Stacking Technology for Motor Core Laminations in Punching Dies

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For the mass production of motor iron cores, punching electrical steel (ES) in a progressive die is the most efficient method. However, except for interlocked ones, most of the core sheets are collected manually, which is labor-intensive and time-consuming. In this study, an ES Buffering and Stacking System (ES BASS) has been developed for the final blanking station of the punching die. This system includes a buffering device, a collecting jig, a rotating and lifting platform, and a jig transporting chain. It collects, counts, and shapes the laminates and orients of the core sheets in a jig for lamination. The buffering device can temporarily store the core sheets without stopping the punching press, allowing the filled jig to be transitioned or rotated for strip thickness compensation. Based on tests conducted on the simulation platform, the system can collect and stack laminations over 100 mm in height and buffer the core sheets at a punching speed of more than 300 SPM (strokes per minute).

Keywords: Motor iron core, Stacking, Buffering, Lamination, Thickness compensation

1. INTRODUCTION

To reduce eddy current loss, iron cores are often made from electrical steel sheets coated with insulation on both sides. Depending on the application, energy efficiency requirements, operating speed, and slot design, there are various methods for combining these sheets into cores, such as riveting, interlocking, and welding. However, these methods can cause mechanical or thermal damage to the steel substrate, leading to residual stress that increases iron loss. Additionally, interlayer short circuits at the joints further increase eddy current losses. Riveting and interlocking can also disrupt the flux paths, causing uneven magnetic flux distribution and easier saturation. These traditional stacking methods, though essential for sheet combination, compromise motor efficiency.

Additionally, to further reduce eddy current loss, the thickness of the sheets has been continuously decreased, weakening the bonding strength between the interlocked sheets. In response, CSC has developed a self-bonding coating (C3S1) applied on electrical steel (SCES) to connect the sheets firmly without breakage, completely retain the ES magnetic properties, and further improve the noise, vibration, and harshness (NVH) performance of the motor.

Punching electrical steel (ES) in a progressive die is the most efficient method for mass-producing motor iron cores. In the press die, the ES strip is continuously transferred and processed at multiple stations according to the designed poles and slots of the motor. At the final station, the core sheet is blanked and detached from the strip. For the most common interlocked cores, sheets are positioned and combined/separated into a stack through the interference/noninterference of interlock joints at the final station.

However, for non-interlocked iron core sheets, the process typically involves collecting, counting, and shaping (laminating and orienting) off-line sequentially and manually into a jig, followed by post-processing steps such as welding or bonding (including SCES) to combine them into a stack. This process is both labor-intensive and time-consuming.

To improve mass production capacity, a system has been developed for the final blanking station. This system includes counting and collecting core sheets, as well as transporting collecting jigs to meet these requirements. In addition, sudden stops of the punching press are avoided to maintain dynamic stability and reduce clutch wear. To address this, a buffering device has been built to temporarily store the core sheets without stopping the punching press, allowing the filled jig to change or rotate for strip thickness compensation.

2. EXPERIMENTAL METHOD

The ES BASS simulation platform consists of four primary components designed, to continuously stack the core sheets at the blanking station of the punching die. Specifically, the structure of the ES BASS can be visualized as comprising feeding, buffering, and collecting modules, which include lifting, compensating, and transporting functions, as shown in Figure 1.

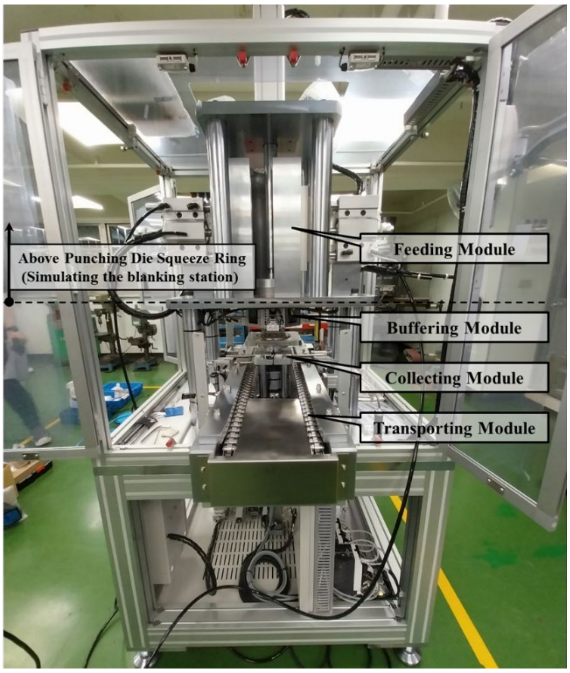

Fig.1. ES BASS.

2.1 Feeding Module

As shown in Figure 2, the feeding module primarily consists of three components (listed from top to bottom):

2.1.1 Storage Tube:

The inner diameter (ID) of the storage tube is designed to provide positioning features to simulate punch blanking behavior (Figure 3).

2.1.2 Pushing Piston:

The pushing piston is actuated by the top servo cylinder and a squeeze ring that is 0.1 mm smaller than the rotor OD.

2.1.3 Squeeze Ring:

The ID of the squeeze ring is 0.1 mm smaller than the rotor's OD. This design allows the squeeze ring to hold the stored sheets above it and release them piece by piece with the same orientation when pushed by the piston to simulate blanking at the final punching station in the press.

2.2 Buffering Module

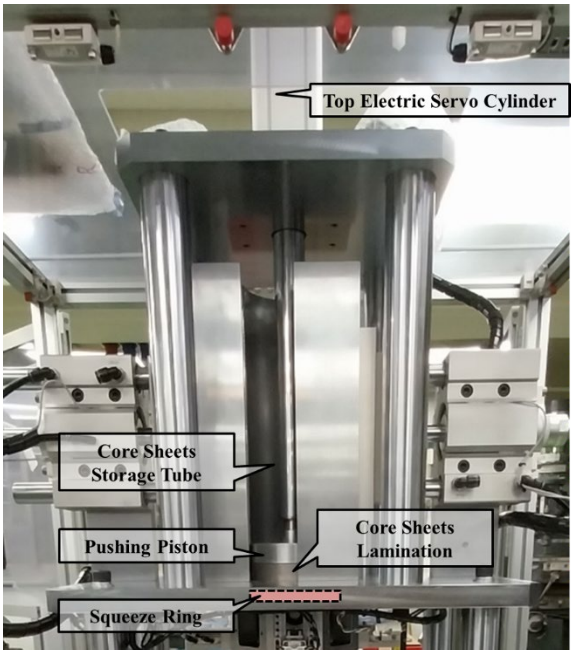

Fig.2. Feeding Module.

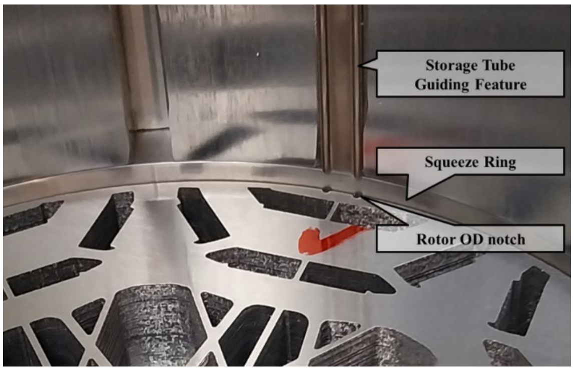

Fig.3. Rotor OD notch and the corresponding storage tube guiding feature.

As shown in Figure 4, the main structure of the buffering module is designed to be octagonal, in accordance with the rotor's symmetry. It consists of a magnetically permeable tube made of S45C, with an inner diameter (ID) slightly larger than the rotor's outer diameter (OD). The module includes a digital fiber optic sensor and two types of actuators: an electromagnet and a pneumatic cylinder.

2.2.1 Digital Fibre Optic Sensor:

The reflective type sensor is installed above the actuators to count the number of core sheets released from the squeeze ring. This optical sensor operates by detecting reflected light from the circumferential edge of the core sheets. If the intensity of the reflected light exceeds a predetermined threshold, the sensor triggers the actuators to buffer the core sheets.

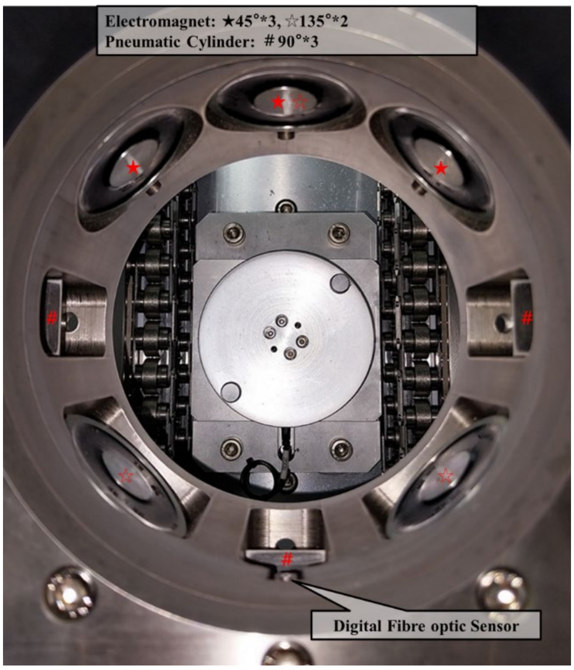

Fig.4. Buffering module (Top View).

2.2.2 Electromagnet:

Five electromagnets, arranged in two sets, are installed with an interference fit inside the tube, positioned according to the rotor symmetry. The electromagnets create a magnetically induced friction force to decelerate and suspend the core sheets released from the squeeze ring.

(1)Set 1: Positioned at 45° angular intervals, this set provides more supporting friction force due to less clearance, which is inversely proportional to the square of the magnetic force. However, it offers less levelness compared to Set 2 due to the cantilever effect.

(2)Set 2: Positioned at 135° angular intervals, this set behaves as the opposite of the above, offering less friction force but better levelness.

Employing both sets of electromagnets offers a synergistic advantage. In comparison with the pneumatic cylinder, sheets will never be impacted in their radial direction. Additionally, the axial rotation angle of the core sheets is no longer random due to the reluctance force, allowing for thickness compensation through rotation.

2.2.3 Pneumatic Cylinder:

The pneumatic actuator is installed below the magnet at the remaining rotor pole positions in the radial direction, spaced at 90° angular intervals, to ensure rotor sheets are blocked in case of insufficient magnetic force.

2.3 Collecting Module

As shown in Figure 5, the collecting module primarily consists of three components listed from top to bottom:

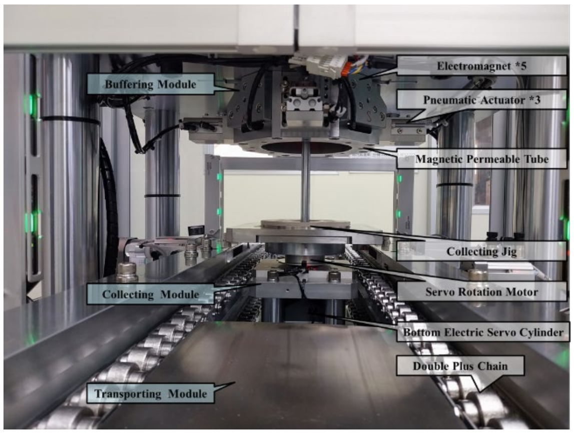

Fig.5. Collecting Module.

2.3.1 Collecting Jig:

The jig includes two tapered pilot pillars positioned vertically on the jig plate. The OD of the pilot pillars is approximately 0.03 mm smaller than the slots, allowing them to fit the rotor's features. Additionally, four tapered notches at the bottom of the jig plate match the dowel pins on the plate set on the servo motor shaft.

2.3.2 Rotation Motor:

The servo motor rotates at specific angles and frequencies that match the rotor's symmetry. This compensates for differences in lamination height caused by the thickness variation of the ES strip. For example, an 8-pole rotor with a height of 240 mm rotates 45° for every 30 mm of lamination height in the stack.

2.3.3 Bottom Electric Servo Cylinder:

This component supports the above mechanisms. It periodically lifts the jig to collect the sheets coming from the buffering module and then lowers the jig onto the transportation module for exchange.

2.4 Transporting Module

The double plus chain, powered by a motor, transports the jigs approximately 1.5 times faster than a standard chain, thereby reducing the time required for jig exchange. This increased speed decreases the number of stored core sheets, allowing the buffering module to be minimized while maintaining the same punching speed. Additionally, pins or stoppers help position the jig accurately.

3. RESULTS AND DISCUSSION

The height of the rotor core ranges up to 100 mm by stacking approximately 400 sheets of 25CS1250HF ES, as shown in Figure 6. The electromagnet in the buffering module can securely store more than 25 pieces of core sheets released from the squeeze ring. The maximum estimated time required for a jig exchange is approximately 5 seconds. In other words, the buffering module can handle a punching speed of more than 300 SPM, which is equivalent to 5 pieces per second. The stack is rotated 180° 8 times for compensation, taking 1 second per rotation. Furthermore, the buffered core sheets roughly align with their slots in orientation due to the reluctance force, as shown in Figure 7.

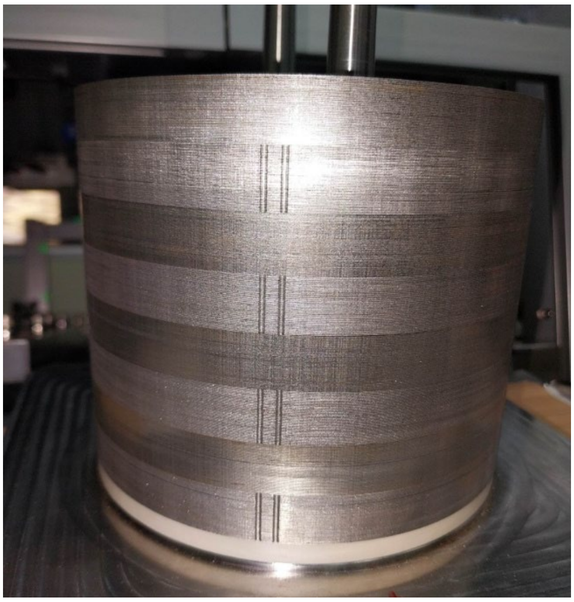

Fig.6. A rotor core comprises 400 sheets of 25CS1250HF ES.

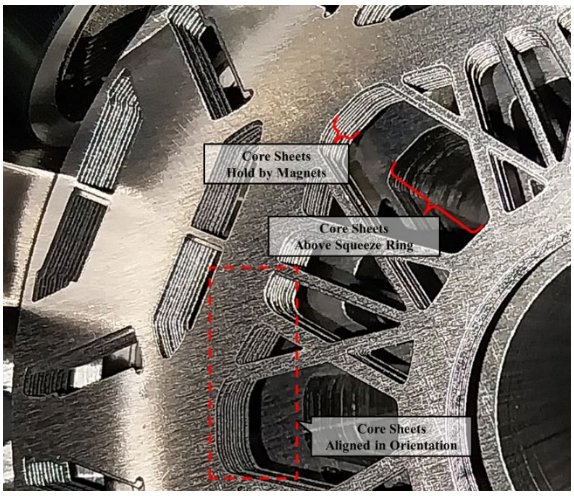

Fig.7. Buffered core sheets aligned in orientation. (Bottom View)

4. CONCLUSIONS

This study successfully developed the ES BASS, which is applicable to the punching die for motor rotor iron core laminations. Experiments conducted on the simulation platform demonstrated that this system can store the core sheets during jig exchanges, allowing the press to operate without interruption and enables a punching speed of over 300 SPM. The system has been verified to collect ES sheets over 100 mm thick and provides functions such as counting, stacking, shaping, and thickness compensation for laminations. With design changes to the buffer module, collecting jig, and adjustment to the collection mode , there will be opportunities to accommodate different stacking shapes (such as skew shape) and types (such as T-segment type) of iron cores in the future.

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