, which was created by ALTSHULLER, a Soviet scholar. L. Fiorineschi et al. (1995) proposed that compared with the traditional innovation methods such as implementation error and brain transfer, TRIZ theory has obvious characteristics and advantages. At present, the most popular classical TRIZ analysis tools include the following: Inventive Problem-Solving

Algorithm (ARIZ), Substance-Field Analysis, and Contradiction Analysis. The latest TRIZ analysis tools will add functional mode, functional analysis, and causality analysis. Table 1 shows the TRIZ problem model.

In recent years, more and more scholars have begun to apply TRIZ theory to mining and metallurgy fields, and some achievements have been made. Wang et al. (2021) used TRIZ theory to solve the problem of low processing capacity in the engineering practice of inertial cone crushers and its mutual restriction relationship with the particle size of crushing products, and finally, nine solutions were obtained. The design example confirmed the feasibility of using the TRIZ method to realize innovative design in the production practice of metallurgical equipment. Nikulin, C et al. (2018) developed an effective and efficient solution tool of TRIZ, which addresses the influencing factors of risk detection and analysis from operational process reliability and takes a mining filter plant as an example to identify and classify current problems and generate solutions. Wei. (2015) solved the problem of cleaning the dielectric box of SLON-1750/2500 strong magnetic machine by using the object-field model method in TRIZ theory. Chen. et al. (2013) studied the application of TRIZ theory in the improved design of slime crushers and discussed the methods and concepts of using TRIZ theory to transform and design new slime crushers. Han et al. (2017) used the innovative theory TRIZ to solve the problem that the single filling system used in domestic mines has low production capacity and cannot meet the filling technical requirements of ultra-large-scale underground mines, and obtained 9 schemes. Yan et al. (2016) creatively put forward the comprehensive mining method of long wall sectioning, trench cutting, moving frame, and caving in view of the disadvantages of traditional mining methods for gently inclined and thin ore body mining, which effectively solved the problem of insufficient production capacity of the mine.

Wang et al. (2020) came up with the above research that have provided beneficial enlightenment for the development of TRIZ theory in the field of mining and metallurgy. However, in practical applications, engineers cannot efficiently and accurately identify the key problems when using causal and functional models and other analytical tools due to the particularity of mining and beneficiation equipment. Many practices have provided important evidence that it takes a long time to solve the key problems of complex equipment, even for experienced technicians. It may also cause deviations in the direction of solving problems due to preconceived ideas.

Therefore, to achieve the purpose that engineers and technicians can timely and accurately identify the root cause behind the problems, and strengthen the interaction and connection between the analysis tools, this paper innovatively integrates the triaxial analysis tools and the functional model analysis module based on the TRIZ analysis problem theory, establishes a systematic process and model for analyzing problems, and analyzes the rationality and feasibility of the innovative process with the engineering problem examples of the mineral processing equipment-zinc stripping machine's shaking cathode plate, frequent jamming, and low success rate of stripping plate. The research results provide a reference for reducing the shaking frequency of the cathode plate and improving the success rate of the stripping plate in the zinc stripping machine.

Table 1. TRIZ problem model.

Problem model	Tool	Solution model
Technology contradiction	Contradiction matrix	40 invention principles
Physical contradiction	Separation method	Separation principle, 40 invention principles
Substance-Field model function model	Substance-Field Analysis	76 standard solutions, 40 invention principles

2. TRIZ problem solving process integrating triaxial analysis and functional model

Yan et al. (2019) presented functional analysis as an important part of the technical system analysis phase, whose main purpose is to transform abstract systems into a specific chart so that engineers and technicians can understand the functions and characteristics of the system required. Therefore, by defining and describing the functions that the system components need to achieve, as well as the interaction between components or with the external environment to analyze the overall system, it can assist engineers and technicians in making complex into simple and rationally carry out an innovative design.

In the process of functional analysis, the most important step is to establish the functional structure or functional model of the system. First of all, it is important to find the main functions of the existing technical system and make it achieve the best state. Wang (2021) proposed it is necessary to find out the harmful, insufficient, and excessive functions of the system to find out the problems of the system and then solve the existing problems completely. In addition, the triaxial analysis is integrated into the existing TRIZ problem-solving process to facilitate the integration of analysis tools. The three axes include the causal axis, operation axis, and system axis. Bai et al. (2020) came up with the purpose of triaxial analysis to analyze and define the initial problem from all aspects, decompose the complex engineering problem into several sub-problems, make full use of system resources, and find the root cause of the problem.

After fusion, the TRIZ analysis and identification problem process is formed, as shown in Figure 1. New engineering problem requires the process of information collection, resource analysis and ideal solution in the early stage. When the preliminary work is properly prepared, it enters the causal axis analysis. It addresses the root cause of the locking problem and its possible results by the normalized description and also provides a good foundation for the next step to determine the key points of the problem in combination with the functional model. Zhu et al. (2021) proposed system axis analysis is based on the functional analysis of the interaction information of the existing technical system components and the establishment of a functional model, combined with the root cause of the location and weaknesses.

The innovative model of integrating triaxial analysis and functional analysis combines their respective characteristics. The causal axis obtains the root cause of the problem and the starting point of solving the problem; the system axis eliminates the root cause from the technical system through component analysis and functional model. The operation axis provides direction for solving problems by improving the operating process.

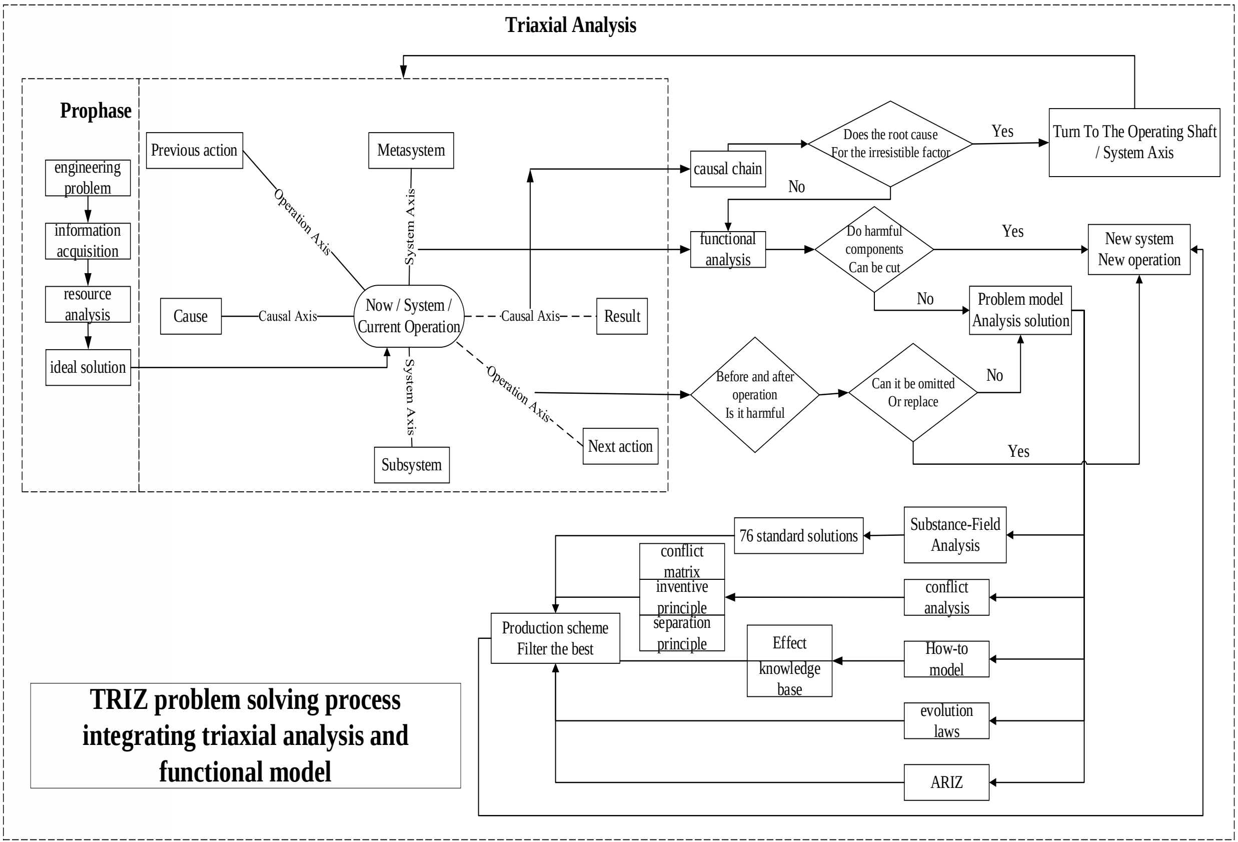


Fig. 1. TRIZ analysis problem flow chart combining triaxial analysis and function model.

3. Project case analysis

3.1 Pre-information collection

There are two methods of zinc smelting, one is called zinc pyrometallurgy, and the other is called zinc hydrometallurgy. Zinc pyrometallurgy uses zinc concentrate as raw material to make calcine by roasting, then distilling the calcine and condensing its zinc vapor to obtain crude zinc. Refined zinc containing more than 99.9% zinc can be prepared from the distillation of crude zinc. Jiang et al. (2022) came up with zinc hydrometallurgy is the roasted sand by solution leaching, the resulting leaching solution is purified to remove impurities. and then it is sent to the electrolytic cell for electrodeposition, and a layer of zinc metal will be generated on the electrolytic cell cathode plate. The layer of zinc will be stripped from the cathode plate and melted into a zinc ingot, which is the finished zinc.

However, stripping metal zinc from the cathode plate is heavy manual labor, especially in the zinc electrolysis workshop. The acid mist is very heavy and the environment is harsh, making manual stripping zinc a very difficult task.

To solve this problem, major zinc smelters in the world have developed and applied zinc stripping machines. Yuan. (2020) presented especially with the development of production scale and large-scale equipment, the plate is too large and heavy, which has exceeded the manual completion of zinc stripping operation limit, and the production cannot be maintained without the application of a zinc stripping machine.

The working principle of the stripping operation of the zinc stripping machine is to increase the pre-stripping before the stripping is applied. The purpose is to make the zinc sheet partially split the gap from the cathode aluminum plate so that the next operation is easy to feed. However, due to the long-running time of the pre-stripping zinc process of the zinc stripping machine, with the movement of the cathode plate aluminum plate on the transmission device, the large weight of the cathode plate will cause the cathode plate to shake. In the process of upward lifting of the zinc stripping blade, the lower edge of the aluminum plate is easy to collide with the head of the tool holder, and it is easy to happen stuck knife accident, resulting in the top of the entire automatic zinc stripping production line.

One of the current treatment measures is to adopt an artificial hook plate for auxiliary treatment on the equipment site. Each production line needs 2 manual workers to hook the lower edge of the aluminum plate every day to ensure that the aluminum plate does not shake and can fall into the tool holder for zinc stripping process. However, two manual hooks are used to operate the cathode plate because of the shaking of the cathode plate, which is a non-value-added operation and increases the operating cost.

Fig. 2. Existing treatment measures of pre-stripping process.

Because the lower edge of the aluminum plate is easy to collide with the head of the tool holder, the feedback of the manual blocking effect is not ideal, and the ideal solution is not obtained by using TRIZ tool analysis many times.

Given this problem, the improved TRIZ analysis process analysis is used. The new technical system requires the function of blocking objects, to control the sloshing of the aluminum plate, avoid the phenomenon of the stuck knife, and make the blade work normally.

The system’s resource analysis list is shown in Table 2.

3.2 Problem analysis stage

The technical system of the current problem is a manual auxiliary scraper pre-stripping zinc system. The function of the technical system is to separate the zinc layer in advance. The constraints to achieve this function are good manual operation and high scraper efficiency. The working principle of the current problem system is that the equipment site now adopts an artificial hook plate for auxiliary treatment. Each production line needs 2 workers to hook the lower edge of the aluminum plate every day to ensure that the aluminum plate does not shake and can fall into the tool holder for zinc stripping process.

For pre-stripping system analysis, the causal axis analysis is first entered to understand the root cause of the event, find the problem entry point. The resulting graphical specification is shown in Figure 3.

According to the causal chain constructed, the causal relationship between the root cause of the problem and the result produced is clarified. After confirming that the problem can be eliminated, the system axis is transferred for functional analysis and functional modules are established, as shown in Figure 4.

In this system, since the zinc element from the electrolytic cell is attached to the surface layer of the aluminum plate, the aluminum plate will shake with the movement of the suspension beam, which will cause the aluminum plate not to accurately enter the scraping range of the scraper. The current system's meta-system components and subsystem hooks act on the scraper. Specifically, the human hand holds the hook and hooks the aluminum plate to ensure that it enters the scraping range of the scraper. It can be seen from the functional model that the supporting effect of the hook on the aluminum plate is a non-value-added operation, and it cannot guarantee that each aluminum plate enters the scraping range of the scraper. The supersystem component person lacks the force on the hook because the person feels tired. The air of the metasystem component will oxidize the electrolytic zinc to a certain extent. The longer the beat of the zinc scraping process, the more serious the degree of oxidation, which will lead to unnecessary impurities such as zinc oxide (ZnO) in the melted zinc solution.

The conflict component and causality axis analysis combined with the function model lock the key points in two aspects: (1) the adhesion between the zinc layer and the aluminum cathode plate is strong; (2) Track frame forward speed is fast.

Table. 2. Resource analysis list of the system.

resource type	available resources		Resource availability evaluation
physical resources	in-house resources	Aluminum material plate	Not available, aluminum plate is used for electrolytic zinc, the function does not match.
		Steel frame	Available, steel occupies most of the material, and the realization of the ideal solution can be associated with it.
		timber	Not available, which is insufficient or harmful effect, should not be used as available resources.
	external resources	temperature	Not available, there is little connection between the workshop temperature and the system.
Field Resources	external resources	barometric pressure	The conditions for the use of air pressure resources are harsh, and magnetic field resources can be used instead.
		mechanical field	Available, mechanical field exists between mechanical equipment, ideal solution can be associated with it.
		thermal field	Unavailable, the thermal field of the supersystem may also be harmful.
	in-house resources	mechanical field	Not available.
		magnetic field	Available, can be generated from the positive charge of zinc （Zn^{2+}） magnetic field as a variable to start.
space resources	in-house resources	Space between the top and bottom of cantilever beam	It is possible to use space resources, and add or improve mechanical equipment.
time resource	in-house resources	Time interval of aluminum plate transmission	Available, interval times may provide a new separation scheme.

3.3 Generation Scheme Screening Optimal

Key point 1: “zinc layer and aluminum cathode plate between the adhesion strength” is taken as the starting point to solve the problem. In this problem, the aluminum plate as the cathode plate in the electrolyzed zinc, can only be by following the usual manual auxiliary zinc stripping machine to operate. This is because the zinc layer is electrolyzed to the cathode plate. As the electrolysis time increases, the zinc element is precipitated and slowly added, and the adhesion between the aluminum plate is increasing.

Tool 1 is the Technology Conflict Resolution Theory.

The Angle of the problem is to reduce the force between the zinc layer and the aluminum plate. Since the cathode plate is suspended above the rail frame, under the influence of gravity, the force between the zinc layer and the aluminum plate should be increased to prevent the zinc layer from falling off during the forward process of the cathode plate. If the force increases, a scraper is required to strip zinc. This requires manual use of hooks to assist in zinc stripping, which is also a non-value-added operation. According to the four principles of ECRS, the force between the zinc layer and the scraper should be reduced. However, if the force between the two is reduced, the speed of the rail frame will not change due to the decrease of the adhesion force, which will lead to the shedding of the zinc layer during the transportation process and the decrease of the output. The force between the two forms a pair of technical conflicts.

The conflict is described. The goal is to reduce the sloshing amplitude of the cathode plate. The way of action is to reduce the forward speed of the cathode plate carried by the rail frame. The result of the deterioration is that the zinc stripping process has a long beat and the output is reduced. Improved engineering parameters: 38 degrees of automation, 39 productivity, deteriorated engineering parameters: 23 material loss. Therefore, regarding the conflict matrix, the corresponding invention principles are No.35 parameter change, No.10 pre-operation, No.28 mechanical system replacement, No.18 vibration, and No.23 periodic action. Filter the best solution: the previous scraper to high-pressure water knife, the function is to separate the object, and the high-pressure water knife will not exist in the lower edge of the cathode plate and its stagnation.

Tool 2 is the Physical Conflict Resolution Theory.

To “reduce the sloshing amplitude of the cathode plate”, the speed is required to be “low”, but to “not affect the yield”, the speed is required to be “high”, in other words, the forward speed of the track frame carrying the cathode plate should be both “high” and “low”. Considering that the “sloshing of cathode plate” has different characteristics in different “space, condition” (space, period time, different condition, system level), the conflict can be separated from “space, time” (space, time, condition, whole and part). The invention principles corresponding to the separation principle are the “No.1 segmentation principle, No.25 self-service principle, No.22 harm-benefit principle, No.24 mediator principle”. The optimal solution is selected, and the conflict between the cathode plate and the scraper is separated from the perspective of time. Based on ensuring the uniform straight-line progress of the transmission device, the time interval and frequency of the cathode plate shaking are used. When the cathode plate is in the opposite direction of the scraper scraping range, pre-stripping can effectively avoid conflicts.

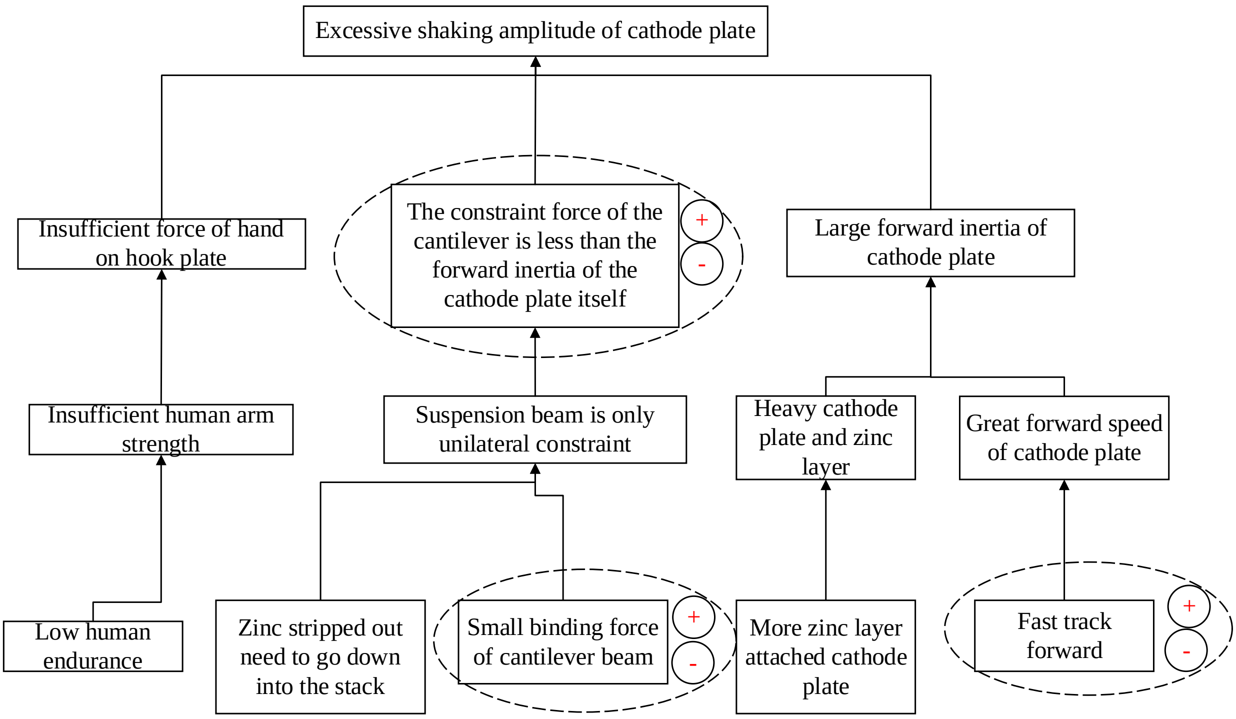


Fig. 3. Causal axis analysis of pre-stripping system.

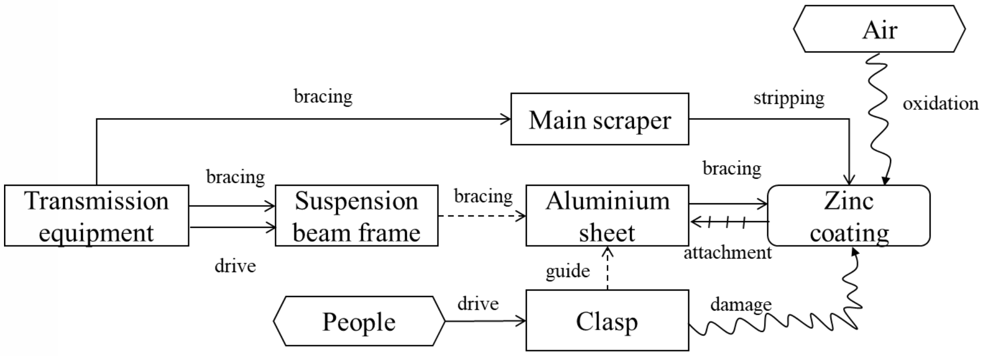


Fig. 4. Function model of pre-stripping system.

Key point 2: "fast forward speed of the rail frame" is the starting point to solve the problem. According to the problems reflected by the functional model, the material field model is established. The material field model of the original system and the material field model of the improved scheme are shown in Figure 5.

This material field model belongs to the insufficient action model. The problem in this model is that the hook has an insufficient blocking force to the cathode plate, which belongs to the insufficient interaction.

According to the material-field model of the problem, the standard solution compute process is applied, and the standard solution is obtained as the first type of standard solution No.7 (1.1.7): the field strength in one system is not enough, and increasing the field strength will damage the system. A field with enough strength will be applied to another component, and then the component will be connected to the original system. Similarly, a substance cannot work well, but it can work when connected to another available substance. Based on this, two schemes are obtained, and the optimal one is to replace the function of the manual and hook with the cost and easier control of the stop lever. By adding a gear bar device, the switch is used to control the lifting of the gear bar, control the sloshing of the aluminum plate, promote the blade to work normally, and eliminate the insufficient effect.

4. Optimal scheme and main mechanism design

Combined with the TRIZ problem-solving process mentioned above, this paper designs a stop mechanism and zinc stripping device. The design diagram is shown in Fig.6. The stopper mechanism comprises a stopper part and a driving part. The stopper part comprises a first stopper rod and a second stopper rod arranged at intervals, and the driving part is used for driving the stopper part to move to the moving path of the aluminum plate or to move away from the moving path of the aluminum plate; the first stop bar and the second stop bar are used to stop at the front and rear sides of the aluminum plate respectively when the first stop bar and the second stop bar are in the movement path of the aluminum plate to prevent the aluminum plate from shaking. In the initial stage, the top part is outside the motion path of the aluminum plate. Before the zinc stripping blade rises upward, the drive part can be used to drive the stop part to move into the motion path of the aluminum plate, and the stop limit of the aluminum plate in front of the stop mechanism is carried out. The first stop bar and the second stop bar are used to stop the front and back sides of the aluminum plate respectively, to avoid the collision between the lower edge of the aluminum plate and the head of the tool holder during the upward lifting of the zinc stripping blade, and the knife sticking accident occurs. When the zinc stripping knife operation is completed, the drive part can be used again to drive the stop part to move away from the motion path of the aluminum plate, to prepare for the stop of the next aluminum plate. By using the stop mechanism, the aluminum plate can be fixed, the purpose of operation automation is realized, and the labor cost is reduced.

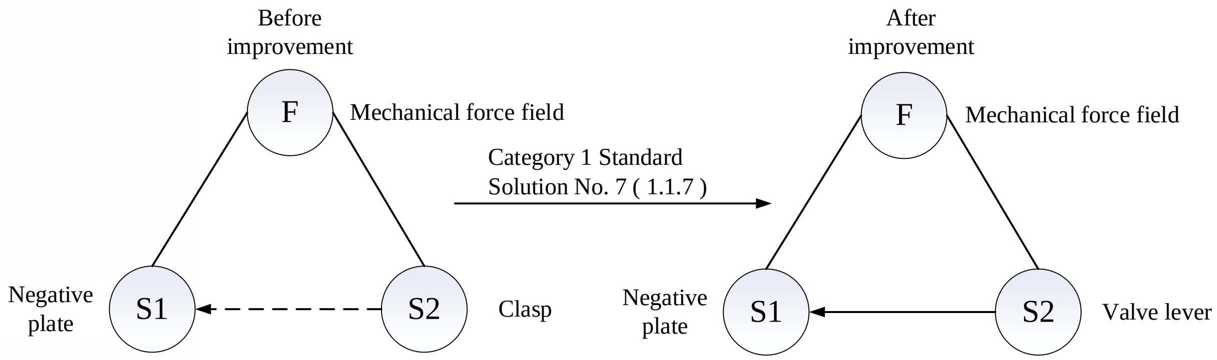
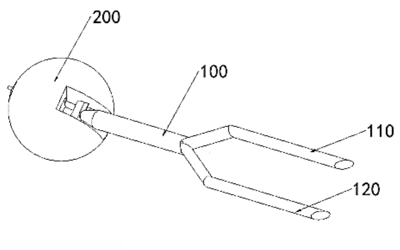
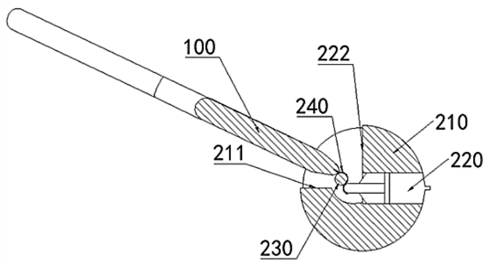


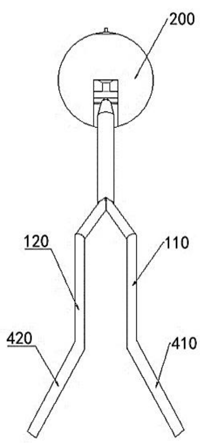
Fig. 5. Substance-field model.



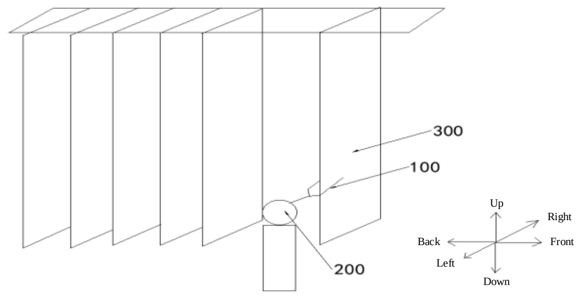
a. Stop mechanism diagram



b. Section view in A-A direction



c. Top view of stop mechanism



d. Schematic diagram of stop mechanism implementation

100-stopper; 110-first gear lever; 120-second gear lever; 200-Drive unit; 210-mounting seat; 211-Support plane; 222-stop surface; 220-expansion cylinder; 230-shaft; 240-warp board; 300-Aluminum plate; 410-first guiding rod; 420-Second guiding rod.

Fig. 6. Structure schematic of a stop mechanism and zinc stripping device.

5. Conclusion

Guided by the classical TRIZ concept, this paper integrates the triaxial analysis and functional model to solve the engineering problems of zinc stripping machine in the process of stripping zinc plate, such as shaking cathode plate, frequent jamming, and low success rate of stripping plate in zinc stripping machine, and it gets the corresponding solution. In this process, to solve the outstanding problems such as the path of technological innovation, the inaccurate identification, and the definition of core key problems in solving practical engineering problems, this paper analyzes the current situation of the analysis tools such as causal analysis and functional model used by engineers and technicians in TRIZ analysis to solve engineering problems. Through the innovative integration of triaxial analysis and functional model, a new TRIZ analysis problem process is formed. The new process strengthens the interaction between analysis tools, timely and accurately redefines the problem, locks the key factors affecting the occurrence of the problem, and finally realizes the identification of the core key problems of the project. The stop mechanism of the final scheme can realize the fixation of the aluminum plate, which not only solves the engineering problems of the shaking cathode plate, frequent jamming, and low success rate of the stripping plate but also realizes the purpose of automatic operation and reduces the labor cost. The research results provide a reference for reducing the shaking frequency of the cathode plate and improving the success rate of the stripping plate in the zinc stripping machine, and further provide the improvement direction and ideas for the existing workshop management.

However, the research time of this paper is short, and the experience is limited. In the future, it still needs to carry out continuous optimization and design of the scheme.

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