

Design and Experimental Evaluation of a Pneumatic Magnetic Gripper with Vision-Based Inspection for Robotic Pick-and-Place Applications

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Abstract - Automation of repetitive material-handling operations is essential for improving productivity, precision, consistency, and workplace safety in modern manufacturing. This research presents the design and development of a robotic pick-and-place system integrated with a pneumatic magnetic gripper and vision sensor for automated handling, processing, and inspection of ferromagnetic metallic disc components. The developed system incorporates a six-axis robotic arm, pneumatic actuation, magnetic gripping, and vision-based inspection. The magnetic gripper enables reliable handling of metallic discs, while pneumatic actuation provides controlled approach and retraction. A 5/2 double-solenoid valve controls the pneumatic operation at an air pressure of approximately 4–5 bar. The automated sequence includes component loading using a pneumatic cylinder and vacuum pad, robotic transfer to a first press for center punching, transfer to a second press for peripheral punching, and movement to an unloading station. The developed system integrates material handling, manufacturing operations, robotic motion, pneumatic actuation, sensing, and quality inspection into a coordinated automated process, demonstrating the potential of magnetic gripping and vision-based inspection for reliable and efficient industrial automation.

Key Words: Robotic Automation, Magnetic Gripper, Pick and Place, Pneumatic Actuation, Vision Inspection, Material Handling.,

1. INTRODUCTION

In modern manufacturing and industrial automation, efficient handling of components is essential for improving productivity, safety, accuracy, repeatability, and overall process efficiency. Robotic manipulators equipped with suitable end-effectors are widely employed for pick-and-place, assembly, loading, unloading, sorting, and material-handling operations. The gripper acts as the interface between the robotic manipulator and the workpiece and therefore plays a critical role in determining the reliability, stability, and effectiveness of an automated handling system. Selection and design of an appropriate gripping mechanism depend on the material, geometry, weight, surface condition, and operational requirements of the workpiece. The gripping performance of a magnetic gripper is influenced by several design and operating parameters, including magnetic flux density, magnet size, pole geometry, air gap, workpiece material and thickness, contact area, and surface condition.

2. WORKING PRINCIPLE OF MAGNETIC GRIPPER

The magnetic gripper works on the principle of magnetic attraction between a magnet and a ferromagnetic work piece. When the robotic arm reaches the metallic disc, the pneumatic cylinder moves the gripper toward the work piece. The magnetic element generates sufficient attractive force to hold the disc securely. The cylinder then retracts, and the robotic arm transfers the component to the required processing station.

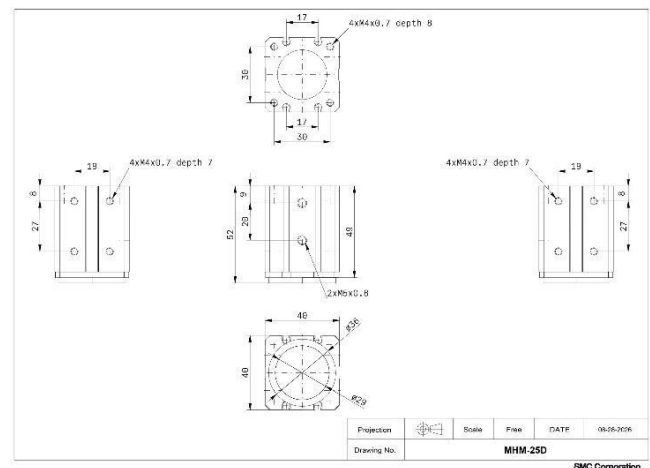


Fig -1: Schematic diagram of a Magnetic Gripper

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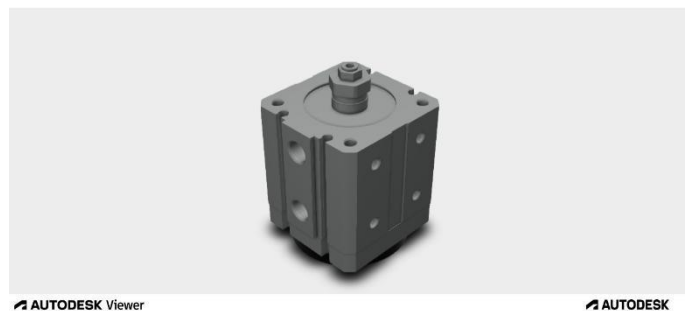


Fig -2: CAD Design of Magnetic Gripper



Fig -3: Electrical Gripper

A 5/2 double-solenoid valve controls the pneumatic cylinder at approximately 4-5 bar air pressure. After processing, the component is transferred to the unloading station, where a vision sensor inspects its dimensions and classifies it as OK or Not OK for automated segregation.

3. MAGNETIC GRIPPING TECHNOLOGY

Magnetic gripping is based on the attractive force generated between a magnetic field and a ferromagnetic workpiece. When the magnet is brought close to the metal surface, magnetic flux passes through the workpiece and a holding force is created that keeps the component attached to the gripper.

One of the major challenges in magnetic gripping is maintaining an appropriate air gap between the magnetic element and the workpiece.

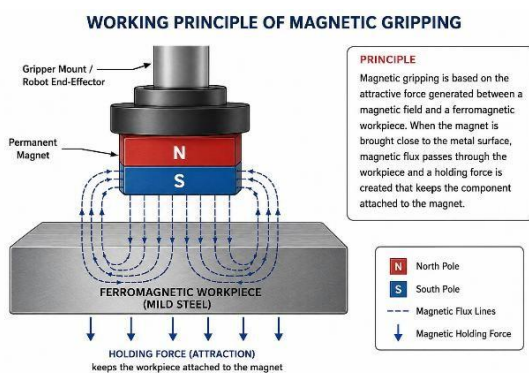


Fig -4: Working principle of the magnetic gripper.

The magnetic configuration has a direct influence on the available gripping force and the overall size and weight of the end-effector.

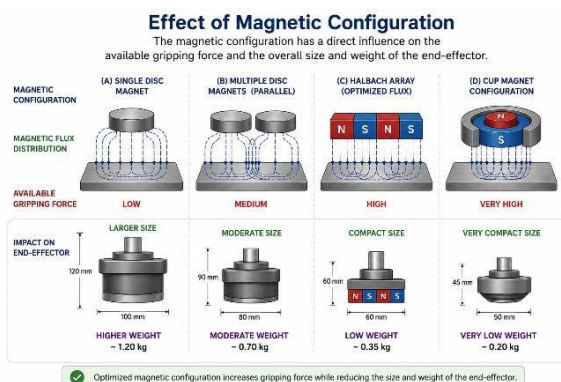


Fig -5: Comparison of different magnetic configurations showing their influence on magnetic flux distribution, available gripping force, and overall size and weight of the robotic end-effector.

Magnetic Abrasive Finishing uses magnetic fields to control abrasive particles and form a flexible abrasive brush. It can produce fine surface finishes but is often limited by material compatibility, component size, and equipment complexity.

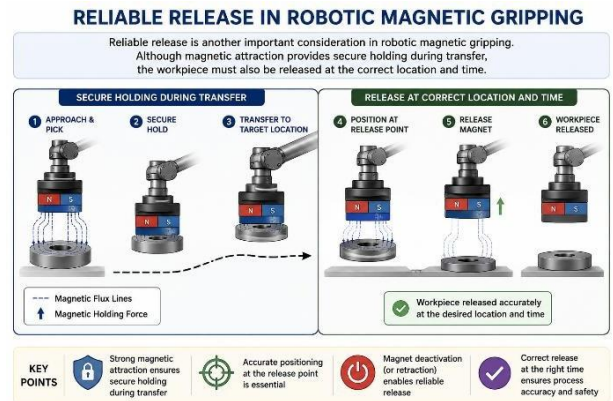


Fig -6: Reliable release of a ferromagnetic workpiece from a robotic magnetic gripper at the correct location and time.

Reliable release is another important consideration in robotic magnetic gripping. Although magnetic attraction provides secure holding during transfer, the workpiece must also be released at the correct location and time.

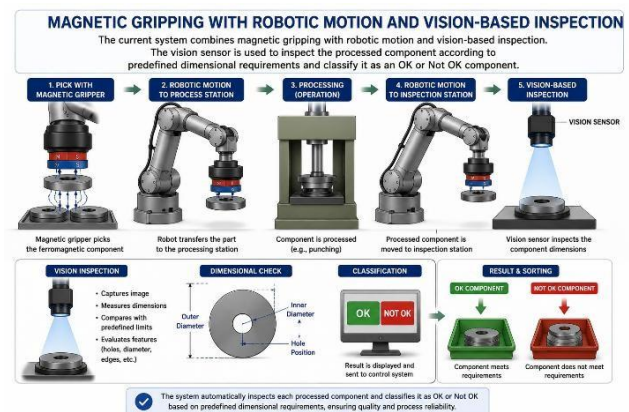


Fig -7: Integrated robotic system combining magnetic gripping, robotic material transfer, processing, and vision-based inspection for OK/Not OK component classification.

The current system combines magnetic gripping with robotic motion and vision-based inspection. The vision sensor is used to inspect the processed component according to predefined dimensional requirements and classify it as an OK or Not OK component.

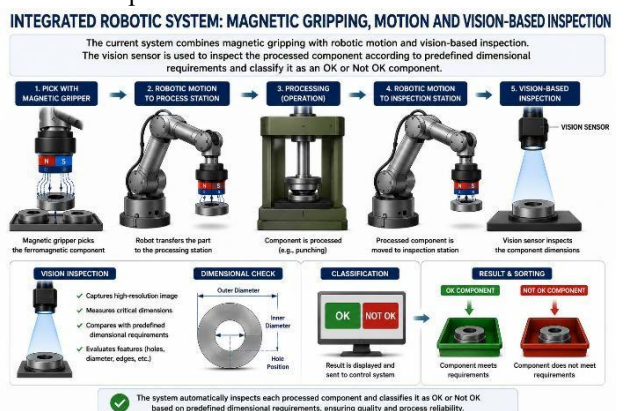


Fig -8: Integrated robotic magnetic gripping and vision-based inspection system.

Robot-assisted Future research can extend this approach by integrating additional sensing capabilities into the gripper.

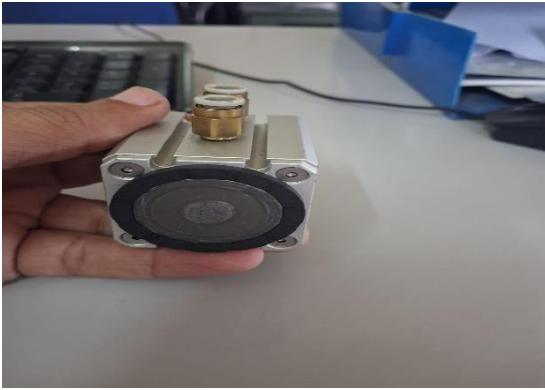


Fig -9: Pneumatic Ports for 5/2 vale on magnetic gripper

The pneumatic actuation system provides controlled movement of the magnetic element and operates at approximately 4–5 bar.

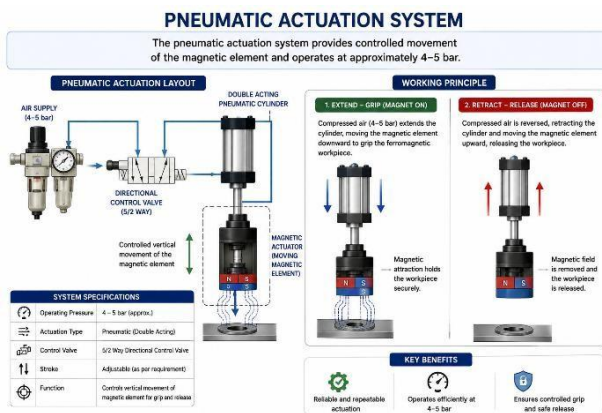


Fig -10: Robot- Pneumatic actuation system for controlled movement of the magnetic element at an operating pressure of approximately 4–5 bar.

4. CHALLENGES AND FUTURE RESEARCH

The literature identified in the thesis includes compact and lightweight magnetic-gripper designs, demonstrating the importance of payload-to-weight optimization in magnetic end-effectors. Research reviewed in the thesis on flexible and smart magnetic grippers has highlighted the potential of embedded Hall-effect and tactile sensor arrays for detecting slip and dynamically optimizing magnetic flux. Future designs may investigate improved magnetic switching mechanisms, electromagnetic excitation, or electropermanent-magnet configurations to obtain controlled gripping and release with reduced residual attraction. The literature reviewed in the thesis includes research on electropermanent magnets and controllable magnetic adhesion. Finite-element analysis (FEA) can be used in future work to investigate magnetic flux distribution and compare different magnet arrangements before fabrication. Previous research identified in the thesis has considered magnetic-force generation, permanent-magnet arrangements, finite-element analysis, fabrication, and experimental

5. CONCLUSIONS

The present research focused on the design and development of a pneumatic magnetic gripper integrated with a six-axis robotic arm for automated handling of ferromagnetic metallic disc components. The developed system combines magnetic gripping, pneumatic actuation, robotic manipulation, manufacturing operations, and vision-based inspection into a coordinated pick-and-place system. The magnetic gripper provides an effective alternative to conventional mechanical gripping mechanisms by using magnetic attraction to securely hold ferromagnetic workpieces during robotic transfer. Overall, robot-assisted abrasive polishing has considerable potential to provide repeatable, flexible, and high-quality surface finishing for precision manufacturing. Continued development of sensing, adaptive control, process modelling, and intelligent automation will be important for achieving more efficient and autonomous polishing operations. The developed magnetic gripper was successfully integrated with the robotic arm and demonstrated reliable handling of the metallic disc during lifting and transfer operations. The magnetic element provides the required holding force, while the double-acting pneumatic cylinder and 5/2 double-solenoid valve provide controlled approach and retraction of the gripping element.

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