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Pulsed magnet design and fabrication for generating background magnetic field in pulse current driven forming

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I. Introduction

- In the electromagnetic forming for metal sheets, the pulse current driven forming (PCDF) shown in Fig. 1 does not need a forming coil, and solves the problem that the induced current of low conductivity materials is too small. PCDF now is mostly used for forming narrow sheets with less than 10 mm width, but for the sheets with large width, the low current density causes the formability is poor. Therefore, it is proposed to add an external magnetic field called the background magnetic field (BGMF) in the PCDF process to increase the electromagnetic force. Aiming at the PCDF process for AA1060 aluminum sheets with 100 mm width, this paper designed a pulsed magnet to provide the BGMF with high uniformity and strength.

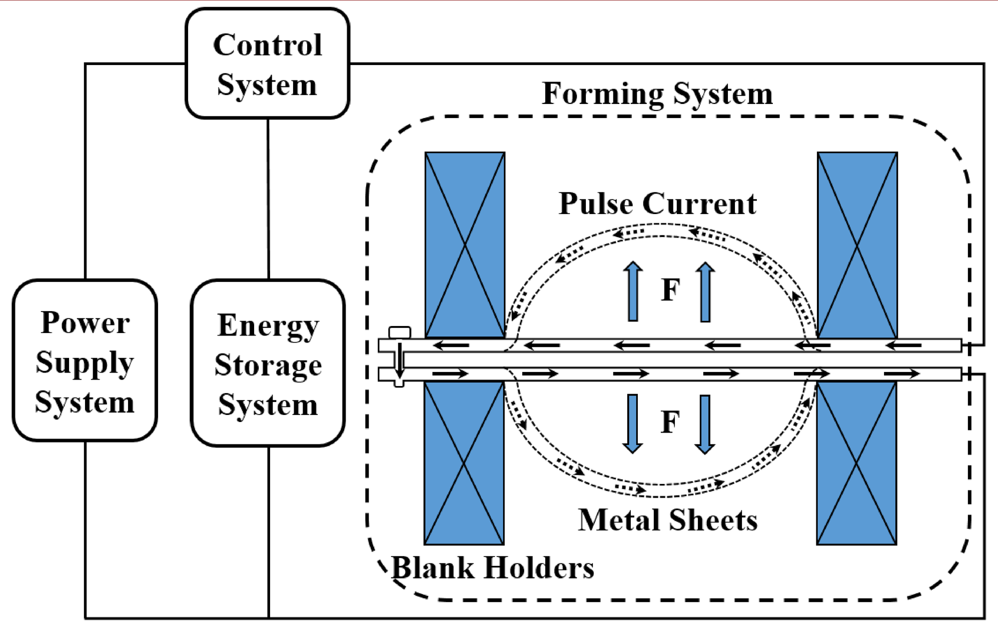

Fig. 1. Diagram of pulse current drive forming system.

II. Magnet Design and Fabrication

- A conventional solenoid coil is selected as the coil shape of the magnet. The BGMF is designed to have a magnetic field strength of 3 T and a uniformity of 95% in a cylindrical forming region with 100 mm length and 50 mm radius. The uniformity of the magnetic field is λ, and defined as:

$$\lambda = \left(1 - \frac{B_{max} - B_{min}}{B_0}\right) \times 100\% \qquad (1)$$

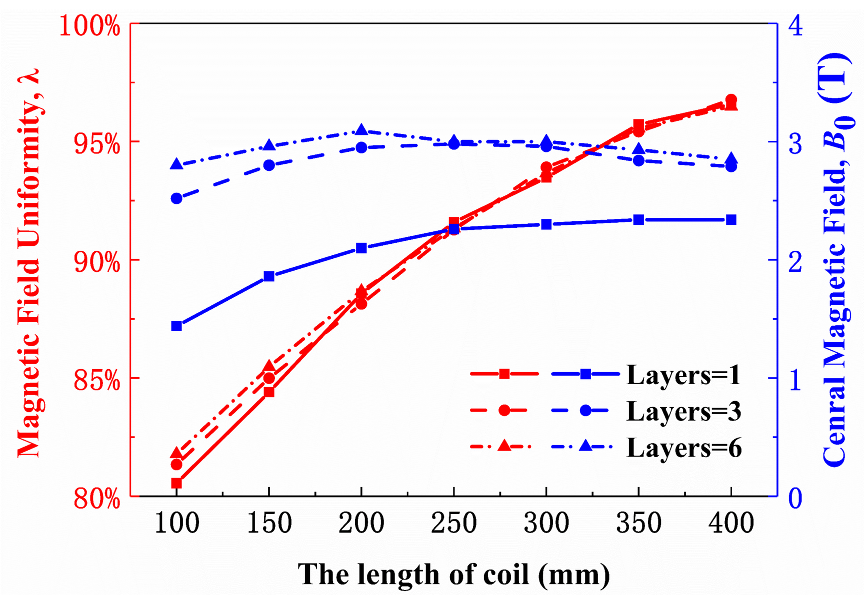

Fig. 2. Variation of λ and B_0 under coil lengths and layers.

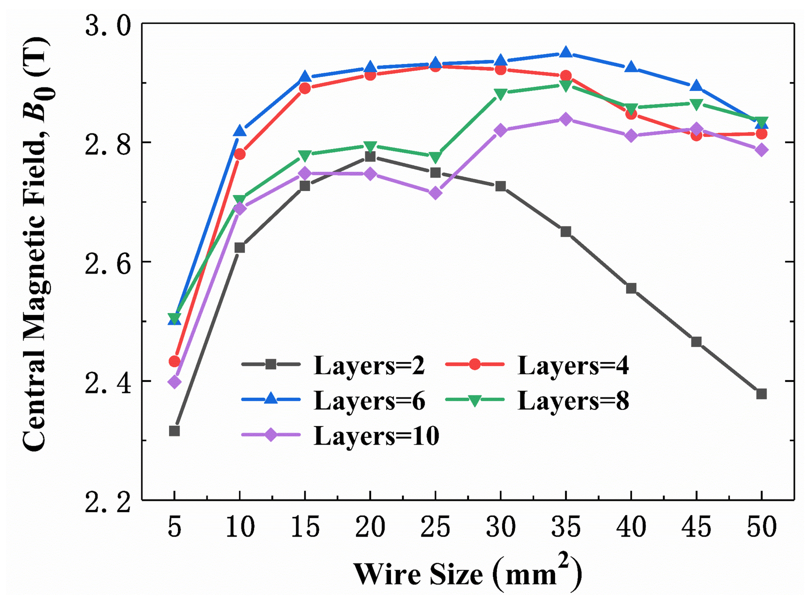

Fig. 3. Variation of B_0 under wire sizes and layers.

- The variations of B_0 and λ obtained by optimizing parameters such as coil length, wire size and turns are shown in Fig. 2 and Fig. 3. The optimal solution is a length of 350 mm, a wire size of 35 mm², and layers of 6.
- The strength and insulation of the magnet is increased by winding Zylon reinforcement between each layer. The simulation results show that the maximum stress in magnet is 90 MPa, and the temperature rises 1.2 K by discharging once. The final design of the magnet is shown in Fig. 5.
- The magnet was completed as shown in Fig. 6 by using the manufacturing technique of pulsed magnets.

Table I
Electrical parameters of the magnet

Parameters	Values
B_0	2.79 T
λ	95.63%
Peak current	3.8 kA
Peak time	12.2 ms
Pulse width	160 ms

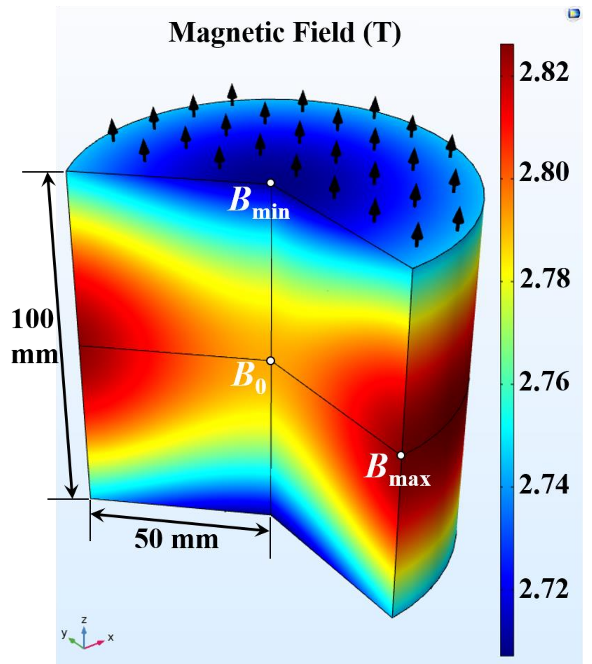

Fig. 4. Magnetic field in the forming region.

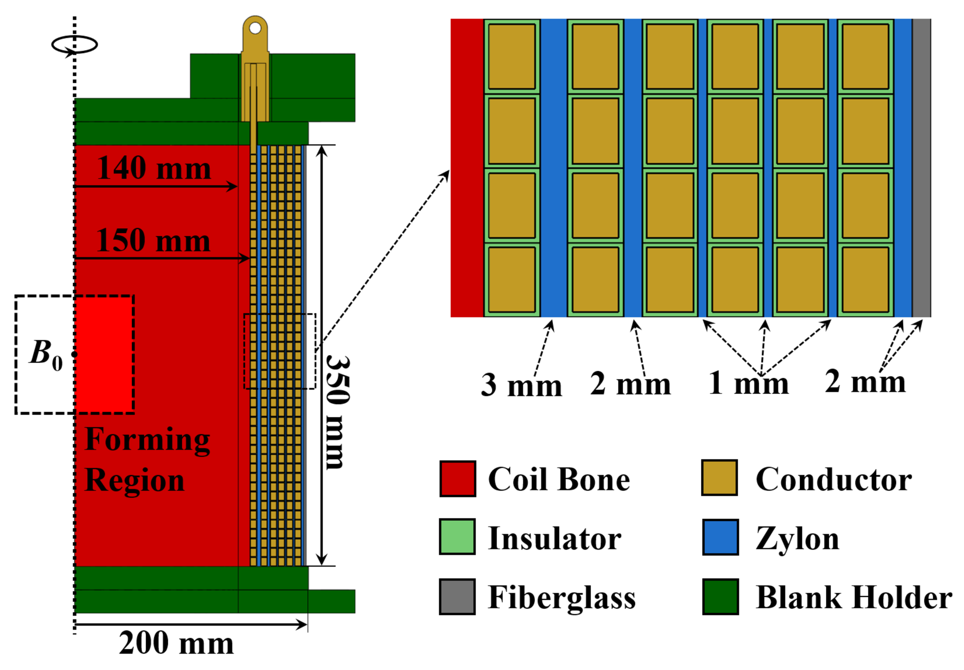

Fig. 5. Structure diagram of the magnet.

Fig. 6. Photograph of the magnet.

III. Experiments and Results

- The magnetic field at three specific points in the forming region measured by the magnetic field probe is shown in Fig. 7, and compared with the simulation results. The measured B_0 is mostly the same as the simulation. The λ calculated by (1) is slightly reduced, probably due to inaccurate probe positioning. Therefore, the performance of the magnet mostly conforms to the design requirements.

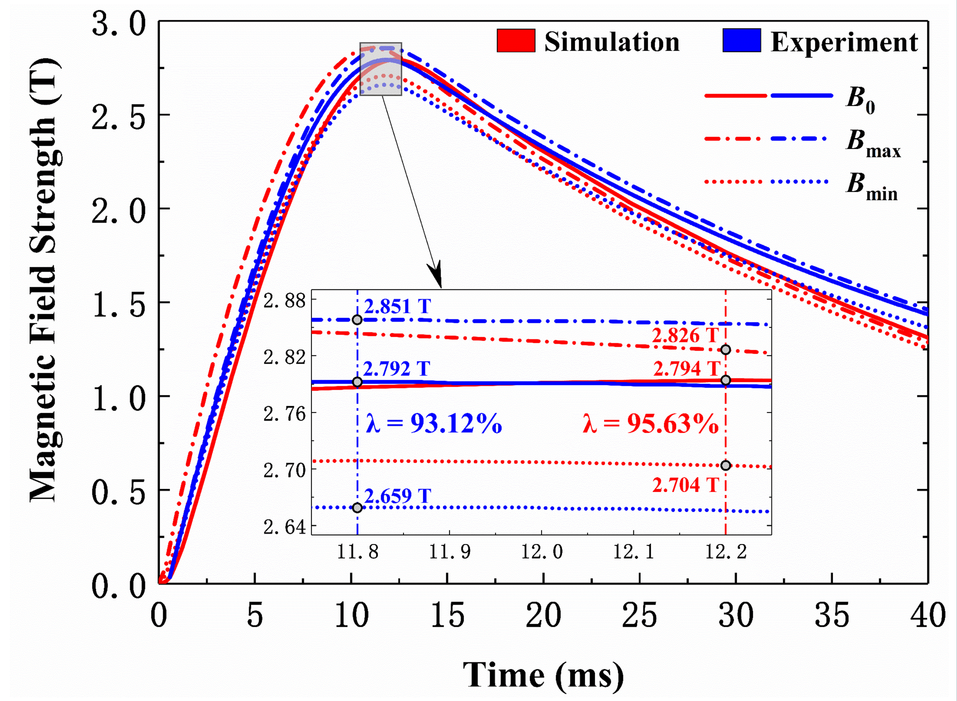

Fig. 7. The simulation and experimental results of the magnetic field. The positions of B_0, B_{max} and B_{min} are shown in Fig. 4.

- As shown in Fig. 8, the PCDF device is designed and placed in the middle of the magnet, and the direction of the pulse current is kept perpendicular to that of the BGMF. The size of the sheet is 190×100×0.5 mm³, and the forming die is an open slot with 65 mm width. It is necessary to flow the current to the sheet when the BGMF reaches the maximum. Therefore, the time delay of the sheet current is 11.75 ms compared with the magnet current, as shown in Fig. 9.
- The forming results are shown in Fig. 10. For each sheet in Fig. 10 (a), the front voltage represents the voltage of the magnet circuit, and the latter represents the voltage of the sheet circuit.
- Comparing the depth and discharge voltages of S_0, S_1 and S_3, it can be known that the BGMF can increase the formability of the sheet by 3 times. Increasing the voltage of the magnet circuit can further enhance the formability of the sheets, while the voltage of the sheet circuit cannot continue to increase because this way may damage the device of the thyristor switch in the circuit. Therefore, adding the BGMF to the PCDF has a great effect.

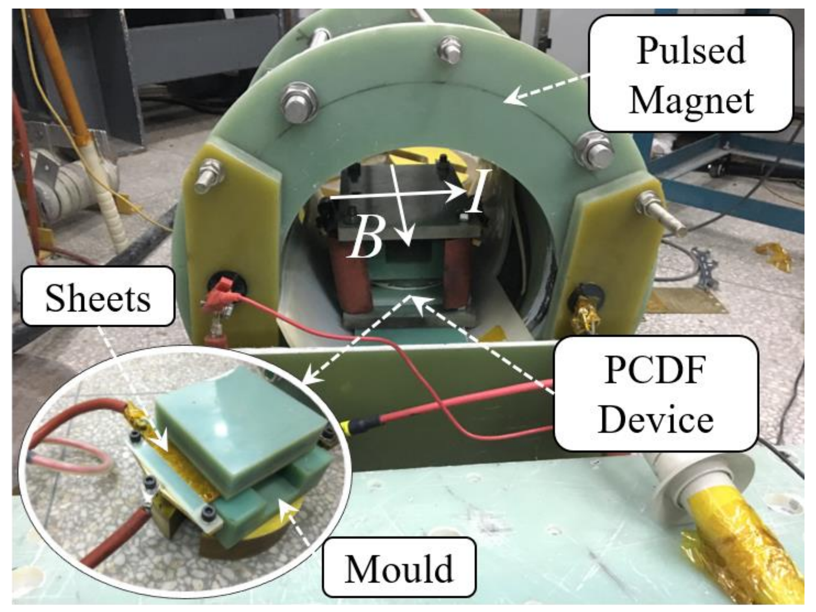

Fig. 8. Experimental devices of PCDF.

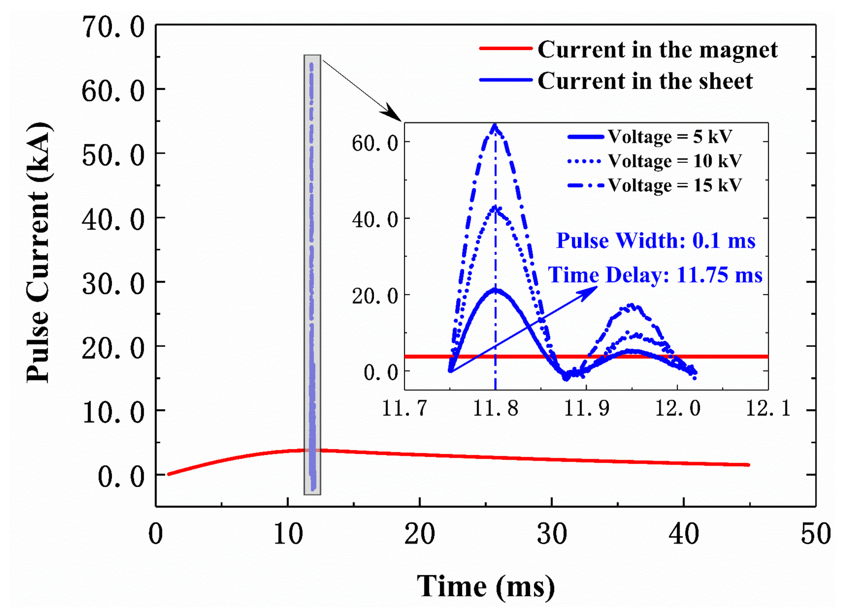

Fig. 9. Pulse current in the magnet and sheet.

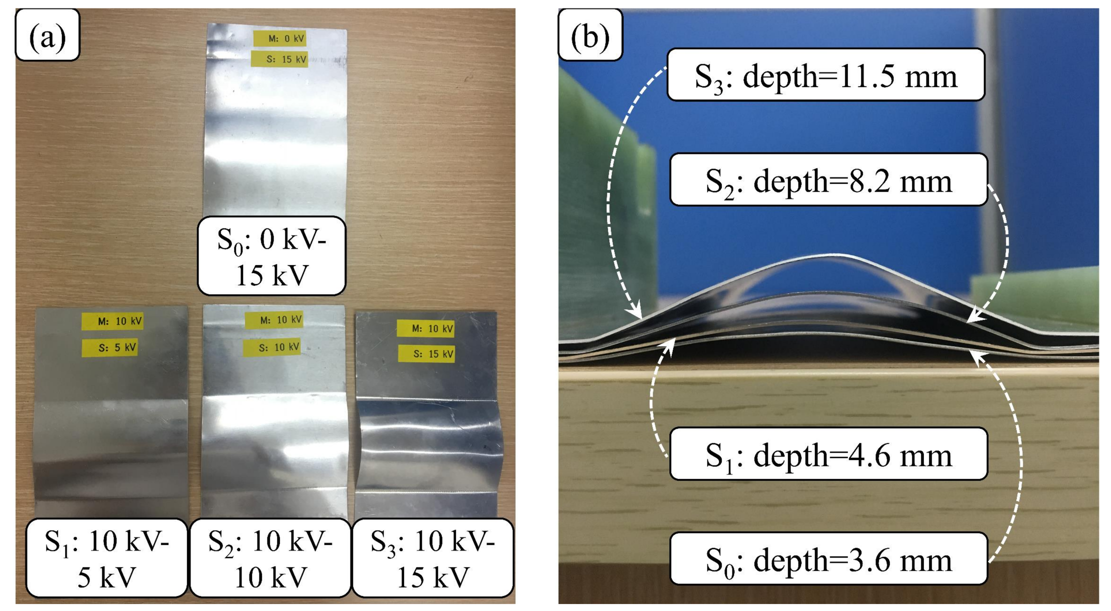

Fig. 10. Forming results. (a) Top view. (b) Side view.

IV. Conclusion

- In this work, a pulsed magnet is fabricated to provide a background magnetic field in the pulse current driven forming for metal sheets.
- Using finite element simulation by COMSOL, the magnet is designed to provide a uniform, high magnetic field during the forming process. The length parameter of the magnet is optimized such that the magnetic field uniformity of the forming region can reach more than 93%, then the wire size and turns parameters are optimized such that the magnetic field strength can reach 2.8 T.
- The experimental results show that the PCDF scheme without the BGMF has a very poor formability for the wide sheets, but it can be greatly improved by 3 times under the BGMF. Furthermore, the solution proposed in this paper can be applied to forming low conductivity materials.