Intelligent transformation of automatic mold adjustment for mechanical curing press

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Abstract: This article introduces a combined device that integrates the functions of mold adjustment and force measurement mechanisms for mechanical tire shaping and curing presses, enabling simultaneous automatic mold adjustment, recording, and display of cold mold clamping force. The device, achieved by adding a rotary displacement encoder and upgrading the PLC program, features a simple structure, convenient operation, and strong versatility. It offers a low-cost and easy-to-implement solution for the intelligent retrofitting of existing curing presses.

Key words: curing press; mold adjustment; intelligence; clamping force; rotary displacement encoder

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The tire shaping and curing press is used in the final process of tire production, which is an important step in tire shaping and qualitative determination. It can be said that the tire shaping and curing press is a key equipment that determines the quality of tires. After more than 40 years of reform and opening up in China, with the great development of electrical and informatization, tire curing equipment has gradually gone through stages of exploration, including curing tanks, single-unit curing presses, groups of curing presses, and pure electric curing presses. In the process of pursuing innovation in curing presses, countless manufacturers have proposed improvements such as automation, structural optimization, energy saving, safety, electric heating, and intelligence for single-unit curing presses, based on their business and development stages. For example, Luo Yongfeng and others have conducted technical automation transformation and promotion of the shaping pressure, manipulator, and curing control program of all-steel tire curing presses, which not only ensures production continuity but also improves production efficiency and curing qualification rate. Guo Lianggang and others have discussed upgrades and transformations in aspects such as replacing hydraulic power with water for mechanical curing presses, dual-column manipulator transformation, steamer to hot plate transformation, and integrated valve group application. Song Peifen, combining enterprise management concepts, has achieved good results in a series of energy-saving improvements for tire curing presses, such as using PLC control for curing press condensate water discharge, which results in a low failure rate and saves 30% to 40% of steam. Zheng Wanli and others have carried out technical transformation and management improvement based on the inherent safety of the curing process, implementing measures such as mandatory inspection of the safety rod of the curing press and linkage protection of the mold opening and closing electrical system to improve the curing process. Shang Rongwu and others have proposed an electromagnetic induction heating device for the segmented mold of the curing press to enhance the quality and performance of vulcanized tires, analyzing the magnetic flux leakage shielding and electromagnetic heating characteristics of the segmented mold.

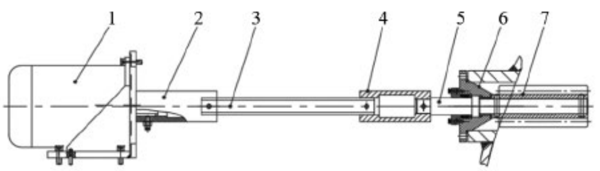
The mold adjustment of a mechanical tire shaping and

Biography: Jiang Hongbin (1991-), male, is an electrical engineer primarily engaged in research and design work related to the electrical aspects of curing presses.

curing press is achieved by matching different mold heights through a mold adjustment device. During mold adjustment, the mold is opened and closed reciprocally to observe the downward movement distance of the mold and check the value on the tonnage gauge of the force measurement mechanism to determine whether the mold adjustment is in place. This mold adjustment method is time-consuming, laborious, and difficult to operate. In addition, the force measurement mechanism mainly displays the mold clamping force through a tonnage gauge installed on the connecting rod. Each time the mold clamping force is read, it requires a distant observation of the tonnage gauge, making it difficult to read. To solve these problems, Xia Houhui et al. proposed adding a sensing mechanism for precise control of mold adjustment height to the mold adjustment device of the curing press, but did not provide a specific implementation plan for the sensing mechanism; You Lican proposed an automatic mold adjustment control system and method for the curing press, installing a mold adjustment encoder on the mold adjustment motor for real-time detection of mold height; Cao Shiliang et al. used a laser ranging sensor to measure the actual height after changing molds for automatic mold adjustment; this paper proposes a different, simpler, and more economical implementation plan, by equipping a hollow shaft rotary displacement encoder in the connecting shaft of the mold adjustment device and upgrading the PLC code, to achieve one-time data calibration and adjustment for the same mold, followed by display of cold mold clamping force values on the industrial control screen and one-click automatic mold adjustment function. This device has a simple structure, easy operation, low labor intensity, good versatility, and low cost for intelligent transformation of existing curing presses, making it easy to implement.

1 Brief description of the mold adjustment mechanism

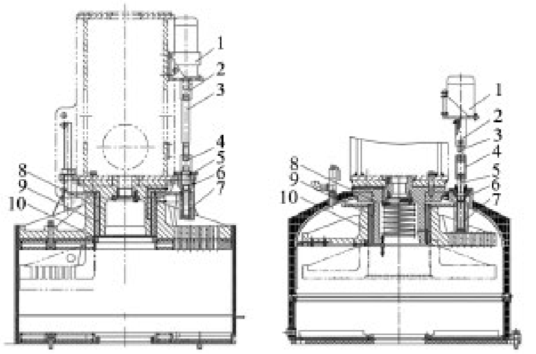
The curing chamber is an important component of the curing press and a functional part for curing tires. After the raw tire is loaded into the lower curing chamber through the tire loading device, the upper curing chamber performs the mold closing action driven by the main drive, and the thermal pipeline starts to work. The raw tire undergoes temperature and pressure effects in the curing chamber, ultimately forming a finished tire. Depending on the molds installed in the curing chamber, the raw tire forms finished tires of different specifications; different molds have different heights, and the curing chamber is equipped with a mold adjustment mechanism designed to accommodate different mold heights. Traditional mold adjustment mechanisms use adjustable wrenches to rotate pinions. With the development of electrical automation and objective factors such as reducing labor intensity, almost all mechanical curing press mold adjustment mechanisms have now achieved electric mold adjustment functionality. Figure 1 shows the mechanical curing press mold adjustment mechanism, which consists of a mold adjustment motor, an upper coupling, a connecting rod, a lower coupling, a shaft, a flange seat, and a pinion. The upper and lower couplings transmit the rotation of the mold adjustment motor to the pinion. The use of upper and lower couplings here mainly facilitates the disassembly and maintenance of the pinion and seals.



1-Die-adjusting motor; 2-Upper coupling; 3-Connecting rod; 4-Lower coupling; 5-Shaft; 6-Flange seat; 7-Pinion gear

Figure 1 Mechanical curing press mold adjustment mechanism

The overall mold adjustment mechanism is installed on the crossbeam web plate through the mold adjustment motor bracket, and is mounted to the crossbeam panel or steam chamber head via a flange base. The small gear of the mold adjustment mechanism is designed with a large thickness to ensure that during mold adjustment, the large gear can move up and down while still meshing with the gears. Figure 2 shows the vulcanization chamber of a mechanical curing press. The inside and outside of the mold adjustment nut are designed with trapezoidal teeth, and the end face forms a combination with the large gear thread. The mold adjustment motor transmits motion to the small gear, which meshes with the large gear on the end face of the mold adjustment nut. The trapezoidal teeth inside the mold adjustment nut drive the trapezoidal teeth on the flange stud, and the trapezoidal teeth outside the mold adjustment nut drive the trapezoidal teeth inside the upper fixed plate. Since the flange stud is fixed and assembled to the crossbeam panel with bolts, the motion is transmitted to the distance adjustment nut through the rotation of the small gear, and ultimately fed back to the upper fixed plate. The mold connected to the upper fixed plate will achieve a motion with twice the pitch of the trapezoidal teeth.



1-Die-adjusting motor; 2-Upper coupling; 3-Connecting rod; 4-Lower coupling; 5-Shaft; 6-Flange seat; 7-Pinion; 8-Flange stud; 9-Die-adjusting nut; 10-Upper fixed plate

Figure 2 Vulcanizing chamber of mechanical curing press

2 Structural design

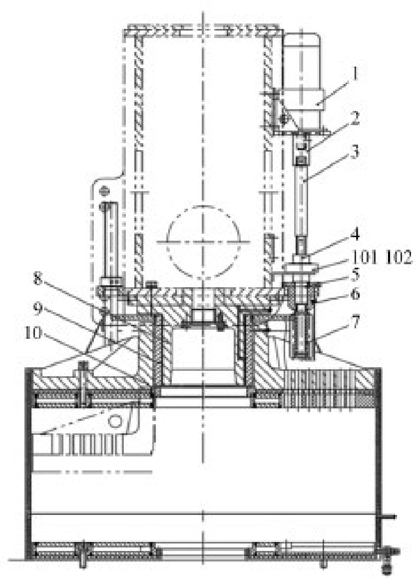
In the intelligent transformation of the curing press discussed in this article, the core of the mechanical structure lies in the application of rotary displacement encoders. These encoders collect rotational data from the mold adjustment motor, and the least squares method is applied for linear fitting to obtain the mold clamping force-displacement relationship curve. Encoding control is performed in the PLC to achieve the one-click automatic mold adjustment function.

2.1 Rotary displacement encoder

A rotary displacement encoder is a kind of sensor capable of recording rotary signals and converting mechanical geometric displacements into pulse outputs. Absolute hollow shaft rotary displacement encoders can capture rotary signals through capacitive, magnetoelectric, or optoelectronic principles. This encoder features strong anti-interference and high accuracy, and in the field of industrial control, it can detect parameters such as distance, angle, position, and speed of mechanical motion. It is currently widely used in various industries as a signal detection method. In this article, an absolute hollow shaft multi-turn rotary encoder is selected. This encoder is annular and hollow in overall shape, suitable for measuring shaft-type rotations, and features a large measurement range, instantaneous position detection upon power-on, and no need for zero search.

2.2 Mechanical displacement relationship

In the retrofitting of the automatic mold adjustment device, a rotary encoder is added to the mold adjustment mechanism. This rotary encoder is installed on the web plate of the crossbeam, and the rotary signal of the lower coupling shaft is measured through the rotary encoder. Figure 3 shows the automatic mold adjustment device, which uses an absolute hollow shaft multi-turn rotary displacement encoder to directly measure the rotary information of the lower coupling shaft and obtain the number of turns output by the mold adjustment motor. Assuming that the rotary encoder signal of the mold adjustment motor's rotation is X, the number of teeth on the large gear is Z_1, the number of teeth on the small gear is Z_2, the trapezoidal thread pitch of the mold adjustment nut is P, and the moving distance of the upper fixed plate for mounting the mold is H, the following relationship exists:



1-Mold adjustment motor; 2-Upper coupling; 3-Connecting rod; 4-Lower coupling; 5-Shaft; 6-Flange seat; 7-Pinion; 8-Flange stud; 9-Mold adjustment nut; 10-Upper fixed plate; 101-Rotary encoder; 102-Support

Figure 3 Automatic mold adjustment device

$$H=2\times X\times Z_2/Z_1\times P \quad (1)$$

Since this rotary encoder has the function of knowing its position immediately upon power-on and eliminating the need for zero-seeking, it can obtain information about any position of the upper fixed plate in the program. When changing molds or readjusting parameter data, you can freely choose whether to "zero" in the program to set the zero point value of H.

2.3 Force measurement principle

The acquisition of clamping force for a mechanical tire shaping and curing press is primarily measured through a force-measuring mechanism at both ends of the connecting rod. When the connecting rod operates, it is subjected to tension, typically experiencing a deformation of 0.3-0.7mm. The main component of the force-measuring mechanism, the tonnage gauge, is modified from a micrometer. By measuring the slight elastic deformation of the connecting rod through the tonnage gauge and combining it with Hooke's law, the tensile force of the connecting rod can be determined. The relationship between the deformation and tensile force measured by the force-measuring mechanism is as follows:

$$\Delta L=\sigma\times L/E \tag{2}$$

$$\sigma=F/A \tag{3}$$

In the formula, L represents the distance between the two axial holes of the connecting rod, E denotes the elastic modulus of the connecting rod, F signifies the tensile force applied to the connecting rod, and A stands for the cross-sectional area of the main plate of the connecting rod. By utilizing the aforementioned formulas (2) and (3), the tensile force on the connecting rod can be determined, and subsequently, the clamping force in the tonnage table can be calculated. From the above, it can be concluded that traditional clamping force is obtained through the measurement of connecting rod deformation, based on the principle of elastic deformation, which is the linear relationship between force and deformation.

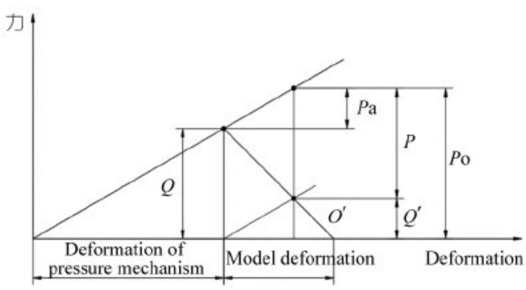


Figure 4 Curing press mold clamping force-deformation diagram

Figure 4 is a mold clamping force-deformation diagram of a curing press, taken from the mold clamping force-deformation diagram in the Rubber Machinery Manual. It indicates that both the pressure mechanism and the mold undergo elastic deformation during the mold clamping process, and the force and deformation of the two are linearly related. For mechanical curing presses, the main parts subjected to force and deformation during mold clamping are the connecting rod, crossbeam, and mold. The force measurement mechanism calculates the mold clamping force by measuring the deformation of the connecting rod.

Based on the above analysis, the mold clamping force-deformation diagram and force measurement mechanism in the rubber machinery manual are both based on the principle of elasticity. The overall force transmission mechanism is relatively stable due to mechanical structural deformation, and the entire assembly dimensional chain is clear. Therefore, the mold clamping force and the displacement of the pressure mechanism or model also exhibit a linear relationship, which can be described by a linear equation. The mold clamping force-displacement curve fitting of the automatic mold adjustment device in this article is constructed based on the linear relationship between mold clamping force and displacement. The mold clamping force values taken are from the tonnage table of the force measurement mechanism, and the displacement values obtained are from the position of the upper fixed plate measured by a rotary displacement encoder. By reading three sets of mold clamping force-displacement (F_i, H_i) data, the least squares method is used to achieve a linear fitting relationship between mold clamping force and displacement, and the linear equation F=aH+b is solved to fit the relationship between mold clamping force and displacement.

There are currently three sets of data points, assumed to be (F_1, H_1), (F_2, H_2), and (F_3, H_3). If these three points are collinear, then there exists an exact solution; however, the three points typically measured are not strictly collinear. In this case, the Least Squares Method is needed to find the best-fit straight line. The Least Squares Method adopts the principle of minimizing the sum of squared errors to obtain the objective function. In the Least Squares Method for univariate linear fitting, suppose a set of N (x, y) sample data is subjected to linear fitting with $y=ax+b$. The key to fitting lies in determining the values of the fitting coefficients (a, b), and then solving for the functional relationship. The fitting coefficients are calculated as follows:

$$a=\frac{N\sum x_i y_i-\sum x_i \sum y_i}{\sum N x_i^2-(\sum x_i)^2} \tag{4}$$

$$b=\frac{\sum y_i \sum x_i^2-\sum x_i \sum x_i \sum y_i}{N\sum x_i^2-(\sum x_i)^2} \tag{5}$$

Therefore, by manually opening and closing the mold to obtain the three sets of mold force and displacement values, substituting them into equations (4) and (5) can yield the functional relationship of the mold force-displacement curve, thus obtaining the curing press mold force-displacement curve.

3 Electrical design

3.1 Electrical design tools

In this article, the core of the electrical part in the intelligent transformation of the curing press lies in the application of Programmable Logic Controller (PLC) and configuration software. The PLC is responsible for reading encoder data, calculating the current position of the mold based on the mechanical displacement relationship in the mold adjustment mechanism, comparing it with the target position, and controlling the action of the mold adjustment motor. The PLC design software used is Mitsubishi GX Works3, an advanced programming software developed by Mitsubishi Electric. It is an engineering software that integrates programming, simulation, intelligent function unit configuration, and other functions, providing users with an efficient engineering environment, improving development efficiency, and reducing development costs. The software supports multiple programming languages, with LAD language (ladder diagram) primarily responsible for implementing complex control logic and process control, supplemented by the embedded structured ST language for simple and data-light arithmetic operations and data processing, achieving the use of different programming languages in the same project and leveraging the respective advantages of LAD and ST languages.

The configuration software is responsible for visualization and human-computer interaction functions. It reads data in the automatic mold adjustment control system, creates a visual curve of mold clamping force-displacement, calculates the target position based on the target mold clamping force, and reads the current position through PLC to calculate the current mold clamping force. All of these are achieved through efficient visualization and human-computer interaction implemented by the configuration software. The human-machine interface software is developed using Huafu Kaiwu controX industrial configuration software, which is a cross-platform general-purpose configuration software. This software has the advantages of good stability, high operational efficiency, simple and efficient functional module configuration, etc. It includes an efficient database system, good openness and portability, a simple and efficient scripting system, an embedded rich and easy-to-use function library, and components such as plugins, graphics elements, and functions based on an open architecture design that are easy to extend. It can handle relatively complex data operations with large amounts of data, and is not prone to overflow.

3.2 Electrical principle

The electrical design of the automatic mold adjustment control system for the curing press is suitable for the same mold. With one-time data fitting, the required mold clamping force can be obtained by inputting the target mold clamping force subsequently, achieving the automatic mold adjustment function. After changing the mold, it is necessary to run the mold adjustment program. Figure 5 shows the mold adjustment process flowchart of the curing press. Start the mold adjustment program, reset the set parameters, and then manually open and close the mold to obtain the mold clamping force-displacement curve data and write it into the PLC program. Customers can set the required mold clamping force (target mold clamping force) for the current equipment on the screen based on the generated mold clamping force-displacement curve. After pressing the automatic mold adjustment button, the mold adjustment motor will automatically operate, enabling the equipment to automatically adjust the mold to the target position corresponding to the mold clamping force, achieving the one-click automatic mold adjustment function. If the mold remains unchanged and only the target mold clamping force is changed, that is, in the case where a mold clamping force-displacement curve already exists, it is only necessary to change the target mold clamping force in the set parameters and then press the automatic mold adjustment button to achieve one-click automatic mold adjustment.

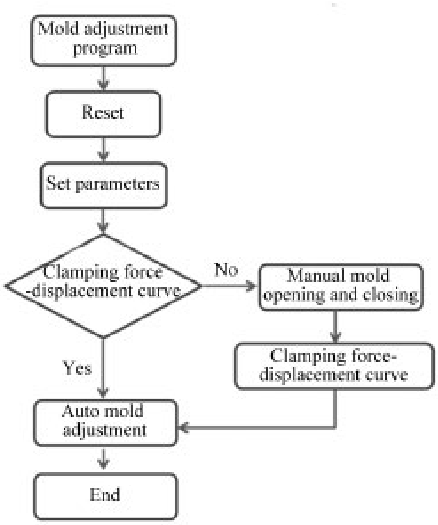


Figure 5 Flowchart of mold adjustment for curing press

Figure 6 shows the control interface for automatic mold adjustment of the curing press. The interface requires setting parameters including the number of teeth on the large gear, the number of teeth on the small gear, the thread pitch, the maximum mold clamping force, and the target mold clamping force information. By inputting these information into the system interface and writing them into the PLC, the PLC will obtain the relationship between the rotary encoder's turn signal and the mold position according to formula (1). Since the rotary encoder directly measures the rotation information of the mold adjustment motor, knowing the relationship between the rotary encoder's turn signal and the mold position means knowing the relationship between the mold position and the number of rotations of the mold adjustment drive motor. The program will upload the current position information to the interface in real time.

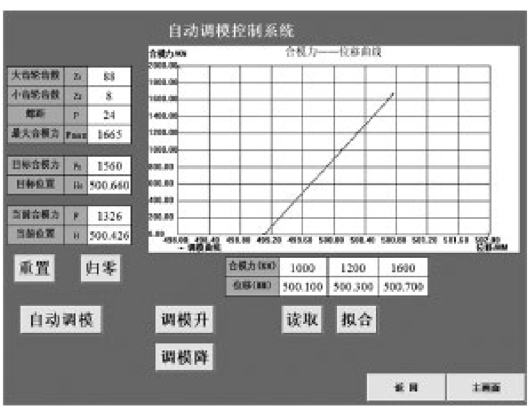


Figure 6 Automatic mold adjustment control interface of curing press

By reading and fitting the three sets of mold clamping force-displacement data obtained through manual mold opening and closing, the data is input into the configuration software. The least squares method is used to obtain the mold clamping force-displacement curve data. The screen script will obtain the target position corresponding to the target mold clamping force based on the mold clamping force-displacement curve. The automatic mold adjustment program will compare the current position value with the target position value based on the target position, drive the mold adjustment motor, adjust the current position to approach the target position, and thus achieve the one-click mold adjustment function.

3.3 Key electrical procedures

3.3.1 Clamping force-displacement curve

Figure 7 shows the mold clamping force-displacement curve script. By obtaining three sets of mold clamping force and displacement information through mold opening and closing, the data is input into the automatic mold adjustment control system. The fitted data is read and substituted into equations (4) and (5). Using configuration software, a least squares method script is written to calculate the coefficients of the linear equation, thus creating a mold clamping force-displacement visualization curve in the control interface. The interface script can also calculate the target position based on the user-set target mold clamping force, write the value into the PLC's automatic mold adjustment control system, read the current position from the PLC in real time, and calculate the current mold clamping force, achieving efficient and visual human-machine interaction.

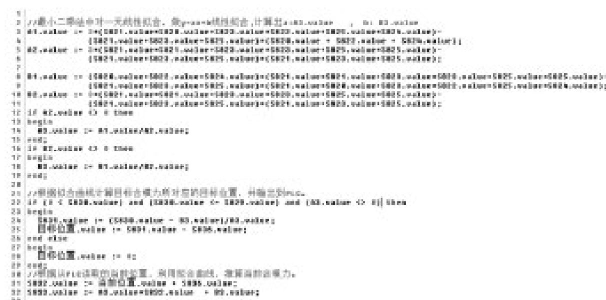


Figure 7 Clamping force-displacement curve script

3.3.2 Automatic mold adjustment

Figure 8 shows the automatic mold adjustment program. After pressing the automatic mold adjustment button, the automatic mold adjustment completion status signal is immediately reset. At the same time, the PLC program compares and judges the current position with the target position in real time, and outputs an automatic mold adjustment up or down signal according to the calculation result until the current position moves into the target position range. At this point, the automatic mold adjustment process is complete, and the automatic mold adjustment completion status signal is set.

Figure 8 Automatic mold adjustment program

When the automatic mold adjustment up or automatic mold adjustment down signal is triggered, the corresponding mechanical mold adjustment control function block is executed. Figure 9 shows the mechanical mold adjustment control program. According to the corresponding triggered up or down signal, the PLC outputs the mold adjustment up or mold adjustment down signal to control the forward and reverse rotation of the mold adjustment motor, achieving the mold lifting and lowering action. Through the above rigorous electrical control design process, the one-button automatic mold adjustment function of the mechanical tire shaping and curing press mold adjustment device is realized, improving the operational convenience and mold adjustment accuracy of the equipment.

Figure 9 Mechanical mold adjustment control program

4 Conclusion

The current positive development of the automotive industry is inseparable from the assurance of tire quality. As an important equipment for tire production, the curing press has gradually evolved towards more intelligent, green, and safe directions through continuous development, improvement, and innovation. This article provides an intelligent transformation plan for the curing press, which has the advantages of being economical and easy to implement. In particular, this transformation plan can achieve the function of one-time data fitting and multiple automatic mold adjustments, reducing the intensity of worker mold adjustments and having positive significance for the intelligent transformation of the curing press.