Design & Development of Scrap Compressing Mechanism (Pneumatic)

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Abstract - *Manufacturing processes such as CNC machining and lathe operations generate a significant amount of metal burrs and shavings, which can create clutter, reduce efficiency, and complicate waste management. This project focuses on designing and developing a scrap compressing mechanism to effectively compact aluminum burrs, making disposal and recycling more manageable. The system features a box-type design with a metal hopper for collecting burrs, which are then compressed using a pneumatic cylinder controlled by a hand lever. The compression structure is fabricated using precision laser-cut metal sheets to ensure durability and efficiency. Reducing the volume of scrap enhances workplace cleanliness, simplifies material handling, and promotes sustainable recycling practices.*

Key Words: CNC, Burr, Waste Management, Pneumatic Cylinder, Sustainable Recycling.

1. INTRODUCTION

Metal machining processes, such as CNC lathes and milling, generate a substantial amount of metal burrs and shavings as byproducts. These scraps often accumulate around the workspace, leading to inefficiencies, safety hazards, and difficulties in disposal or recycling. Managing these metal burrs manually is time-consuming and inefficient, making it necessary to develop a system that can automate the collection and compression process. This project focuses on designing and developing a scrap compressing mechanism specifically for aluminum burrs. The system consists of a box-type structure with a hopper for collecting burrs, a pneumatic compression unit operated by a hand lever, and a robust frame made from laser-cut metal sheets. By compacting the metal scraps into denser forms, the mechanism reduces waste volume, facilitates easy handling, and promotes sustainability in manufacturing. The primary objective of this project is to provide an efficient, cost-effective, and environmentally friendly solution for scrap management in machining industries. By integrating a simple yet effective compression system, this mechanism can enhance workplace cleanliness, minimize manual labor, and streamline the recycling process. This innovation can potentially improve productivity and contribute to a more sustainable approach to metal waste handling.

1.1 SCOPE

The scrap compressing mechanism is designed to efficiently manage and reduce the volume of aluminum burrs generated during machining processes, particularly in CNC lathes and other metal-cutting machines. The system aims to improve waste handling, workplace cleanliness, and recycling efficiency. The key aspects covered within the scope of this project include This project focuses primarily on aluminum burrs but can be adapted for other metal scraps, making it a versatile solution for machining industries. The system is designed for small- to medium-scale operations where efficient scrap management is essential for improving productivity and maintaining a clean working environment.

1.2 METHODOLOGY

The development of the scrap compressing mechanism follows a systematic approach to ensure efficient collection and compression of aluminum burrs. The methodology consists of the following steps:

1. **Problem Identification** – Analyzing the issues associated with aluminum burr accumulation in machining processes and identifying the need for a compacting mechanism.

2. **Conceptual Design** – Developing design concepts for the compression system, including the hopper, pneumatic cylinder, and supporting structure.

3. **Material Selection** – Choosing appropriate materials such as MS sheets for the frame and hopper to ensure durability and efficiency.

4. **Fabrication Process** – Manufacturing the components using laser cutting, welding, and assembly techniques to achieve precise construction.

5. **Pneumatic System Integration** – Installing the pneumatic cylinder and hand lever control to apply compression force effectively.

6. **Testing and Evaluation** – Assessing the system's performance in terms of compression efficiency, ease of operation, and scrap volume reduction.

7. **Optimization and Modifications** – Making necessary adjustments to improve performance, reduce air consumption, and enhance user-friendliness.

8. **Final Implementation** – Deploying the mechanism in a machining environment to evaluate its practical effectiveness in real-world conditions.

This structured approach ensures that the scrap compressing mechanism is efficient, cost-effective, and suitable for integration into manufacturing setups.

2. LITERATURE REVIEW

Effective management of metal burrs and shavings generated during machining processes has been a subject of research for improving manufacturing efficiency and sustainability. Various studies have explored scrap collection, compression techniques, and recycling strategies to minimize waste and enhance workplace safety.

1. **J. Smith et al. (2018)** studied the impact of metal chip accumulation on CNC machine efficiency and proposed automated collection methods to reduce downtime and improve machining accuracy.

2. **R. Patel & K. Sharma (2019)** investigated pneumatic and hydraulic compression techniques for metal waste management, concluding that pneumatic systems are more suitable for small-scale manufacturing due to lower costs and maintenance.

3. **M. Liu & T. Wong (2020)** focused on the environmental benefits of metal chip compaction, highlighting its role in reducing storage space requirements and increasing recycling efficiency.

4. **D. Brown et al. (2017)** analyzed various designs of scrap handling systems in manufacturing units and suggested that integrated hopper-fed compression mechanisms enhance operational efficiency.

5. **A. Verma & P. Gupta (2021)** examined the effectiveness of laser-cut structural components in machine design, emphasizing their role in improving the durability and precision of compression mechanisms.

6. **L. Rodriguez & E. Thompson (2016)** explored cost-effective solutions for metal waste disposal and recommended compacting systems as an alternative to conventional waste management techniques.

7. **K. Nakamura et al. (2022)** conducted experimental studies on aluminum scrap compression, demonstrating that compressed burrs occupy significantly less volume.

3. DESIGN

The given design is a pneumatic aluminum scrap compactor that utilizes a pneumatic cylinder, and a compression chamber mounted on a supportive frame. The structure includes key components such as a pneumatic actuator, compression box, hopper, and guiding system. Scrap aluminum is fed into the chamber through a hopper positioned at the top, allowing for easy loading and gravity-assisted flow of material into the compression zone.

The compression is performed by a pneumatic cylinder, which moves a piston in a forward and backward motion. During operation, the piston pushes into the chamber, compressing the loosely packed aluminum scrap against a closed surface or a front gate, which is designed to retain the material during compression. Once the cycle is complete, the front gate can be opened to remove the compacted aluminum block. The piston then retracts to its initial position, ready for the next cycle.

This system is designed for efficiency and ease of use, offering a controlled method to reduce the volume of aluminum scrap. The use of pneumatic power ensures smooth and consistent movement, making the setup suitable for small-scale or semi-automated scrap processing. The design is compact, functional, and adaptable, with potential for further improvements such as sensor integration, automation, and optimized ejection mechanisms.

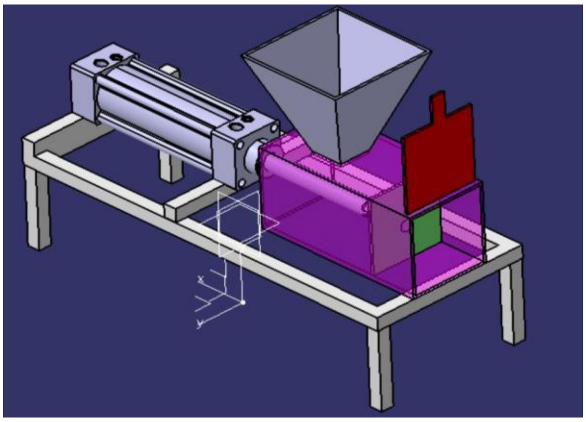

Fig 1. 3D Desing of Scrap Compressor (Isometric view)

3.1. COMPRESSING MECHANISM

The displayed setup is a **pneumatically operated aluminum scrap compactor**, designed to reduce the volume of metal waste for easier handling, storage, or recycling. This type of machine is commonly used in workshops, small-scale industries, or recycling facilities where aluminum scrap is generated regularly and needs to be managed efficiently.

At the core of the system is a **pneumatic cylinder**, which is responsible for powering the compression process. Pneumatic cylinders work by using compressed air to push parts in a straight line, which makes them great for jobs that need the same motion done over and over reliably, the cylinder is mounted horizontally on a rigid supporting frame and aligned directly with a compression chamber. The piston rod of the cylinder extends into the chamber to push the aluminum scrap and apply compressive force.

The **compression chamber** is a rectangular box placed in front of the cylinder. It is designed to hold the aluminum scrap in place during the compression stroke. The structure is fully enclosed except for the opening at the top where the hopper is mounted and the front side, which has a movable gate or plate. The top-mounted **hopper** allows for easy feeding of aluminum scrap into the chamber. Scrap is loaded into the hopper, and it naturally falls into the chamber due to gravity. This design makes loading efficient and helps in preparing the material for compression without manual intervention inside the chamber.

Once the chamber is filled with scrap, the pneumatic cylinder is actuated. The piston moves forward into the chamber and compresses the aluminum against the closed end. The red-colored gate at the front, as seen in the image, functions either as a **removable or swingable door** that retains the material during compression. It may also serve as a manual or automated ejection mechanism once compression is complete. After the piston reaches the end of its stroke, the compressed aluminum takes the shape of the chamber's inner cavity, forming a dense, manageable block.

After compression, the gate can be opened to remove the compressed block, either manually or with the help of an automated pusher or ejector system. The piston is then retracted, resetting the machine for the next compression cycle.

This system is a good example of a **simple, efficient, and low-maintenance solution** for handling metal waste. Pneumatic systems are relatively quiet, safe, and easy to control, making them suitable for both manual and semi-automated operations. The overall design ensures minimal manual effort and provides consistent output in terms of block shape and size. It can be further enhanced with automation features like sensors for piston positioning, safety interlocks, and pressure regulators for varying compression needs depending on the material being processed.

In essence, the design integrates mechanical strength, ease of operation, and functional efficiency, making it ideal for small-scale recycling or metalworking applications focused on reducing scrap volume and improving material handling.

3.2 DESIGN CALCULATIONS

Pneumatic Cylinder Selection

The selection of the **63 × 250 mm** pneumatic cylinder is based on the force required for compression, stroke length, and available air pressure.

1. Force Required for Compression

Formula: Force (F) = Pressure (P) × Piston Area (A)

Given Data:

- Required compression pressure = 5 bar = 0.5 MPa = 5×10^5 Pa
- Cylinder bore diameter = 63 mm = 0.063 m

Step 1: Calculate Piston Area

Formula:
Piston Area (A) = (π / 4) × (Diameter × Diameter)
Substituting values:
$A = (3.1416 / 4) \times (0.063 \times 0.063)$
$A = 3.117 \times 10^{-3}\ m^2$

Step 2: Calculate the Force Exerted by the Cylinder

Formula:
Force (F) = Pressure (P) × Piston Area (A)
Substituting values:
$F = (5 \times 10^5) \times (3.117 \times 10^{-3})$
F = 1558.5 N
F ≈ 1.56 kN

This force is sufficient to compress aluminium burrs effectively.

2. Stroke Length Selection

The stroke length is chosen based on the required movement of the compression plate inside the box.

Given Data:

- Initial burr volume per cycle = 3 litters = $0.003\ m^3$
- Cross-sectional area of the box = 6 inches × 6 inches = 150 mm × 150 mm = $0.0225\ m^2$

Formula:

Stroke Length (L) = Volume / Cross-sectional Area
Substituting values:
L = 0.003 / 0.0225
L = 0.133 m
L = 133 mm

Since 133 mm is the minimum required stroke, we select a **250 mm stroke cylinder** to allow extra movement and ensure complete compression.

Final election:

- A **63 × 250 mm pneumatic cylinder** is chosen as it provides **sufficient force (1.56 kN)** and **an appropriate stroke length (250 mm)** to fully compress the aluminium burrs.

2. Pneumatic Cylinder Selection

- Selected cylinder = 63 × 250 mm
- Stroke length = 250 mm

3. Material Strength Analysis

- Frame material = Mild Steel (MS)
- Thickness = 5 mm
- Yield strength of MS = 250 MPa
- Factor of Safety (FoS) = 2

4. Hopper Capacity Calculation

- Designed to hold 3 litters (0.003 m^3) of burrs per cycle

5. Compression Ratio Calculation

- Initial loose burr density = 2700 kg/m^3
- Compressed density = 5400 kg/m^3
- Compression Ratio = Initial Density / Compressed Density
  - = 2700 / 5400
  - = 2:1
- This means the volume is reduced by 50% after compression.

6. Air Consumption Estimation

- Air consumption per stroke = Piston Area × Stroke Length
  - = $(3.117 \times 10^{-3}) \times (0.25)$
  - = 7.79×10^{-4} m^3
- Since it is a double-acting cylinder (compression and retraction), total air per cycle = 2 × Air per stroke
  - = $2 \times (7.79 \times 10^{-4})$
  - = 1.558×10^{-3} m^3 per cycle.

Strength Calculation for 5mm Thick MS Plate.

1. As per values

- Material: Mild Steel (MS)
- The thickness of Plate (t): 5 mm = 0.005 m
- Force Applied (F): 1.56 kN = 1560 N
- Plate Width (b): 150 mm = 0.15 m
- Yield Strength of MS (σy): 250 MPa = 250×10^6 Pa
- Modulus of Elasticity (E): 200 GPa = 200×10^9 Pa

2. Stress Calculation

The formula for Bending Stress:
Stress (σ) = Force (F) / Area (A)
Substituting values:
σ = 1560 / (0.15 × 0.005)
σ = 1560 / 0.00075
σ = 2.08 MPa

Since the yield strength of MS is 250 MPa, the induced stress (2.08 MPa) is very low, meaning the plate can safely handle the load.

3. Factor of Safety (FOS)

Formula:
Factor of Safety (FOS) = Yield Strength (σy) / Induced Stress (σ)
Substituting values:
FOS = 250 / 2.08
FOS ≈ 120

Since the FOS is very high, the 5mm MS plate is more than sufficient to sustain the applied force without failure.

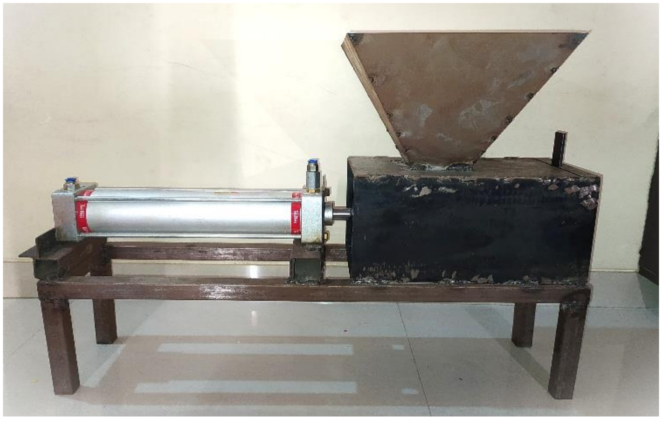

Fig 2. Working Model of Scrap Compressor

3.3 CONCEPT IN M.D.P

The project involves the design and fabrication of a pneumatically operated aluminum scrap compactor aimed at reducing the volume of metal waste generated in workshops and small-scale industries. With the increasing use of aluminum in various sectors, managing its scrap efficiently is essential. This machine uses compressed air to power a pneumatic cylinder that compresses loose aluminium scrap into dense, uniform blocks. The compacted scrap occupies significantly less space, making it easier to store, transport, or recycle. The working principle of the machine is based on the conversion of pneumatic energy into linear mechanical motion. Aluminium scrap is loaded into a compression chamber through a top-mounted hopper. When the pneumatic cylinder is actuated, its piston moves forward, pushing the scrap against the chamber's closed-end or front gate. This action compresses the scrap into a solid block. Once compression is complete, the block is manually or automatically removed by opening the front gate, and the piston retracts to its original position, ready for the next cycle. The setup consists of several key components, including a pneumatic cylinder, a hopper for feeding scrap, a compression chamber, a front gate for ejection, and a strong frame to hold everything in place. The pneumatic system is controlled using valves and pressure regulators, ensuring smooth and safe operation.

3.4 PNEUMATIC CYLINDER SELECTION

Fig 3. Pneumatic Cylinder

A pneumatic cylinder is a mechanical device that uses compressed air to generate force in a reciprocating motion. In this project, we use a 63 × 250 mm pneumatic cylinder to compress aluminum burrs. The cylinder converts pneumatic energy into linear mechanical motion, applying force to compact the burrs efficiently.

➢ Specifications of Selected Pneumatic Cylinder:

- Type: Double-acting pneumatic cylinder
- Bore Diameter: 63 mm
- Stroke Length: 250 mm
- Operating Pressure: 2 to 10 bar
- Rod Diameter: 20 mm (approx.)
- Material: Aluminium alloy cylinder body with stainless steel piston rod
- Mounting Type: Flange or foot-mounted
- Seals Material: Nitrile Rubber (NBR) / Polyurethane
- Operating Medium: Filtered, lubricated, or non-lubricated compressed air
- Temperature Range: -10°C to +60°C
- Max Operating Speed: 500 mm/sec

A double-acting pneumatic cylinder operates by applying compressed air alternately to both sides of the piston,

enabling both forward and return strokes. The cylinder is controlled using a directional control valve, and movement is regulated based on air pressure and flow rate.

- Extension Stroke: Compressed air enters from the cap end, pushing the piston rod outward.

- Retraction Stroke: Air is released from the cap end, while compressed air enters the rod end to pull the piston rod back.

This cycle ensures smooth operation in compressing aluminum burrs inside the compression box.

3.5 TESTING AND OUTCOMES

Initial Volume: $500 \times 500 \times 500 = 125{,}000{,}000\ mm^3$

Compressed Volume: $150 \times 150 \times 200 = 4{,}500{,}000\ mm^3$

Volume Reduction:

$125{,}000{,}000 - 4{,}500{,}000 = 120{,}500{,}000 mm^3$

Therefore, the metal scrap is reduced by 96.4%.

Fig 4. Compressed Scrap

The image illustrates the successful testing and performance of a pneumatic scrap compactor, used to compress various metallic turnings generated during machining processes. In this trial, the machine was tested on materials including Aluminium 7075, Mild Steel, and similar high-volume industrial waste metals. These metals were selected due to their frequent occurrence in workshops and their high recyclability value. Aluminium 7075, a high-strength alloy commonly used in aerospace and automotive applications, tends to produce long, tangled chips during machining. These chips are lightweight but bulky, making them difficult to store and transport in their raw form. When compressed in the fabricated machine, the aluminium scrap exhibited excellent compaction behaviour, reducing its volume by up to **96.4%**, as supported by earlier calculations and graphically represented in the testing data. The result was a dense, uniform briquette ideal for recycling. Mild Steel turnings, on the other hand, are heavier and tougher, but the pneumatic system was still capable of compressing them effectively. Although mild steel may require slightly higher force compared to aluminium due to its density and spring-back nature, the test showed successful volume reduction and shaping without damage to the compactor or safety risks to the operator.

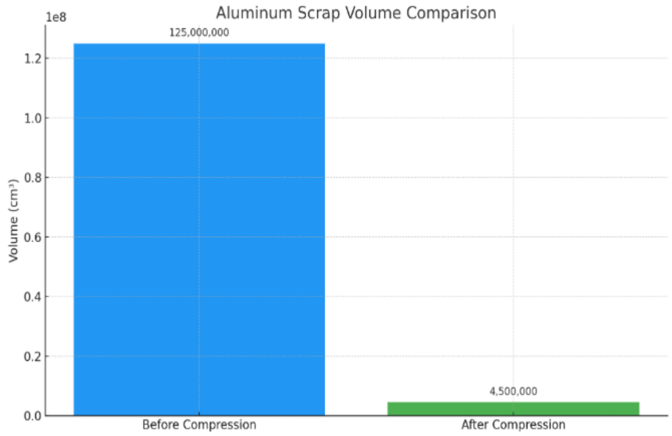

Fig 5. Reduction of Scrap Volume

4. CONCLUSION

The designed pneumatic scrap compressing mechanism provides an effective and practical solution for handling metal burrs and shavings generated from CNC lathe and other machining processes. Utilizing a pneumatic cylinder operated via a manual hand lever valve, the system compresses loose, tangled metal scrap into compact, manageable blocks. This significantly reduces the volume of waste material, optimizing storage space and simplifying transportation and recycling. The system not only addresses the problem of space-consuming scrap but also enhances workplace safety by preventing the accumulation of loose, sharp metal turnings on the shop floor. This results in a cleaner, more organized, and safer working environment. Its compact design, low cost, and minimal maintenance requirements make it highly suitable for small-scale workshops and medium industrial setups.

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