© 2026 ADYPJIET, Volume 1(1), Online ISSN: 3049-1517, June 2026, pp. 55-66

Ajeenkya DY Patil Journal of Innovation in Engineering & Technology

Journal Homepage: https://www.adypsoe.in/adypjiet

Pneumatic Scraper Blade for CNC Laser-Bed Cleaning

[1] **Devanshu Borase,**
[2]**Rushikesh Dhumal ,**
[3]**Pratik Kadam,**
[4]**Yusuf Patwa,**
[5]**Prof Ujwal Gawai**
[1-4] UG students, Ajeenkya D Y Patil School of Engineering, Pune, INDIA
[5]Assistant Professor, E & TC Dept, Ajeenkya D Y Patil School of Engineering, INDIA

Article History:
Received: 30/04/2026
Revised: 10/05/2026
Accepted: 23/06/2026

Abstract:

CNC laser cutting machines are widely used in manufacturing industries because of their ability to produce accurate and high-quality cuts on different materials. During continuous operation, slag, metallic dust, and cutting residues accumulate on the machine bed. If these deposits are not removed regularly, they can affect machine performance, reduce cutting accuracy, and increase maintenance requirements. Most industries still rely on manual cleaning methods, which require considerable effort and expose operators to sharp metallic particles and dust. To overcome these issues, a pneumatic scraper blade system was designed and developed for cleaning CNC laser-bed surfaces. The proposed system consists of a double-acting pneumatic cylinder, a scraper blade manufactured from EN31 spring steel, a 5/2-way solenoid valve, and a supporting frame. Compressed air is used to generate the motion required for slag removal from the bed surface. A CAD model of the assembly was created and a working prototype was fabricated. Operational testing confirmed successful movement of the scraper mechanism and demonstrated the capability of the system to remove deposited slag and dust from the bed surface. The proposed design offers a simple, economical, and practical approach for reducing manual cleaning effort in CNC laser cutting operations. Further improvements may be achieved through the integration of sensors and automated control systems.

Keywords: Pneumatic Cylinder, Scraper Blade, CNC Laser Cutting, Slag Removal, Bed Cleaning, Industrial Automation.

1.0 Introduction

CNC laser cutting technology has become an important manufacturing process due to its ability to provide high precision, excellent surface finish, and high production rates. It is commonly used in industries such as automotive, aerospace, fabrication, and sheet metal processing. During laser cutting, molten metal and fine particles are generated and gradually accumulate on the machine bed. Over time, these deposits form a layer of slag and dust that can interfere with proper work piece support and affect the overall cutting process. Regular cleaning of the CNC bed is necessary to maintain machine performance and ensure safe operation. In many workshops, cleaning is carried out manually using brushes, scrapers, or compressed air. Although these methods are simple, they are time-consuming and require significant operator involvement. In addition, exposure to sharp slag particles and airborne dust may create safety concerns for workers. Automation of bed cleaning can reduce maintenance effort and improve consistency. Pneumatic systems are particularly suitable for this purpose because they are simple, reliable, cost-effective, and easy to maintain. Pneumatic actuators can generate sufficient force for cleaning applications while maintaining a compact design The present work focuses on the design and development of a pneumatic scraper blade system intended for CNC laser-bed cleaning. The system uses a double-acting pneumatic cylinder to move a scraper blade across the bed surface. The objective is to provide a practical cleaning solution that can be implemented with minimal modification to existing CNC machines.

During CNC laser cutting operations, molten metal particles, slag, and dust are continuously produced as by-products of the cutting process [1]. These materials accumulate on the bed surface and gradually form an uneven layer that can affect work piece positioning and machine operation. If cleaning is not performed regularly, the deposited material may lead to reduced cutting quality and increased maintenance requirements. Most industries depend on manual cleaning methods for removing slag from CNC beds. These methods require operator effort, consume production time, and often provide inconsistent cleaning results. Therefore, there is a need for a cleaning system that can simplify the maintenance process while reducing operator involvement and improving workplace safety. The present study focused on design and development a pneumatic scraper blade mechanism for cleaning CNC laser cutting beds [2]. The study also aims to reduce manual labour associated with bed cleaning and improve operational safety. Another objective is to provide a compact and economical system that can be installed on existing CNC machines with minimal modification. The proposed design is intended to offer reliable cleaning performance while maintaining simple construction and low maintenance requirements.

2.0 Literature Survey

2.1 CNC Laser Cutting and Slag Formation

The formation of molten metal, dross, and slag during CNC laser cutting is a well-documented phenomenon. Genna et al. [3] investigated the influence of material properties and process parameters on kerf quality and reported that improper cutting conditions contribute significantly to residue formation and surface contamination. Similarly, Wandera and Kujanpaa [4] studied melt removal mechanisms during laser cutting and concluded that thermal gradients and process parameters strongly affect dross formation. The accumulation of slag and metallic particles on CNC beds can adversely affect machining accuracy, work piece positioning, and overall process efficiency. These studies emphasize the importance of implementing effective cleaning systems to maintain machine performance.

2.2 Mechanical Cleaning Methods

Various mechanical cleaning methods have been proposed for the removal of slag and debris from industrial equipment. Easwaramoorthi et al. [5] developed an automated chain-drive slag handling and removal system for CNC gas-cutting applications. Their work demonstrated a reduction in manual cleaning effort; however, the system involved multiple moving components that increased maintenance requirements. Rhoades, investigated the performance of pneumatic scraper blades for industrial cleaning applications and reported that proper blade geometry and contact force significantly influence cleaning effectiveness. These studies indicate that while mechanical cleaning systems can improve productivity, their complexity may limit widespread adoption.

2.3 Pneumatic Systems in Automation [6]

Pneumatic systems are widely used in industrial automation because of their simple construction, reliability, and low maintenance requirements. Boyko and Weber [7] examined the energy efficiency of pneumatic actuating systems and reported that optimized air-supply control can improve actuator performance while reducing energy consumption. Pneumatic actuators are capable of generating sufficient force for repetitive industrial operations and are particularly suitable for environments where simplicity and reliability are important. These characteristics make pneumatic systems attractive for automated cleaning applications.

2.4 Pneumatic Scraper Applications

Pneumatic scraper mechanisms have been applied successfully in several industrial cleaning applications. Research conducted by Rhoades et al. [8] demonstrated that pneumatic scraper blades provide effective material removal while minimizing damage to the underlying surface. The study also highlighted the importance of selecting suitable blade materials and operating pressures to achieve consistent cleaning performance. Such findings provide valuable guidance for the design of pneumatic scraper systems intended for CNC laser-bed cleaning.

The reviewed literature shows that existing cleaning systems either depend heavily on manual labour or involve complex mechanical arrangements that increase maintenance costs. Advanced automated systems are often expensive and difficult to integrate with existing CNC machines. Furthermore, limited research has focused specifically on pneumatic scraper blade mechanisms for CNC laser-bed cleaning applications. Therefore, there is a need for a simple, economical, and easily retrofit table cleaning system capable of reducing manual intervention while maintaining reliable cleaning performance. The pneumatic scraper blade system proposed in this study aims to address this gap through the use of standard pneumatic components and a compact mechanical design.

3.0 Design & Construction

3.1 Design Considerations

Several factors were considered during the design of the pneumatic scraper blade system. The primary requirement was to develop a mechanism capable of removing slag and dust from the CNC laser-bed surface while maintaining a compact structure. The system was designed to generate sufficient scraping force without causing damage to the machine bed. The operating pressure was selected based on the available workshop compressed-air supply and the force required for scraper blade movement. The scraper blade material was chosen to provide adequate strength, wear resistance, and service life under repeated cleaning operations. Ease of installation and portability were also considered so that the system could be used on different CNC machines without major structural modifications. Safety was another important design factor. Proper pneumatic components were selected to control airflow, reduce leakage, and ensure smooth operation during extension and retraction of the cylinder [9].

3.2 Pneumatic Cylinder

A double-acting pneumatic cylinder was selected as the main actuator for the cleaning mechanism. The cylinder has a bore diameter of 32 mm and a stroke length of 50 mm. The cylinder converts compressed-air energy into linear motion, which is used to move the scraper blade across the bed surface. At an operating pressure of 1.0 MPa, the theoretical force generated by the cylinder can be calculated using: $F = P \times A$

where: F = Force (N)
P = Pressure (Pa)
A = Effective piston area (m^2)
The calculated force is sufficient for moving the scraper blade and removing deposited slag under normal operating conditions.

Scraper Blade: The scraper blade was manufactured from EN31 high-carbon spring steel. This material was selected because of its high hardness, wear resistance, and ability to withstand repeated contact with metallic slag. The blade is mounted at a suitable angle to improve cleaning action and reduce the possibility of damaging the CNC bed surface.
Solenoid Valve: A 5/2-way solenoid-operated directional control valve was used to control the movement of the pneumatic cylinder. The valve operates using a 12 V DC power supply and directs compressed air to either side of the cylinder, enabling extension and retraction.
Pneumatic Tubing and Fittings: Pneumatic connections were established using standard polyurethane tubing and push-fit connectors. The main supply line utilized 8 mm tubing, while 6 mm tubing was used for branch connections within the system.

3.3 Working Principal

The working principle of the pneumatic scraper blade system is based on the conversion of compressed-air energy into linear mechanical motion. Compressed air from the workshop

© 2026 ADYPJIET, Volume 1(1), Online ISSN: 3049-1517, June 2026, pp. 55-66

compressor first passes through the FRL unit, where it is filtered and regulated before entering the directional control valve. When the valve is energized, compressed air is supplied to one side of the double-acting cylinder, causing the piston rod to extend. The attached scraper blade moves forward and removes slag and dust from the CNC bed surface. When the valve position changes, compressed air is directed to the opposite side of the cylinder. This causes the piston rod to retract and return the scraper blade to its original position. A flow control valve is used to regulate piston speed and ensure smooth movement during both forward and return strokes. This arrangement provides a simple and reliable cleaning mechanism that can be operated repeatedly with minimal operator effort.

3.4 CAD Modelling

The complete assembly was modelled using SolidWorks software. The CAD model included all major components such as the pneumatic cylinder, scraper blade, support frame, pneumatic fittings, and control elements. The CAD model was used to verify component placement, assembly clearances, and overall dimensions before fabrication. Motion studies were also performed to confirm that the selected cylinder stroke was capable of producing the required scraper movement without interference between components. The modelling process helped identify potential design issues before manufacturing and contributed to the development of a compact and practical prototype.

.

Fig. 1. CAD Model of Pneumatic Scraper Blade

3.5 Fabrication and Assembly

The prototype frame was fabricated using mild steel sections. Individual members were cut according to design dimensions and assembled using arc welding. The frame was designed to provide sufficient rigidity while maintaining a lightweight structure. The pneumatic cylinder was mounted securely on the frame using steel brackets. The scraper blade was connected to the piston rod through a mechanical linkage arrangement that allows straightforward replacement when required. Pneumatic tubing and fittings were installed according to the circuit layout. The solenoid valve was connected to a 12 V DC switch-mode power supply through a manual control switch. Following assembly, the system was inspected for proper alignment, leakage, and operational functionality. Basic testing was carried out to verify cylinder movement, valve response, and scraper blade operation. The prototype successfully completed the intended extension and retraction movements.

Fig. 2. Frame Fabrication

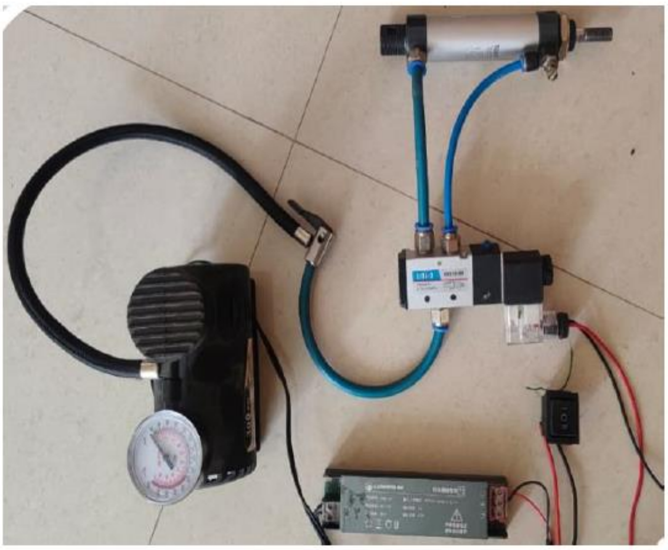

Fig. 3. Experimental Setup of Pneumatic Actuation System.

Fig 4: Developed Prototype of Pneumatic Slag Removal System.

3.6 Pneumatic Circuit

The pneumatic circuit consists of an air compressor, air receiver, directional control valve, flow control valve, and double-acting pneumatic cylinder. Electrical power for valve operation is supplied through a 12 V DC converter and control switch. The circuit was designed to provide stable cylinder operation while maintaining simple construction and ease of maintenance.

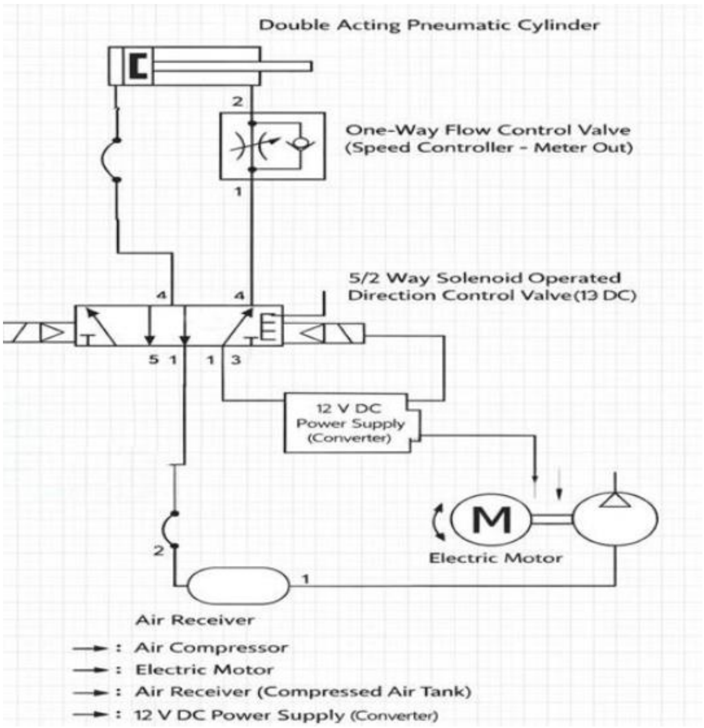

Fig. 5. Pneumatic Circuit

4.0 Calculations and Performance Analysis [10]

4.1 Pneumatic Force Calculation

The engineering calculation is based on the following specific physical parameters of the chosen prototype system components:

- **Bore Diameter (*D*):** 32 mm (0.032 m)
- **Operating Pressure (*P*):** 1.0 MPa (1.0×10^6 Pa)
- **Stroke Length (*L*):** 50 mm (0.05 m)
-

4.2 Effective Piston Area Calculation

The cross-sectional area of the working cylinder bore is foundational for determining output force properties, derived using the geometry relation:

$A = (\pi / 4) \times D^2$

$A = (\pi / 4) \times (0.032)^2$

$A = 8.042 \times 10^{-4}\ m^2$

4.3 Theoretical Output Force Calculation

Using the calculated area and standard operating fluid pressure, the absolute maximum non-frictional axial output force is formulated as:

$F = P \times A$

$F = (1.0 \times 10^6) \times (8.042 \times 10^{-4})$

$F \approx 804.2$ N

Therefore, the maximum nominal theoretical force generated by the actuator during normal extension is approximately **804.2 N**.

4.4 Volumetric Air Displacement Per Stroke

To establish consumption metrics, fluid volume shifted per complete linear path execution is evaluated:

$V = A \times L$

$V = (8.042 \times 10^{-4}) \times 0.05$

$V = 4.021 \times 10^{-5}\ m^3$

$V \approx 0.0402$ litres

4.0 Discussion of Practical Performance

In practical operation, the actual force generated by the pneumatic system may differ from theoretical calculations due to factors such as air leakage, friction between moving components, pressure fluctuations, and mechanical losses within the system. During prototype testing, the mechanism successfully completed the required extension and retraction movements and demonstrated the feasibility of pneumatic actuation for CNC bed-cleaning applications. The observed performance confirmed that the selected cylinder and pneumatic components were capable of operating the scraper mechanism effectively. The results indicate that further optimization of blade geometry, operating pressure, and control arrangements may improve overall cleaning performance in future versions of the system.

Table 1: Cost Breakdown of the Prototype

Component	Quantity	Estimated Cost (INR)
Double-Acting Pneumatic Cylinder	1	₹ 1,200
5/2-Way Solenoid Valve	1	₹ 850
Flow Control Valve	1	₹ 150
Pneumatic Pipes & Fittings	-	₹ 500
Scraper Blade	1	₹ 400
Mild Steel Frame Material	-	₹ 1,200
DC Power Supply & Wiring	-	₹ 600
Toggle Switch	1	₹ 50
Fasteners & Fabrication Cost	-	₹ 1,000
Miscellaneous Components	-	₹ 500
TOTAL		**₹6450**

The total fabrication cost of the developed prototype was approximately ₹6450.

5.0 Results & Discussion

The fabricated prototype was tested to evaluate the operational performance of the pneumatic scraper blade mechanism. During testing, the pneumatic cylinder successfully produced the required extension and retraction motion, enabling the scraper blade to travel across the CNC bed surface. The movement of the cylinder was smooth and consistent, and the directional control valve responded satisfactorily during repeated operating cycles. The scraper blade was able to remove loose slag particles, metallic dust, and surface debris accumulated on the test bed. The effectiveness of cleaning depended on factors such as slag thickness, surface condition, blade alignment, and operating pressure. While the system demonstrated satisfactory cleaning performance under laboratory conditions, variations were observed when different types of deposited material were encountered. The practical performance of the system differed from theoretical calculations due to frictional losses, minor pressure fluctuations, and mechanical resistance within the assembly. Such variations are common in pneumatic systems and should be considered during future design improvements. The fabricated prototype confirmed the feasibility of using pneumatic actuation for CNC laser-bed cleaning applications. The results indicate that the proposed mechanism can reduce manual cleaning effort while maintaining a simple and economical design. The total fabrication cost of the developed prototype was approximately INR 8,700, making it significantly more economical than many automated industrial cleaning systems. In addition, the compact structure and portable frame allow the system to be positioned and operated on different CNC machines with minimal setup requirements.

6.0 Advantageous & Disadvantageous

6.1 Advantageous:

The proposed pneumatic scraper blade system offers several practical advantages. The mechanism reduces the amount of manual effort required for cleaning CNC laser beds and helps maintain a cleaner working environment. Pneumatic operation provides a simple and reliable method of actuation while requiring relatively low maintenance. Since the system operates using compressed air, it eliminates the need for chemical cleaning agents and associated disposal concerns. The compact design allows easy installation and transportation between machines. The use of commercially available pneumatic components also contributes to lower manufacturing and maintenance costs. Furthermore, the system improves operator safety by reducing direct contact with sharp slag particles and accumulated debris.

6.2 Limitations:

Although the developed system performed satisfactorily during testing, certain limitations remain. The current design utilizes a 50 mm cylinder stroke, which may require repositioning of the cleaning assembly when larger bed areas must be covered. Periodic inspection of pneumatic tubing, fittings, and seals is necessary to maintain reliable operation and prevent leakage. The present prototype is operated through a manual switching arrangement. As a result, operator involvement is still required during the cleaning process. Additional automation will be necessary to achieve fully autonomous operation.

7.0 Future Scope

The developed prototype provides a foundation for future improvements and advanced automation. Integration of proximity sensors, ultrasonic sensors, or vision-based monitoring systems could enable automatic detection of slag accumulation on the CNC bed surface. Such sensors could be connected to a controller that initiates cleaning cycles without operator intervention. Further development may include integration with CNC machine control systems or programmable logic controllers (PLCs). This would allow cleaning operations to be automatically performed after completion of machining cycles. The cleaning area could also be increased by mounting the scraper assembly on a guided linear rail system capable of covering larger bed dimensions. Additional research may focus on optimizing scraper blade geometry, operating pressure, and pneumatic control strategies. Adaptive pressure control systems could be implemented to adjust cleaning force according to the condition of the deposited slag. Integration of waste collection mechanisms may further improve system cleanliness and reduce maintenance requirements.

8.0 Conclusion

This study presented the design, development, and testing of a pneumatic scraper blade system intended for CNC laser-bed cleaning applications. The proposed mechanism utilizes a double-acting pneumatic cylinder, a scraper blade fabricated from EN31 spring steel, and a 5/2-way directional control valve to perform cleaning operations through pneumatic actuation. A CAD model of the assembly was developed and a working prototype was successfully fabricated. Operational testing confirmed that the system was capable of performing the intended scraping action and removing slag and debris from the bed surface. The study demonstrated the practical feasibility of applying pneumatic technology to CNC bed-cleaning applications. The proposed design offers a simple, economical, and maintainable solution that can reduce manual cleaning effort and improve workplace safety. The use of standard pneumatic components makes the system suitable for implementation in small and medium-scale manufacturing environments. Future work may focus on automation, sensor integration, expanded cleaning coverage, and optimization of system performance. These improvements have the potential to further enhance the effectiveness and industrial applicability of the proposed pneumatic scraper blade system.

References:

1. A. Esmaeilzadeh, M. Shabgard and M. Azadi, Laser cutting process optimization and quality characteristics: A review, Journal of Manufacturing Processes, 56,133–150, 2020.

2. J. C. Ion, Laser Processing of Engineering Materials: Principles, Procedure and Industrial Application, Elsevier, 2005.

3. S. Genna, E. Menna, G. Rubino and V. Tagliaferri, Experimental investigation of industrial laser cutting: The effect of material selection and process parameters on kerf quality, Applied Sciences, 10(14),4956, 2020.

4. C. Wandera and V. Kujanpää, Characterization of the melt removal rate in laser cutting of thick-section stainless steel, Journal of Laser Applications, 22(2), 62–70, 2010.

5. M. Easwaramoorthi, C. Saravanan, R. Senthil Nathan, D. Siva Shankar and G. P. Vivek, Design of automated chain drive slag handling and removal machine for CNC gas cutting process, International Journal of Engineering Research & Technology, 5(7), 2017.

6. Y. Li, X. Zhang and H. Wang, Laser cleaning technologies for industrial surface treatment: A review, Surface Engineering, 39(4),285–302, 2023.

7. V. Boyko and J. Weber, Energy efficiency of pneumatic actuating systems with pressure-based air supply cut-off, Actuators, 13(1), 44, 2024.

8. C. A. Rhoades, S. G. Grannes and T. L. Hebble, Development and testing of a pneumatic scraper blade for conveyor belt cleaning, U.S. Bureau of Mines Report of Investigations, 1989.

9. A. Esposito, Fluid Power with Applications, 7th ed., Pearson Education, 2014.

10. B. Shah and R. Patel, Automation techniques in pneumatic material handling systems, International Journal of Mechanical Engineering and Robotics Research, 8(3), 412–418, 2019.