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Design of an Automatic Grinding Machine for the Bottom of Ceramic Plates based on TRIZ Theory

S. Zhang[1], X. Gao*[2], Q. Chen[1], Y. Qi[1], M. Lei[1]

[1]Institute of Intelligent Manufacturing and Smart Transportation, Suzhou City University, Suzhou, 215104 China
[2]Department of Electromechanical Engineering, Tangshan University, Tangshan, 063000, China
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Abstract

To address the issue of high labor intensity and potential hand injury associated with manual grinding of the bottom of ceramic plates, an automatic bottom grinding machine for ceramic plates was designed using the TRIZ theory product design process. Demand analysis was conducted to obtain the composition and function decomposition model of each mechanism of the machine. TRIZ theory's contradiction matrix, "HOW TO" model, and physical field analysis methods were then utilized to analyze the design problems and identify solutions. The resulting automatic bottom grinding machine can automatically feed a ceramic plate into the grinding station, apply pressure and grind the plate bottom automatically, and then return the ceramic plate to the initial station. This machine eliminates the need for manual pressing and grinding, mitigating the risk of operator injury. The successful application of TRIZ theory in the development of this mechanical equipment demonstrates its effectiveness as a practical method for designing new products and upgrading old equipment.

Keywords: TRIZ theory, contradiction matrix, physical field analysis, ceramic plate, bottom grinding machine

I. Introduction

Daily ceramics are closely related to people's lives. In order to meet customer needs, related product designs are becoming increasingly personalized and diversified [1,2], and their production processes are becoming more and more advanced, with various new technologies and methods being applied successively [3–5]. The ceramic plate is the most common type of daily ceramics. Although the forming process for the ceramic plate is quite mature, uneven bottoms may occur in some products produced by individual enterprises. The bottom of these plates is then usually ground further in a manual process. That is, an operative holds the edges of a ceramic plate in two hands and presses the bottom of the plate against a moving sand belt. Although the bottom of the ceramic plate can be ground flat, the operative's hands can easily be injured because they are very close to the sand belt. In order to avoid this situation, it is necessary to develop an automatic bottom grinding machine for ceramic plates. In recent years, TRIZ theory has become a very important innovation design method and has been widely used in predicting product failures [6,7], product improvement [8,9] and new product design [10,11]. At the same time, TRIZ theory is constantly enriched and improved based on combination with other methods, and it has played new positive roles [12–14]. Therefore, based on TRIZ theory, this paper proposes a structural scheme for an automatic bottom grinding machine for ceramic plates, and details the successful design and manufacture of the machine, which has been applied in production with good operating results.

* Corresponding author: 2086722020@qq.com

II. Design Process based on TRIZ Theory

The design of a new product is a complex process. Firstly, effective communication with the customer is necessary to understand their actual needs, including customer budget costs, functional goals, development cycles, etc. Secondly, the problem of grinding the bottom of the ceramic plate needs to be transformed into an engineering model, which serves as the main framework. During the specific implementation process, various problems may be encountered. Then, the engineering model for grinding the bottom of the ceramic plate is converted into a theoretical TRIZ model. Through the physical conflict, technical conflict, and relevant solutions provided by the TRIZ theory, the TRIZ model for grinding the bottom of the ceramic plate is solved, and the final design scheme of the bottom grinding machine for the ceramic plate is obtained. According to reference [15], the design process for an automatic bottom grinding machine for the ceramic plate based on TRIZ theory is shown in Fig. 1.

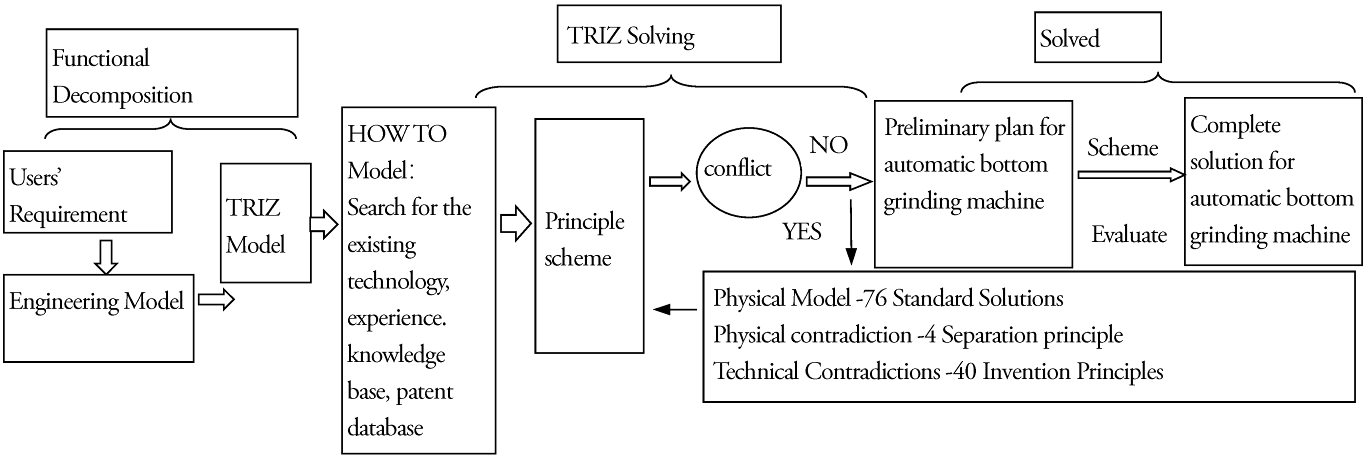


Fig. 1: Design process for an automatic machine for grinding the bottom of ceramic plates based on TRIZ theory.

III. Function Decomposition

The traditional method of grinding the bottom of the ceramic plate is shown in Fig. 2. This involves holding the edges of the ceramic plate with two hands and pressing it against the moving sand belt. Although the operative wears gloves, their fingers can still be easily injured even it they make just a slight mistake. To solve this problem, an automatic bottom grinding machine for ceramic plates that does not injure hands needs to be developed in line with user requirements. The designed grinding machine must be able to automatically feed the plate to the grinding station, automatically grind a ceramic plate, and automatically exit the plate, ultimately achieving automatic grinding of the bottom of a ceramic plate and avoiding hand injuries.

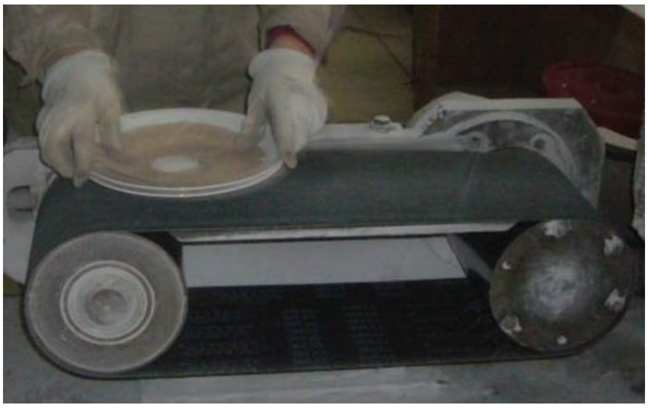


Fig. 2: Traditional way of grinding the bottom of ceramic plates.

Based on the demand analysis and functional analysis, the automatic bottom grinding machine for ceramic plates mainly includes the porcelain entry and exit mechanism, porcelain grinding mechanism, height adjustment mechanism, and corresponding control system. By decomposing each mechanism, the automatic bottom grinding machine for ceramic plates and its functional decomposition model are obtained, as shown in Fig. 3. The porcelain entry and exit mechanism mainly realizes the automatic entry of the ceramic plate into the grinding station and returns it to the initial position after grinding. The porcelain grinding mechanism mainly completes the automatic grinding of the ceramic plate. The height adjustment mechanism adjusts the appropriate grinding height for the ceramic plate with different height specifications before grinding.

VI. Function Solving and Mechanism Design

Based on the established mechanism and functional model of an automatic bottom grinding machine for ceramic plates, TRIZ theory system, problem modeling and tools, existing technologies were used to solve the functional requirements and detailed design of each mechanism of the automatic bottom grinding machine for ceramic plates, completing the innovative design of the automatic bottom grinding machine for ceramic plates.

(1) Porcelain grinding mechanism

In order to improve the safety performance and increase the level of automation, the following issues need to be considered in the design of the automatic bottom grinding machine for ceramic plates: ① how to achieve automatic positioning of the ceramic plate into the grinding position; ② how to perform automatic grinding. These issues are actually related to the safety and automation of grinding, and in TRIZ theory's contradiction matrix, the parameters that need to be improved are safety and automation level, while the parameter that would deteriorate is the complexity of the device. The invention principles corresponding to the contradiction between safety and complexity of the device are: 2 separation, 6 universality, 4 asymmetry, 17 dimensionality change, 13 reverse, 26 duplication; while the invention principles corresponding to the contradiction between automation level and complexity of the device are: 4 asymmetry, 10 preliminary action, 13 reverse action, 15 dynamics, 17 one-dimensional to multi-dimensional, 24 intermediary, and 28 substitution of mechanical systems.

As shown in Fig. 4, there are mainly three types of sand belt grinding methods: contact wheel type, free type, and pressure grinding plate type. Because the grinding of the bottom of a ceramic plate belongs to plane grinding, using the pressure grinding plate type is more reasonable. In the traditional grinding method shown in Fig. 2, the sand belt is under the plate and the plate is on top. Pressing the plate still requires transporting it to the sand belt and completing the pressing action. The plate needs to achieve automatic horizontal and vertical displacement, which would

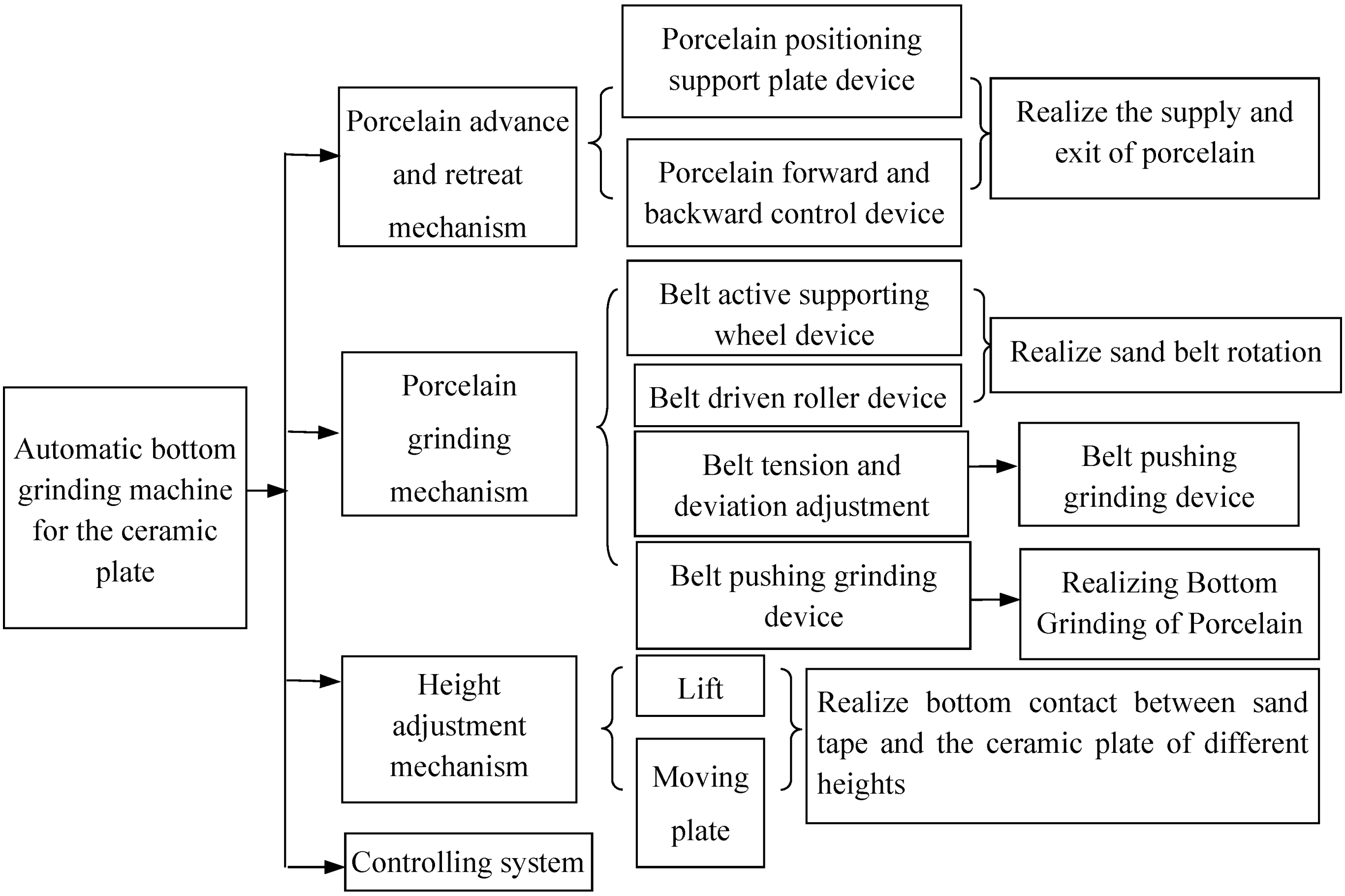


Fig. 3: Mechanism and function decomposition model for an automatic machine for grinding the bottom of ceramic plates.

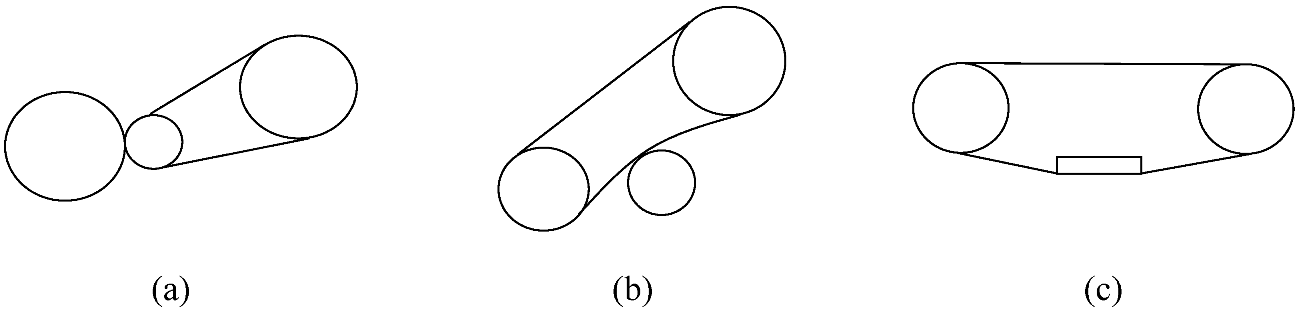
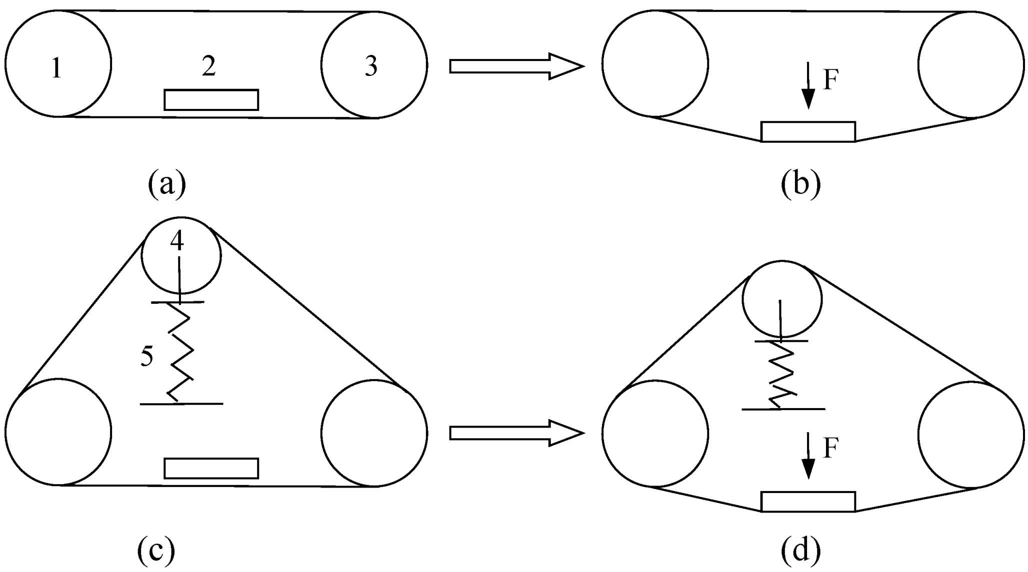


Fig. 4: Abrasive belt grinding: (a) Contact wheel type, (b) Freestyle, (c) Freestyle.

result in a complex structure that is difficult to implement. According to the invention principles provided by the safety, automation level, and complexity of the device contradiction matrix, principles such as 2 separation, 13 reverse, and 10 preliminary action can be used to solve the problem of automatic grinding.

According to the principle of 13 reverse action, the sand belt, which was originally set below the plate, is now set above it with the plate facing downwards. Using the principle of 2 separation, the pressure grinding plate is separated and operated independently to achieve sand belt grinding each time. According to the principle of 10 preliminary action, the ceramic plate is pre-set below the sand belt before each grinding cycle. This way, the plate only needs to move horizontally, and the pressure grinding plate pushes down the sand belt, replacing the vertical movement of the plate. The pressure grinding plate is driven by a guide rod cylinder, which enables automatic grinding of the ceramic plate. Fig. 5 shows the design scheme of the grinding mechanism. Fig. 5(a) shows the initial state of the pressure grinding plate. During each grinding cycle, the sand belt between the active and driven support wheels will experience a certain displacement downwards as the guide rod cylinder pushes down the pressure grinding plate, as shown in Fig. 5(b). As the sand belt has a fixed length and is forcefully pressed downwards, its strength will be affected, leading to damage. This problem can be attributed to improving the length of a moving object, while the deteriorating parameter is the strength of the object. The invention principles corresponding to the contradiction between the length and strength of a moving object are: 35 parameter change, 40 composite materials, 8 weight

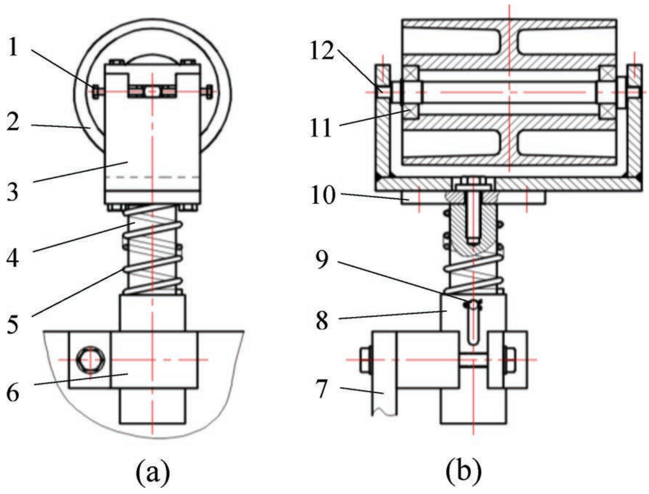


1. Driven supporting roller, 2. Grinding plate, 3. Active supporting roller, 4. Tensioning supporting roller, 5. Spring

Fig. 5: Design scheme of grinding mechanism, (a) Initial state of original pressure grinding plate, (b) Pressure belt status of original pressure grinding plate, (c) Initial state of dynamic tensioning device, (d) Pressing status of dynamic tensioning device.

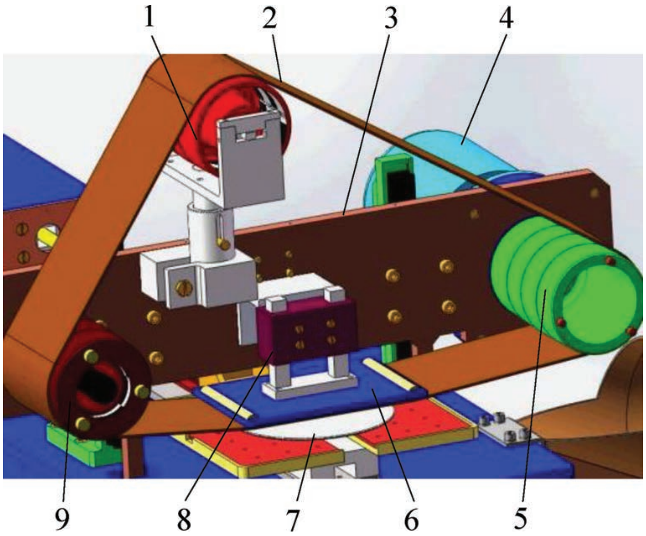
compensation, 34 abandonment and restoration, 3 partial mass, 31 porous materials, 15 dynamization, 29 pneumatic and hydraulic structures, and 30 flexible shells or films. Based on the analysis, according to the principle of 15 dynamization, "making objects adaptive or changing stationary objects to movable," the length of the original sand belt is increased, and a dynamic tensioning device is added to the equipment to dynamically adjust the length of the sand belt between the active and driven support wheels using the stretching and shrinking of the spring during device operation, as shown in Fig. 5(c). A dynamic tensioning device is installed on the upper part of the original grinding mechanism, and a tensioning support wheel and a spring are set below the tensioning support wheel. When the pressure grinding plate presses the sand belt, the sand belt in the lower part of the grinding mechanism moves downwards, and the length of the sand belt between the active and driven support wheels at the lower edge increases. Simultaneously, after the sand belt is stressed, the sand belt in the upper part of the grinding mechanism presses the spring through the tensioning support wheel, and the length of the sand belt between the active and driven support wheels at the upper edge decreases. The decrease is equal to the increase in length at the lower edge, as shown in Fig. 5(d), thus avoiding the damage caused by the sand belt being forcibly stretched under pressure.

The specific structure of the dynamic tensioning device is shown in Fig. 6, which mainly includes an adjustment bolt, a tensioning support wheel, a tensioning support wheel frame, a guiding shaft, a tensioning spring, a tensioning seat, a moving plate, a fixed shaft sleeve, a guiding pin, a connecting plate, and a tensioning support wheel shaft. When the pressure grinding plate presses the sand belt for grinding, the tensioning support wheel is subjected to increased pressure from the sand belt. This increased force is transmitted to the tensioning spring through the tensioning support wheel, tensioning support wheel frame, and connecting plate. The tensioning spring is further compressed, causing the guiding pin, which crosses the guiding shaft, to move downward along the strip hole in the upper part of the fixed shaft sleeve. This prevents the tensioning support wheel from deviating. When the pressure grinding plate is retracted, the sand belt at the upper edge between the active and driven support wheels returns to its original length, and the tensioning support wheel returns to its initial position under the action of the tensioning spring. When the running sand belt deviates laterally on the active and driven support wheels or the tensioning support wheel, the position of the tensioning support wheel shaft can be adjusted by rotating the adjustment bolt.



1. Deflection bolt, 2. Tensioning roller, 3. Tensioning roller frame, 4. Guide shaft, 5. Tensioning spring, 6. Tensioning seat, 7. Moving plate, 8. Fixed shaft sleeve, 9. Guide pin, 10. Connecting plate, 11. Deep groove ball bearing, 12. Tensioning roller shaft

Fig. 6: Dynamic tension device, (a) Main view, (b) Left view.



1. Dynamic tensioning device, 2. Sand belt, 3. Moving plate, 4. Drive motor, 5. Active support roller, 6. Grinding plate, 7. Ceramic plate, 8. Guide rod cylinder, 9. Driven support roller

Fig. 7: Three-dimensional model of the grinding mechanism.

Therefore, the porcelain grinding mechanism designed according to TRIZ theory is shown in Fig. 7, which mainly includes a dynamic tensioning device, a sand belt, a drive motor, an active support wheel, a pressure grinding plate, a guide rod cylinder, and a driven support wheel. The drive motor is directly connected to the active support wheel, making the structure simple and compact. The pressure belt cylinder adopts a double guide rod cylinder with good bending moment resistance, which can effectively resist the lateral force generated by the sand belt during porcelain grinding on the piston rod of the pressure belt cylinder. As the grinding object is a circular ceramic plate with a maximum diameter of 300 mm or a rectangular ceramic plate with a maximum outer dimension of 300 × 300 mm, with a bottom size not exceeding 150 mm, the sand belt width specification is 180 mm, and the pressure grinding plate length and width are 200 mm and 180 mm, respectively.

(2) Automatic feeding and retraction mechanism

To grind the bottom of the ceramic plate, it is necessary to first determine whether to move the plate to the sand belt station or the rotating sand belt to the plate station. Considering that the device for rotating the sand belt is relatively complex, it is easier to move the plate to the sand belt station. As porcelain is brittle and not easily in contact with metals, its stability must be ensured during transportation. Therefore, appropriate positioning and transportation methods need to be selected. This problem can be transformed into the "HOW TO" model of TRIZ theory, and corresponding functional implementations, scientific effects, and phenomena can be found in Table 1.

Since the automatic feeding of the ceramic plate requires prior detection of whether the porcelain is present on the tray, scientific effects and phenomena that achieve the function of "F5 detecting the displacement and motion of objects" can be found. As each porcelain is not fixed and cannot be marked for easy detection, and deformation, electric fields, magnetic fields, and discharge methods are not suitable for detection, the "reflection and emission lines" method is used to identify if there is porcelain on the tray. Therefore, a through-beam sensor is selected to detect whether the ceramic plate is placed on the tray.

Regarding the problem of automatic transportation of porcelain, scientific effects and phenomena that achieve the function of "F6 controlling the displacement of objects" can be found. However, magnetic force, inertia force, thermal expansion, thermal bimetallic strips, electronic force, liquid power, buoyancy, vibration, and other methods are not suitable for transporting ceramic plate. Therefore, "pressure: the pressure of liquid or gas, the pressure of liquid or gas" is used as a solution, and a cylinder is considered as the power to transport ceramic plate.

During the grinding process of the ceramic plate, the vibration caused by the rotation of the motor can easily cause slight collisions between the ceramic plate and the metal tray, which can damage the porcelain. The physical-field analysis method of TRIZ theory can be applied to solve this problem. If one substance has both useful and harmful effects on another substance in the substance-field model, and they do not need to be closely adjacent, another ready-made substance S3 can be introduced between the two substances to eliminate the harmful effects. This additive may be temporary or permanent.

Firstly, the substance-field model is constructed as shown in Fig. 8, where the target substance S1 is the dish-type porcelain, the tool substance S2 is the tray, and the mechanical field is the grinding force Fm. The external ready-made substance "rubber pad" can be used as an

Table 1: The corresponding table of scientific effect, phenomenon and function.

Feature code	Functions	The scientific effects, phenomena and serial numbers recommended by TRIZ
F5	Detecting the displacement and motion of the objects	Introduction of easily detectable markers: E6 markers, E16 magnetic materials, E37 luminescence, E38 luminescent bodies, E95 permanent magnets; deformation: E78 plastic deformation, E85 elastic deformation; changing electric and magnetic fields: E13 magnetic field, E22 electric field; discharge: E25 arc discharge, E31 corona discharge, E53 spark discharge; reflection and emission lines: E38 luminescent bodies, E41 reflection, E43 radiation phenomena, E45 photosensitive materials, E50 spectroscopy.
F6	Controlling the displacement of the objects	Pressure: E91 pressure of liquids or gases, E93 pressure of liquids or gases; electronic force: E2 Ampere force, E64 Lorentz force; magnetic force E15, buoyancy E44, inertia force E49, thermal expansion E75, bimetallic strip E76, liquid dynamics E92, vibration E98.

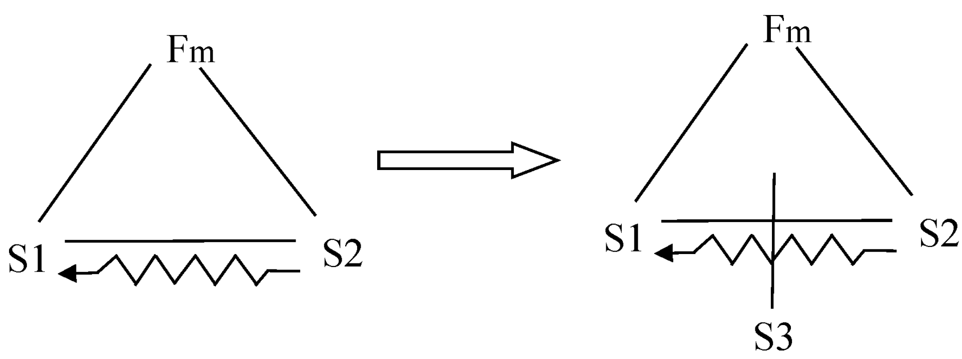
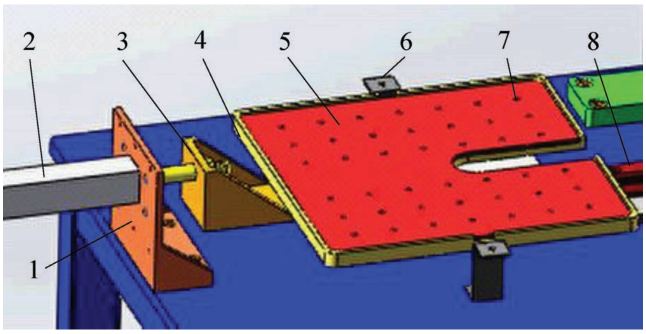


Fig. 8: Material-field model, Fm: Grinding force, S1: Disc type porcelain, S2: Support plate, S3: Rubber pad.

intermediate substance S3 introduced between the two substances in the system. The rubber pad can reduce or eliminate the slight collisions between the ceramic plate and the metal tray, ensuring that the porcelain is not damaged. Therefore, the scheme of the automatic feeding and retraction mechanism for the ceramic plate is shown in Fig. 9, where the piston rod head of the cylinder is connected to the tray through a connecting bracket, and the cylinder can push the tray to move left and right along the linear guide rail. When the through-beam sensor senses the ceramic plate on the tray, the cylinder moves, and the piston rod extends to push the tray under the sand belt for grinding the porcelain. Due to the buffering effect of the rubber pad, the porcelain will not be damaged during grinding. To prevent the ceramic plate from moving significantly during transportation and grinding, multiple pinholes are drilled on the tray and a rubber pad is used for installation of the stop pins, and appropriate holes are selected to insert the stop pins according to the size of the ceramic plate to prevent significant displacement.

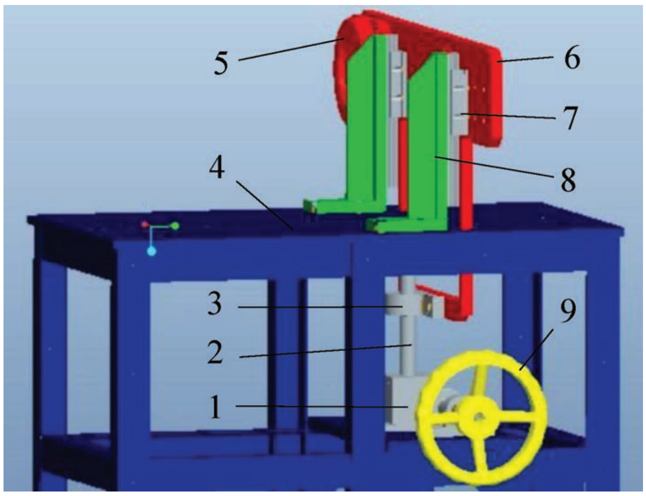


1. Cylinder seat, 2. Cylinder, 3. Connection frame, 4. Support plate, 5. Rubber pad, 6. Opposite sensor frame, 7. Positioning pin hole, 8. Linear guide rail

Fig. 9: Design scheme of the feeding mechanism.

(3) Grinding height adjustment mechanism

To adapt to the grinding of the ceramic plate of different heights, the initial height of the grinding mechanism needs to be adjusted. As all the components of the grinding mechanism are installed on a moving plate, the plate only needs to slide up and down along a linear guide rail. However, due to the large size of the moving plate, its stability during vertical movement is poor. Therefore, the parameter to be improved is the stability of the structure, while the parameter to be reduced is the complexity of the device. The contradiction between improving the stability of the structure and reducing the complexity of the device corresponds to the invention principle numbers: 13 reverse thinking, 31 porous materials, 2 extraction, 10 pre-operation, 40 composite materials, 35 parameter change, 26 replication, and 17 dimensional change. According to the "17 dimensional change" principle, the linear guide rail is increased from one to two, as shown in Fig. 9, which significantly enhances the stability of the moving plate. The height adjustment is mainly completed by the lifting platform, with the model number of SWL2.5 – 2AIII-120 and a screw thread at the head, and the stroke is 120 mm. The height adjustment process: by rotating the handwheel, the lifting platform rotates the screw rod, and the moving plate will slide up and down along the two linear guide rails under the action of the nut. The height adjustment range is 5 – 100 mm. The 3D model of the grinding height adjustment mechanism is shown in Fig. 10.

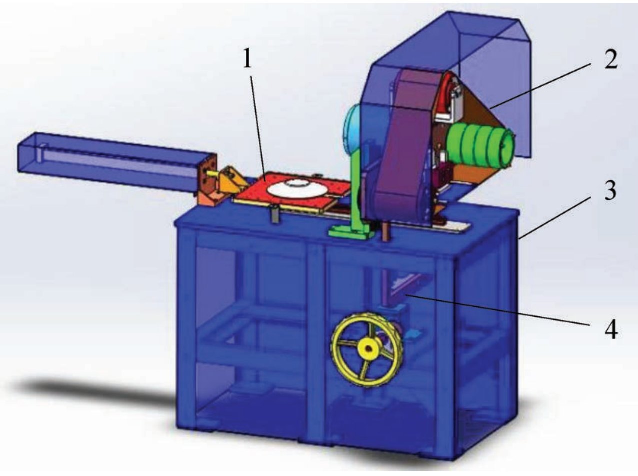


1. Elevator, 2. Screw, 3. Nut, 4. Frame, 5. Motor mounting seat, 6. Moving plate, 7. Linear guide rail, 8. Linear guide rail seat, 9. Handwheel

Fig. 10: Design scheme of the grinding height adjustment mechanism.

(4) Three-dimensional model of the mechanism

Based on the above design schemes, an overall 3D model of the automatic bottom grinding machine for ceramic plates is established, as shown in Fig. 11. The automatic bottom grinding machine mainly includes the automatic feeding and retraction mechanism for the ceramic plates, the grinding mechanism, the frame, and the grinding height adjustment mechanism. Considering the safety requirements, protective covers are installed around the cylinders of the grinding mechanism, frame, and automatic feeding and retraction mechanism for the ceramic plate. The working process is as follows: on rotation of the handwheel, the lifting platform adjusts the vertical distance between the sand belt and the support plate in the grinding mechanism to determine the grinding height. Around the diameter or edge length of the ceramic plate, 4 to 5 stop pins are selected and inserted into appropriate holes on the support plate and rubber pad to prevent any significant displacement. The driving motor is started to rotate the active support wheel, which drives the sand belt on the active support wheel, driven support wheel, and tension support wheel to rotate through friction. The ceramic plate is placed upside down on the porcelain support plate between the stop pins, and the through-beam sensor detects the porcelain. Then, the piston rod of the automatic feeding and retraction mechanism for the ceramic plate extends to push the porcelain to the grinding station under the sand belt. The piston rod of the guide rod cylinder in the grinding mechanism extends to push down the pressure plate, pressing the rotating sand belt onto the bottom of the porcelain for grinding. After grinding for the set time, the guide rod cylinder retracts the pressure plate. Then the piston rod of the automatic feeding and retraction mechanism for the ceramic plate retracts, and the ground plate is transported back to the initial position for removal, and the process is repeated for the next plate.



1. Automatic forward and backward mechanism for porcelain, 2. Ceramic grinding mechanism, 3. Rack, 4. Grinding height adjustment mechanism

Fig. 11: Three-dimensional model of automatic machine for grinding the bottom of ceramic plates.

V. Application Effect

Based on the above design and analysis, the automatic bottom grinding machine for ceramic plates has been successfully developed and adopted by Tangshan Longda Bone China Co., Ltd. Field operation shows that the safety performance of the automatic bottom grinding machine for the ceramic plate has been significantly improved, especially for the grinding of thin ceramic plates, and there have been no accidents involving hand injury, achieving the expected effect. Additionally, workers can also operate the machine while sitting, significantly reducing labor intensity. Fig. 12 shows a photo of a worker operating the automatic bottom grinding machine for ceramic plates.

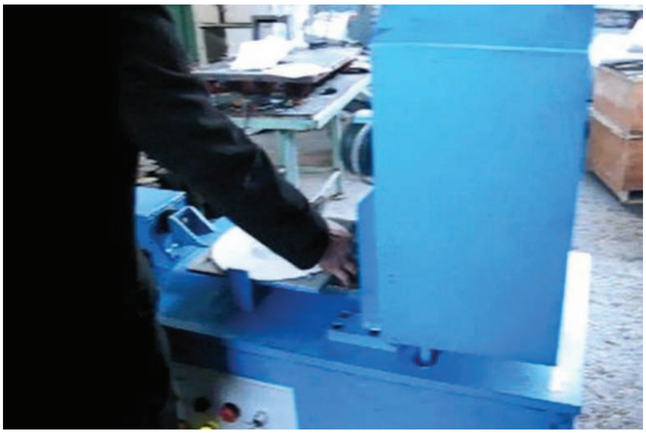


Fig. 12: Grinding plates on the automatic grinding machine.

VI. Conclusions

Based on an analysis of the working characteristics of existing bottom grinding machines for ceramic plates, and with consideration of practical work and safety performance requirements, an engineering model was established using the TRIZ theory product design process in line with user needs. Innovative methods, including TRIZ theory‘s contradiction matrix, scientific effects and knowledge base, and field analysis were comprehensively applied to address the automation and safety performance problems associated with bottom grinding of ceramic plates.

The resulting innovative solution is an automatic bottom grinding machine for ceramic plates that meets customer needs. The 3D model was designed using SolidWorks and manufactured by the enterprise. Practical application has demonstrated that the machine satisfies operational requirements, enables automatic plate feeding and retraction, and automatic grinding for plates of various specifications and heights. Compared with manual pressing and grinding, the machine significantly improves the accuracy, safety, and automation level of bottom grinding for ceramic plates. This study also confirms the feasibility and practicality of TRIZ theory in solving problems encountered in production practice.

Acknowledgments

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