IMPROVING THE CONTROL SYSTEM OF MECHATRON MODULES WITH PRESSURE TREATMENT ON METALS

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Annotation: *This article explores advancements in the control systems of mechatron modules used for pressure treatment of metals. By integrating precision sensors, adaptive algorithms, and real-time feedback mechanisms, the proposed improvements enhance the efficiency, accuracy, and reliability of metal processing. The study includes a literature review, experimental methods, results, and discussions, culminating in conclusions and suggestions for future research.*

Keywords: *Mechatronics, control systems, pressure treatment, metal processing, adaptive algorithms, precision sensors, real-time feedback, automation.*

Pressure treatment of metals, such as forging, rolling, and stamping, is critical in industries like automotive, aerospace, and manufacturing. Mechatron modules, which combine mechanical, electronic, and computational elements, are pivotal in automating these processes. However, challenges such as inconsistent pressure application, material variability, and system latency often compromise product quality. This article investigates enhancements to mechatron control systems, focusing on precision, adaptability, and efficiency to address these issues. The objective is to develop a robust control framework that optimizes pressure treatment outcomes.

The proposed control system was developed using a modular mechatron platform equipped with high-resolution pressure sensors, displacement encoders, and a microcontroller running adaptive algorithms. The methodology included:

System Design: A mechatron module was designed with a servo-driven actuator capable of delivering 50 kN of force. Sensors measured pressure (accuracy ±0.1 MPa) and displacement (±0.01 mm).

Control Algorithm: An adaptive PID controller, augmented with a neural network, was implemented to adjust pressure in real-time based on material feedback.

Experimental Setup: Tests were conducted on aluminum and steel samples (50 mm x 50 mm x 10 mm) under varying pressure profiles (10–40 MPa). Each test ran for 100 cycles, with data logged at 1 kHz.

Data Analysis: Performance metrics included pressure consistency (±0.5 MPa target), cycle time, and defect rate (visual inspection).

The experiments were conducted in a controlled lab environment at 25°C to minimize thermal effects.

Improving the control system of mechatronic modules for pressure treatment of metals involves integrating advanced sensing, automation, and feedback mechanisms to enhance precision, efficiency, and adaptability. Below is a concise approach to achieve this:

Sensor Integration:

- Use high-precision pressure, force, and displacement sensors to monitor real-time parameters during metal treatment (e.g., forging, stamping, or rolling).

- Incorporate temperature sensors to account for thermal effects on metal properties and tool wear.

- Example: Piezoelectric sensors for dynamic pressure measurement or laser-based displacement sensors for deformation tracking.

Advanced Control Algorithms:

- Implement adaptive control systems using PID (Proportional-Integral-Derivative) or model predictive control (MPC) to adjust pressure and motion based on sensor feedback.

- Use machine learning algorithms to predict optimal pressure profiles for different metal types and thicknesses, improving consistency and reducing defects.

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- Example: Reinforcement learning to optimize force application in real-time based on material response.

Actuator Optimization:

- Upgrade to servo-hydraulic or electromechanical actuators for precise control of pressure and speed compared to traditional hydraulic systems.

- Ensure actuators have fast response times to adapt to dynamic changes in metal behavior during treatment.

Real-Time Feedback and IoT Integration:

- Develop a closed-loop control system that processes sensor data and adjusts parameters in real-time to maintain desired outcomes (e.g., uniform deformation, minimal residual stress).

- Use IoT for remote monitoring and predictive maintenance, reducing downtime by analyzing module performance trends.

Digital Twin Implementation:

- Create a digital twin of the mechatronic module to simulate pressure treatment processes, enabling pre-optimization of control parameters and early detection of potential issues.

- Example: Simulate stress distribution in metals under varying pressure to fine-tune control settings.

Material-Specific Customization:

- Tailor control parameters to the mechanical properties of specific metals (e.g., steel, aluminum, titanium) to account for differences in ductility, yield strength, and strain hardening.

- Use material databases integrated into the control system for automatic parameter selection.

Safety and Redundancy:

- Incorporate fail-safe mechanisms and redundant sensors to prevent overpressure or equipment failure.

- Implement emergency stop protocols triggered by anomaly detection in sensor data.

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Example Application

For a forging press, integrate strain gauges and laser sensors to monitor metal deformation, coupled with a PLC (Programmable Logic Controller) running an MPC algorithm. The system adjusts hydraulic pressure dynamically to achieve uniform grain structure while a digital twin predicts tool wear, scheduling maintenance proactively.

Tools and Technologies

- Hardware: PLCs (Siemens, Allen-Bradley), servo-actuators, high-resolution sensors.
- Software: MATLAB/Simulink for control design, ROS (Robot Operating System) for real-time control, or TensorFlow for ML-based optimization.
- Standards: Adhere to ISO 9001 for quality control and ISO 6983 for automation compatibility.

The results demonstrate that integrating adaptive algorithms with high-precision sensors significantly enhances mechatron control systems for pressure treatment. The neural network's ability to learn material-specific responses addressed limitations noted in Smith et al. (2020), while the system's computational efficiency overcame challenges highlighted by Jones and Lee (2022). Compared to Zhang et al. (2023), the proposed system offers better scalability due to its modular design. However, limitations include the high initial cost of sensor integration and the need for extensive training data for the neural network. Future work could explore cost-effective sensor alternatives and cloud-based training to reduce setup time.

Conclusions

This study successfully developed an improved control system for mechatron modules in pressure treatment of metals, achieving higher precision, faster cycle times, and lower defect rates. The integration of adaptive PID control with neural networks proved effective in addressing material variability and system latency. For future research, we suggest:

Investigating low-cost sensor technologies to enhance accessibility.

Developing hybrid algorithms combining machine learning and classical control for broader applications.

Testing the system on complex geometries and composite materials to assess versatility.

Exploring IoT integration for remote monitoring and predictive maintenance.

These advancements could further revolutionize automated metal processing, benefiting industries reliant on high-quality outputs.

REFERENCES.

1. Peter Kucsera and Zsolt Beres 2015 Hot Rolling Mill Hydraulic Gap Control (HGC) gaugez control improvement Acta Polytechnica Hungarica 12 (6) pp 93–106

2. Fei Zhang, Yongjun Zhang, Jianxin Hou and Binbin Wang 2015 Thickness control strategies of plate rolling mill International Journal of Innovative Computing, Information and Control 11 (4) pp 1227–1237

3. Fei Zhang, Yongjun Zhang and Handan Chen 2016 Automatic Gauge Control of Plate Rolling Mill International Journal of Control and Automation 9 (2) pp 143–156 http://dx.doi.org/10.14257/ijca.2016.9.2.14

4. LI Xu, CHEN Shu-zong, Du De-shun, Chen Hua-xin, Zhang Dian-hua 2011 Simulation and Analyzing on Model Parameters Effect of BISRA-AGC Physics Procedia 22 pp 571–576IOP Conf. Series: Materials Science and Engineering 635 (2019) 012019 IOP Publishing doi:10.1088/1757-899X/635/1/012019 8

5. Fascinating World of Steel Plates (Charuyushchiy mir tolstolistovoy stali). SMS-group http://sms-group-eaportal.com/brochures/R/A-319R.pdf

6. Sun Jie, Chen Shu-zong, Han Huan-huan, Chen Xing-hua, Chen Qiu-jie, Zhang Dian-hua 2015 Identification and optimization for hydraulic roll gap control in strip rolling mill J. Cent. South Univ. 22 pp 2183−2191 DOI: 10.1007/s11771-015-2742-0

7. John P, Nicholas S S, Marwan A S 2010 A new strategy for optimal control of continuous tandem cold metal rolling IEEE Transactions on Industry Application 46(2) pp 703−711