

# A slate grinding machine based on green design

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**Abstract.** In this paper, a new slate grinding machine based on green design is investigated. To save a lot of cast iron, large natural stones are used in the structure of the machine. Three key components of the body frame, the crossbeam and the power head are introduced in detail. In view of the body frame structure, the process of combination of stone and steel is given. The design method of the important parameters of the power polishing head is proposed. The deformation of the crossbeam under the gravity action of the 12 power polishing heads is analysed. Due to the crossbeam moving laterally with all the power heads, they have great inertia. Therefore, it is difficult to control the motion. In this case, a new buffer brake mechanism is proposed and the dynamic process of the crossbeam reversing is analysed. Finally, the calculation method of the required output torque of the driving motor is proposed. The results show that the functions of the slate grinding machine meet the requirements of use, the proposed method of design and analysis is correct and the concept of green manufacturing is realized.

## 1. Introduction

Slate is a common building material and it is widely used in indoor and outdoor surfaces, walls, etc. Surface polishing is an important process of slate processing. The slate grinding machine is a special equipment for slate surface polishing and it plays a key role in the quality of stone processing, whether it is the production line of stone sheet processing or the production line of large slate.

With the rapid development of the construction industry, the demand for slate is increasing more and more. The slate grinding machine production enterprise has got a good opportunity for development. The quality and performance of the slate grinding machine have also been greatly improved. Some of the most advanced slate grinders are produced in Italy. The main companies are SIMEC, MORDENTI, GAS-PARIMENOTTI, BRA, TE-MAFRU-GOLI, PEDRINI S.P.A, BREETN, GREGORI, BARSANTI, BRETON, PROTEC, ACIMM, COGE-MAR, LOFFLER, FIGKRT & WINTERLING, SCHULZE DR GMBH, BAVELLONI, TESMEC, etc. [1]. China's slate grinding machines production enterprises have also achieved great development. A new type of continuous grinding machine with resin grinding disc is developed by HUAXING machinery company limited [2]. The PLC control system has been successfully applied in slate grinding machine [3, 4]. PLC automatically collects the shape of the stones by collecting data information from all parts of the field, and completes automatic control of more than ten valves, grinding heads and swing arms on site by means of high-speed counting of the encoder and the HT7A00T touch screen makes the maneuverability of the stone equipment control system more convenient and flexible [4]. To improve the precision and the life of the stone mill measurement system, an online detection system of

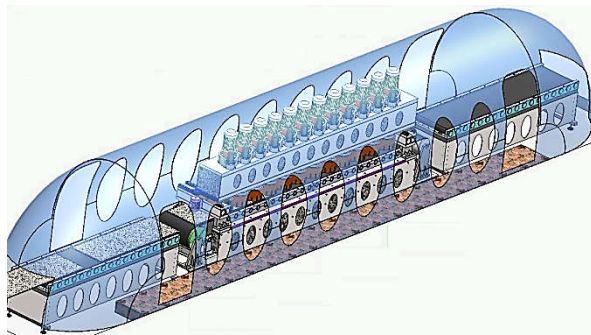


continuous rock grinder is proposed based on the machine vision [5]. Achievements have been obtained in mainly three aspects, driving power grinding head with two stage planetary reducer, using multifunction grinding disc and adding a grinding head pressure regulating device [6].

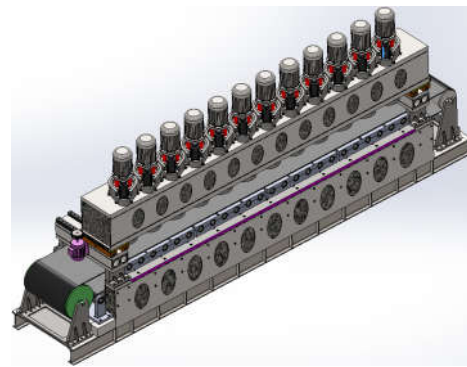
From the trend of the development of slate grinding machine, high automation and new material and new structure, green and environmental protection are the main directions. In this paper, a new slate grinding machine based on green design is introduced and studied, whose main feature is the use of a mixed structure of stone and steel. China's Xinjiang, Kuandian and Xiuyan in Liaoning are the main producing areas of large granites. This provides natural raw materials for the new slate grinding machine studied in this paper.

## 2. Structure design

A new slate grinding machine is designed, which is composed of the body frame, the power polishing head, the crossbeam, etc. The whole work system is shown in figure 1 and the structure of the machine is shown in figure 2. The main parameters are listed in table 1.



**Figure 1.** Whole work system of the new machine.



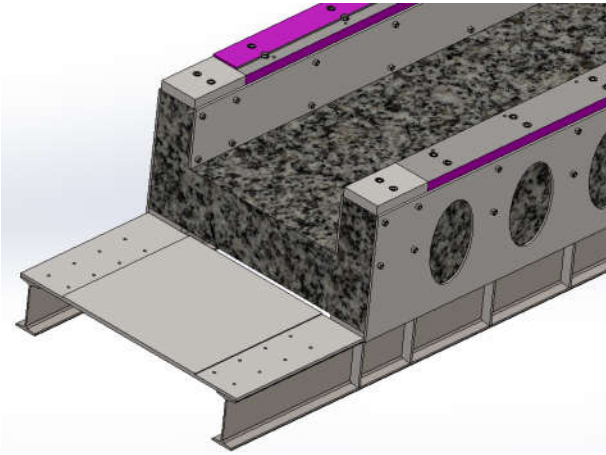
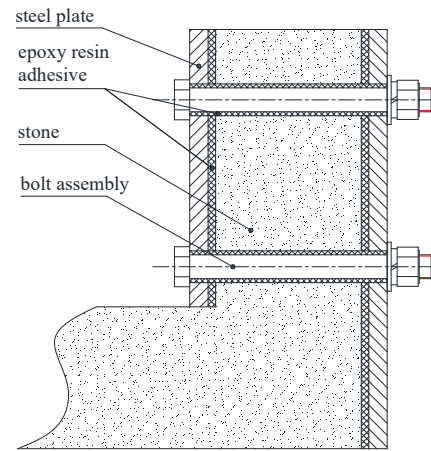
**Figure 2.** Structure of the machine.

**Table 1.** Main parameters.

| Parameters                  | Values         |
|-----------------------------|----------------|
| Working thickness           | 8-50 mm        |
| Working width               | $\leq 800$ mm  |
| Conveyor belt speed         | 0.2-5.0 m/min  |
| Crossbeam swinging speed    | 1-60 m/min     |
| Total power                 | 100 Kw         |
| Grinding head power         | 7.5 Kw         |
| The number of grinding head | 12             |
| Machining precision         | $\leq 0.20$ mm |

### 2.1. Body frame

The body frame is the foundation of the whole slate grinding machine and supports other parts and slates. It is an important component of the processing precision. In this paper, a mixed structure of stone and steel has been adopted, which is shown in figure 3. The processing of large special-shaped stones can be completed by many companies in China, such as Zheng Shu Technology Co., Ltd. in the Zhejiang province. Since stone and steel have different physical properties, their combination process is very special. Stone connection with left and right steel plates is taken as an example, which is shown in figure 4. The epoxy resin adhesive is the connection medium of the steel and the stone and plays an important role in vibration absorption.

**Figure 3.** Body frame of the machine.**Figure 4.** Connection of stone and steel.

### 2.2. Power polishing head

The power polishing head is the most important component in the slate grinding machine. In this paper, a new power polishing head is designed, which has 2 degrees of freedom and with automatic locking device. The overall structure of the power polishing head is shown in figure 5. The motor I drives the principal axis to rotate, so that the main motion of the grinding process is realized. The gear I is meshed with the gear II, and the gear II and the long shaft form a thread pair. Hence, the motor II can make the polishing head with principal axis and motor I move vertically by the gear pair and the thread pair. The gravity of the polishing head, the principal axis, the long shaft, the motor I and other auxiliary parts, acts on the thread pair. Therefore, in order to reduce the force acting on the thread pair, the spring plays a key role. The motor III can drive the locking mechanism, which includes gear meshing and thread meshing, as shown in figure 6. The gear III is meshed with the gear IV, and the gear IV is fixed with the rotating sleeve with internal thread. The rotating sleeve and the upper and lower wedge-shaped sleeves with different screw threads form two thread pairs, respectively. The upper and lower wedge-shaped sleeves move vertically, so the holding block can be pushed to lock or release the long shaft by them.

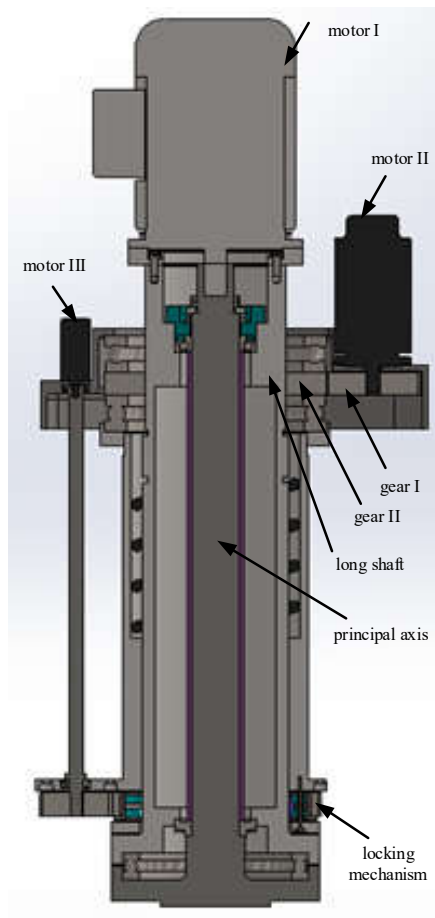
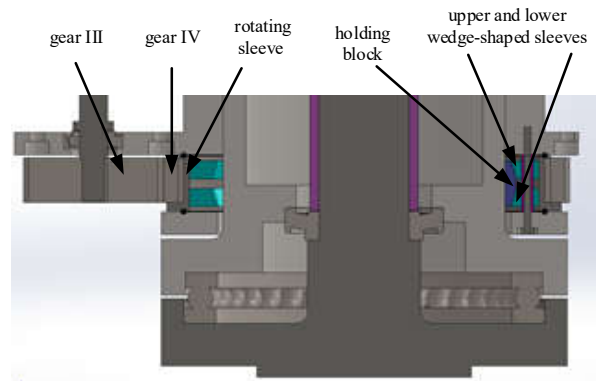
The initial pretension and stiffness of the spring are designed according to the following equations:

$$\begin{cases} k\Delta x - Mg = F_s \\ k\left(\Delta x - \frac{H}{2}\right) - Mg = 0, \quad \min(F_s) \end{cases} \quad (1)$$

subject to

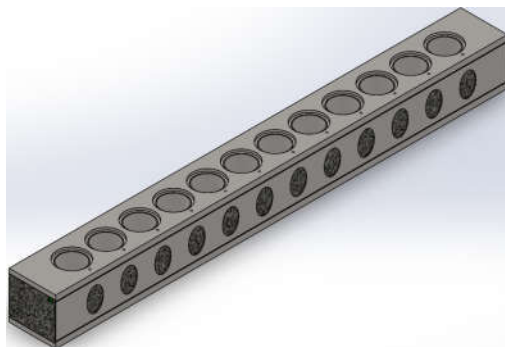
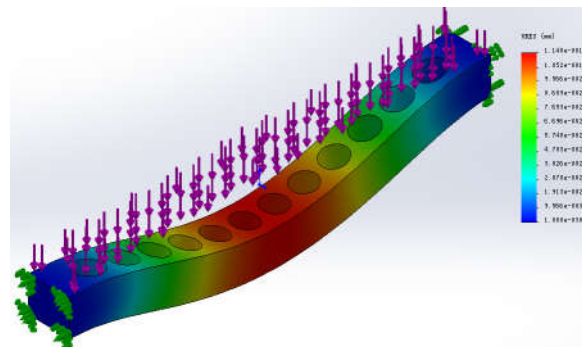
$$\begin{cases} \Delta x > H \\ |k(\Delta x - H) - Mg| \leq F_s \\ |k(\Delta x - H) - Mg + pS_h| \leq F_s \end{cases} \quad (2)$$

where:  $k$  is the spring stiffness,  $\Delta x$  is the initial maximum compression of the spring,  $M$  is the total mass of the polishing head, the principal axis, the long shaft, the motor I and other auxiliary parts,  $F_s$  is the force acting on the screw pair between the gear II and the long shaft,  $H$  is the total length of the thread of the long shaft,  $p$  and  $S_h$  are, respectively, the pressure and action area of the polishing head acting on the slate,  $g$  is the acceleration of gravity.

**Figure 5.** Cross-section of the power polishing head.**Figure 6.** Locking mechanism details.

### 2.3. Crossbeam

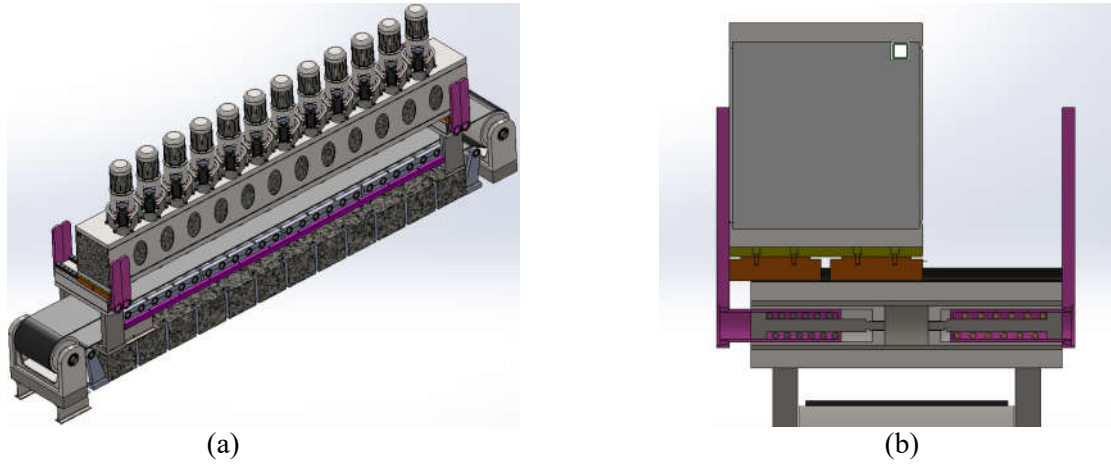
The crossbeam is also a part of a mixed structure of stone and steel, shown as in figure 7. The epoxy resin adhesive is also the connection medium of the steel and the stone. Welding is used between the upper and lower steel plate and the side plate. Under the gravity of its own and total 12 power polishing heads, the maximum deformation of the crossbeam is about 0.115 mm, as shown in figure 8.

**Figure 7.** Structure of crossbeam.**Figure 8.** Maximum deformation of crossbeam.

## 3. Dynamic simulation of crossbeam movement

As all power polishing heads are mounted on the crossbeam, they are swinging laterally during grinding. In the process of the reciprocating movement, the acceleration will change greatly. This is an

important basis for calculating the parameters of the driving mechanism. Because the inertia of the crossbeam is very large, the barrier brake mechanism is added on the basis of the original structure of the crossbeam, as shown in figure 9(a).



**Figure 9.** Barrier brake mechanism.

In this paper, in order to obtain the output torque required for the driving mechanism, a computational simulation model is established according to the actual structure. The crossbeam begins to decelerate after contact with the baffle and its speed drops to 0 when the location is shown in figure 9(b), and then they start the reverse acceleration. For this deceleration and reverse acceleration process, the velocity of the crossbeam is designed as cosine curve and can be expressed by:

$$v(t) = v_{\max} \cos \omega t, \quad t \in [0, T] \quad (3)$$

where:  $v_{\max}$  is the main parameter of the crossbeam, that is, the maximum motion velocity,  $\omega$  is the angular frequency to be determined,  $T$  is the total time of the deceleration and reverse acceleration process,  $T = 2\pi/\omega$ .

The maximum compression of the spring of the barrier brake mechanism is the braking distance of the crossbeam, which depends on the distance that the centre of the polishing head is beyond the slate. We can get the equation

$$d_{\text{bk}} = \int_0^{T/4} v_{\max} \cos \omega t dt \quad (4)$$

where  $d_{\text{bk}}$  is the braking distance of the crossbeam.

In this paper,  $d_{\text{bk}} = 0.07$  m and  $v_{\max} = 1$  m/s. Solving the Eq. (4),  $\omega = 14.2857$ . Hence, the crossbeam swings from the middle position with  $v_{\max}$  as the initial velocity, the velocity curve of a complete cycle can be obtained, as shown in figure 10.

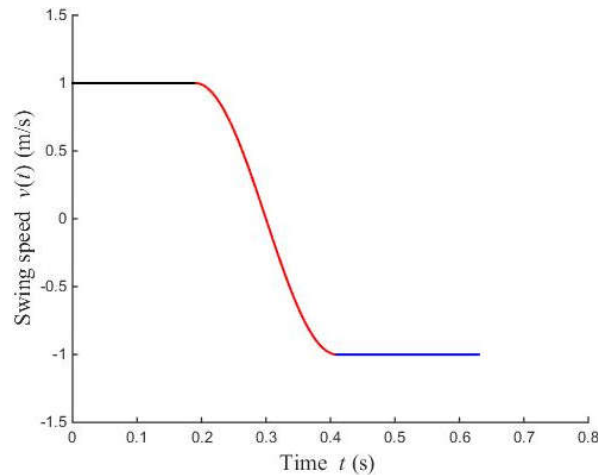
When the crossbeam contacts with the baffle, the output torque of the drive motor changes the direction in a moment. For the process of the deceleration and reverse acceleration, neglecting all frictions, the following equation can be obtained:

$$\begin{cases} T_q = F_t r \\ 2F_r + 4k_{\text{bk}}s + f = M\ddot{s}, \quad t \in \left[0, \frac{T}{2}\right] \\ s = \int_0^t v_{\max} \cos \omega t dt \end{cases} \quad (5)$$

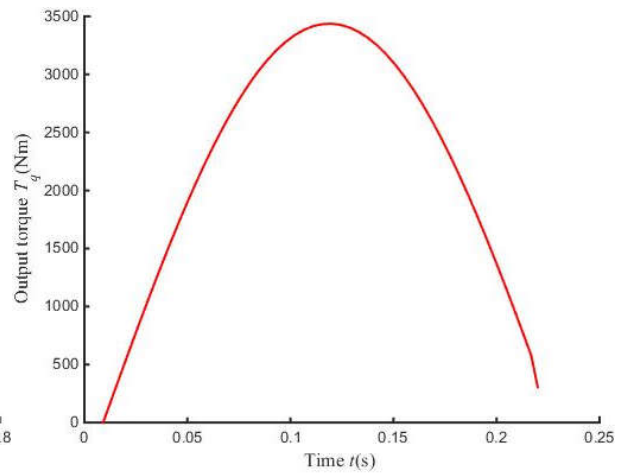
where:  $T_q$  is the output torque of the drive motor,  $F_t$  is the driving force acting on the crossbeam,  $r$  is the radius of the gear in the gear and rack meshing pair,  $k_{\text{bk}}$  is spring stiffness of the barrier brake mechanism,  $s$  is the displacement from the beginning to the stop,  $f$  is the friction force of slide rail.



MATLAB software is often used in the process analysis by using motion equations [7-12]. According to the eq. (5),  $F_t$  and  $T_q$  can be obtained by using MATLAB/SIMULINK software. The known parameters are shown in table 2. The curve of  $T_q$  is shown in figure 11, for the process of the deceleration and reverse acceleration, which is an important basis for selecting the drive motor.



**Figure 10.** Swing speed of crossbeam.



**Figure 11.** Output torque of the drive motor.

**Table 2.** Known parameters.

| Parameters | Values      |
|------------|-------------|
| $r$        | 150 mm      |
| $k_{bk}$   | 500,000 N/m |
| $f$        | 130 N       |
| $M$        | 13,000 kg   |

#### 4. Conclusions

A new slate grinding machine based on green design is described and studied. China is rich in natural stone resources, especially large stones, and China also has advanced stone processing technologies. All these provide basic conditions for the design of slate grinding machine with mixed structure of stone and steel. The three key structures of the machine are introduced and analyzed. Due to the large inertia of the crossbeam, the method of adopting the buffer brake mechanism is given in this paper, and the movement process of the crossbeam is analyzed. For a given ideal crossbeam swing speed, the required output torque of the driving motor is obtained, which is the most important parameter of the dynamic device of the crossbeam movement.

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