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Automated Metal Sorting System Using Magnetic Separation and Eddy Current Roller Technology

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Abstract- Efficient recovery of metals from mixed waste streams remains a critical challenge in modern recycling systems due to material heterogeneity and increasing waste volume. This paper presents the design, implementation, and performance evaluation of an automated metal sorting system that integrates magnetic separation and eddy current roller technology. The system operates in two stages: ferrous metals are extracted using a permanent magnetic separator, followed by non-ferrous metal separation using a high-speed eddy current rotor. Experimental evaluation was conducted by varying conveyor speed, rotor speed, and feed rate. Results indicate that separation efficiency is strongly dependent on operational parameters, with an optimal rotor speed range and reduced efficiency at higher conveyor speeds due to limited interaction time. The system achieved ferrous separation efficiency above 90% and non-ferrous efficiency up to 91% under optimized conditions. The proposed system provides a cost-effective and scalable solution for small-scale recycling applications while highlighting the importance of parameter tuning for performance optimization.

***Key Words:** Metal Sorting, Magnetic Separation, Eddy Current Separator, Recycling Systems, Waste Management, Non-Ferrous Recovery*

I. INTRODUCTION

The rapid growth of industrialization and urban development has led to a significant increase in the generation of solid waste, particularly metallic waste originating from municipal, industrial, and electronic sources. Metals such as iron, aluminum, and copper are valuable recyclable materials; however, their recovery from mixed waste streams remains inefficient due to the heterogeneous nature of the input and limitations of conventional sorting methods.

Traditional manual sorting techniques are widely used in small- and medium-scale recycling operations, but they suffer from low efficiency, inconsistent accuracy, and high labor dependency. In addition, manual handling exposes workers to hazardous conditions, making it unsuitable for large-scale or continuous processing environments. These challenges have created a need for automated systems capable of improving both the speed and reliability of metal separation.

Among available technologies, magnetic separation and eddy current separation are commonly employed due to their simplicity and effectiveness. Magnetic separation utilizes the magnetic properties of ferrous materials to extract them from mixed waste, while eddy current separation relies on electromagnetic induction to separate non-ferrous conductive materials. Although both techniques are individually well established, their combined implementation in compact, cost-effective systems remains limited, particularly for small-scale applications.

A major challenge in such systems is not merely the selection of separation techniques, but the optimization of operational parameters such as conveyor speed, rotor speed, and material feed rate. These parameters directly influence interaction time, induced forces, and material trajectories, ultimately determining separation efficiency. In many existing implementations, insufficient attention is given to parameter tuning, leading to suboptimal performance despite using appropriate technologies.

This work presents the design and experimental evaluation of an automated metal sorting system that integrates magnetic separation and eddy current roller technology. The focus is not only on system development but also on analyzing the influence of key operating parameters on separation efficiency. By identifying optimal operating conditions and practical limitations, the study aims to contribute toward the development of efficient, low-cost, and scalable metal sorting solutions for recycling applications.

II. LITERATURE REVIEW

Magnetic separation and eddy current separation are widely used techniques for metal recovery in recycling systems due to their reliability and relatively low operational cost. Magnetic separation has been extensively applied for the extraction of ferrous materials, leveraging differences in magnetic susceptibility. Studies have shown that permanent magnet-based systems provide stable performance with minimal energy consumption [1], [2]. However, their application is limited to ferrous metals and is influenced by particle size and material distribution [3].

Eddy current separation has been developed as a complementary technique for recovering non-ferrous metals such as aluminum and copper. It operates on the principle of electromagnetic induction, where a time-varying magnetic field induces eddy currents in conductive materials, resulting in repulsive forces. Previous research indicates that parameters such as rotor speed, magnetic field intensity, and particle size significantly affect separation efficiency [4], [5]. In particular, higher rotor speeds improve separation up to an optimal limit, beyond which performance may degrade due to unstable particle trajectories [6].

Several researchers have investigated hybrid systems that combine magnetic and eddy current separation to improve overall metal recovery. These systems demonstrate enhanced efficiency by enabling sequential separation of ferrous and non-ferrous materials [7]. However, most of these implementations are designed for large-scale industrial applications and often overlook parameter optimization in compact or low-cost systems [8].

Recent advancements in automated sorting have introduced sensor-based and AI-driven approaches for material classification. While these methods offer high accuracy, they increase system complexity and cost, making them less suitable for small- and medium-scale recycling operations [9], [10].

A critical observation from existing literature is that although the underlying separation technologies are well established, limited attention has been given to the optimization of operational parameters such as conveyor speed, feed rate, and rotor dynamics in integrated systems [5], [6]. These factors play a crucial role in determining separation efficiency but are often treated as secondary considerations.

Therefore, there exists a need for a compact, cost-effective system that not only integrates magnetic and eddy current separation but also systematically evaluates the influence of key operating parameters on performance. The present work addresses this gap through experimental analysis and parameter optimization

III. METHODOLOGY

3.1 System Description

The proposed system is a conveyor-based automated metal sorting setup designed to separate ferrous and non-ferrous metals from mixed waste. The system consists of two sequential separation stages:

1. Magnetic Separation Unit – for extraction of ferrous materials
2. Eddy Current Separation Unit – for separation of non-ferrous conductive materials

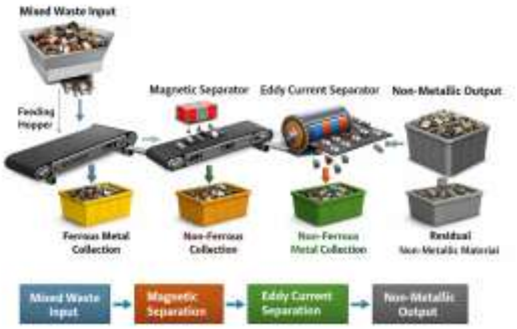

Fig 1: Block Diagram

Mixed materials are fed onto a conveyor belt, transported through the magnetic field region, and subsequently passed over a high-speed rotating magnetic rotor for eddy current separation.

3.2 Working Principle

The separation process is based on two distinct physical phenomena:

- Magnetic attraction for ferrous materials
- Electromagnetic induction for non-ferrous materials

Ferrous metals are attracted toward the magnetic field and removed from the material stream. Non-ferrous metals experience induced eddy currents when exposed to a time-varying magnetic field, resulting in repulsive forces that alter their trajectory.

3.3 Conveyor System Modeling

The conveyor belt controls the residence time of materials within the separation zones. The belt velocity is given by:

$v=\pi DN/60$

Where:

v = belt velocity (m/s)
D = pulley diameter (m)
N = rotational speed (RPM)

The interaction time ttt of particles with the separation field is:

$t=L/v$

Where:

L = effective length of magnetic field region

Insight: Increasing velocity reduces interaction time, directly affecting separation efficiency.

3.4 Magnetic Separation Modeling

The force acting on a ferrous particle in a magnetic field is expressed as:

$Fm=\chi VB\nabla B/\mu 0$

Where:

Fm = magnetic force
χ = magnetic susceptibility
V = particle volume
B = magnetic field strength
$\mu 0$ = permeability of free space

For successful separation:

$Fm>Fg+Fd$

Where:

Fg = gravitational force
Fd = drag or inertial forces

This condition ensures that ferrous materials are effectively lifted or diverted from the main stream.

3.5 Eddy Current Separation Modeling

The eddy current separator operates on Faraday's Law of electromagnetic induction:

$E=-d\Phi dt$

Where:

E = induced electromotive force
Φ\ = magnetic flux

The induced current generates a secondary magnetic field, producing a repulsive force on conductive materials. The magnitude of this force can be approximated as:

$Fe \propto \sigma B^2 vr$

Where:

σ = electrical conductivity of material
B = magnetic field strength
vr = relative velocity between rotor and particle

Higher conductivity and rotor speed increase separation force.

3.6 Experimental Procedure

Experiments were conducted using a mixture of:

- Ferrous metals (iron)
- Non-ferrous metals (aluminum)
- Non-metallic materials (plastic, rubber)

Steps:

1. Materials were fed into the hopper at controlled rates
2. Conveyor speed was varied across predefined levels
3. Rotor speed was adjusted between 1000–2500 RPM
4. Output materials were collected and weighed
5. Separation efficiency was calculated

3.7 Performance Metrics

1. Separation Efficiency

$\eta=Mout/Min\times 100$

Where:

$Mout$ = mass of separated material
Min = initial mass

2. Recovery Rate

R=Mrecovered/Mtotal×100

3.8 Parameter Variation

The following parameters were systematically varied:

- Conveyor speed (low, medium, high)
- Rotor speed (1000–2500 RPM)
- Feed rate (2–10 kg/min)

Each test was repeated to ensure consistency.

3.9 Assumptions

To simplify analysis:

- Uniform material distribution on conveyor
- Negligible air resistance
- Constant magnetic field in separation zone
- No slippage in conveyor system

3.10 Methodological Limitations

- Simplified force models may not capture complex particle interactions
- Material irregularities affect consistency

External disturbances (vibration, misalignment) are not fully modelled

IV. RESULTS AND DISCUSSION

4.1 Overview of Experimental Results

The developed system was evaluated under varying operating conditions to determine the influence of conveyor speed, rotor speed, and feed rate on separation performance. The results are presented in terms of separation efficiency and recovery rate for both ferrous and non-ferrous materials.

4.2 Effect of Conveyor Speed

The variation of separation efficiency with conveyor speed is summarized in Table 1.

Table 1: Conveyor Speed vs Separation Efficiency

Conveyor Speed Level	Efficiency (%)
Low	94
Medium	90
High	82

Analysis

A clear inverse relationship is observed between conveyor speed and separation efficiency. At lower speeds, materials remain within the influence of the magnetic and eddy current fields for a longer duration, resulting in improved separation. As speed increases, the interaction time decreases, leading to incomplete separation.

This aligns directly with the interaction time model:
t=Lv
Less time → weaker separation effect.

4.3 Effect of Rotor Speed

The performance of the eddy current separator at different rotor speeds is presented in Table 2.

Table 2: Rotor Speed vs Non-Ferrous Separation Efficiency

Rotor Speed (RPM)	Efficiency (%)
1000	78
1500	85
2000	91
2500	89

Analysis

The results show a non-linear relationship between rotor speed and separation efficiency. Efficiency increases with rotor speed up to an optimal value (~2000 RPM), beyond which it declines slightly.

Reason:

- Increasing rotor speed increases induced eddy currents
- Beyond optimal speed, particles become unstable and misdirected

This confirms that maximum speed is not equal to maximum efficiency.

4.3 Effect of Feed Rate

The influence of feed rate on system accuracy is shown in Table 3.

Table 3: Feed Rate vs Sorting Accuracy

Feed Rate (kg/min)	Accuracy (%)
2	95
5	90
8	85
10	78

Analysis
An increase in feed rate leads to a decrease in sorting accuracy. This is primarily due to material overlapping, which reduces exposure to both magnetic and eddy current fields.

Translation:
More material ≠ better output
It actually kills your efficiency.

4.5 Overall System Performance

Under optimized conditions:

- Ferrous separation efficiency: 90–94%
- Non-ferrous separation efficiency: 85–91%

The system demonstrates consistent performance for medium-sized particles and controlled feed conditions.

4.6 Discussion of Results

Parameter Sensitivity
The system is highly sensitive to operating parameters. Small variations in speed or feed rate significantly impact performance.

Trade-Off Between Speed and Efficiency

- High speed → high throughput, low accuracy

Low speed → high accuracy, low throughput.

V. CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

This study presented the design, implementation, and performance evaluation of an automated metal sorting system integrating magnetic separation and eddy current roller technology. The system was developed to address the limitations of manual sorting and to improve the efficiency of metal recovery from mixed waste streams.

Experimental results demonstrate that the system is capable of effectively separating ferrous and non-ferrous metals under controlled conditions. Ferrous materials were successfully extracted using magnetic attraction, while non-ferrous metals were separated through induced eddy current repulsion. The system achieved ferrous separation efficiencies in the range of 90–94% and non-ferrous separation efficiencies up to 91% when operated under optimized parameters.
A key outcome of this work is the identification of the strong dependency of system performance on operational parameters. Conveyor speed was found to have an inverse relationship with separation efficiency due to reduced interaction time at higher speeds. Rotor speed exhibited an optimal operating range, beyond which separation efficiency declined due to instability in particle trajectories. Similarly, increased feed rate resulted in reduced sorting accuracy due to material overlap.

These findings confirm that system effectiveness is not solely determined by the choice of separation technology, but significantly influenced by parameter tuning and operational control. The developed system provides a practical and cost-effective solution for small-scale recycling applications where simplicity and reliability are essential.

5.2 Future Work

Let’s not pretend this system is complete—it isn’t. Here’s how it can actually evolve:
1. Adaptive Speed Control
Implement closed-loop control systems (PID or microcontroller-based) to dynamically adjust conveyor and rotor speeds based on real-time conditions.
2. Sensor-Based Material Detection
Integrate proximity, optical, or infrared sensors to improve detection and sorting of complex waste streams.
3. AI-Based Sorting Enhancement
Incorporate machine vision and machine learning algorithms for intelligent classification of materials beyond magnetic properties.
4. Multi-Stage Separation
Extend the system with additional separation stages to improve recovery of fine and mixed particles.
5. Electromagnetic System Optimization
Replace permanent magnets with electromagnets to enable adjustable magnetic field strength and improved control.
6. Industrial Scale Development
Enhance system capacity, durability, and automation for deployment in large-scale recycling facilities.
7. Data Monitoring and IoT Integration

Enable real-time monitoring, performance tracking, and predictive maintenance using IoT-based systems.

5.3 Final Remark

The work demonstrates that combining simple physical separation techniques with proper parameter optimization can significantly improve metal recovery efficiency. While the system is effective for controlled environments, further advancements in sensing, control, and scalability are required to meet industrial demands.

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