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Design and Development of an AI-Assisted Dual-Mode Multipurpose Sieving Machine

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ABSTRACT: Sieving is a critical material separation process widely used in agriculture, construction, food processing, pharmaceuticals, and laboratory applications to ensure particle size uniformity and product quality. Conventional manual sieving methods are highly labour-intensive, time-consuming, and often produce inconsistent results due to uneven motion. On the other hand, fully electrically operated sieving machines provide higher efficiency but are expensive, energy-dependent, and unsuitable for rural or small-scale industries where uninterrupted power supply is not always available.

To overcome these limitations, this research presents the design, development, and experimental evaluation of a multipurpose dual-mode sieving machine capable of operating in both pedal-driven (manual) and electric motor-driven modes. The proposed system integrates a roller-guided reciprocating vibration mechanism, which replaces conventional spring-based systems to ensure smooth, controlled, and low-friction vibration motion of the sieve tray. Interchangeable mesh screens of different sizes allow the machine to handle a wide range of materials such as sand, grains, and powdered substances, making it suitable for multipurpose applications.

The pedal-operated mechanism utilizes a crank and chain drive to convert human effort into mechanical oscillation, enabling operation in off-grid environments while reducing operator fatigue compared to traditional hand sieving. The electric mode employs a motor-driven eccentric mechanism to generate uniform vibration, resulting in higher throughput and consistent separation quality. Experimental testing demonstrates that the proposed machine significantly improves sieving efficiency, reduces processing time, and offers reliable performance under both operational modes.

The machine is fabricated using locally available materials, ensuring low manufacturing cost, ease of maintenance, and long service life. Overall, the developed dual-mode multipurpose sieving machine provides an economical, energy-efficient, and environmentally sustainable solution for rural industries, small-scale manufacturing units, and laboratory applications, demonstrating the effective integration of mechanical design principles with AI-assisted technical documentation.

KEYWORDS: Multipurpose Sieving Machine, Pedal Operated Mechanism, Dual-Mode System, Sustainable Design, Mechanical Separation

I. INTRODUCTION

Material separation based on particle size is a fundamental operation in a wide range of industrial, agricultural, and laboratory processes, as it directly affects product quality, processing efficiency, and operational consistency. Sieving is commonly used for separating materials such as sand, grains, cement, food powders, and pharmaceutical substances. Traditional manual sieving methods rely heavily on human effort and repetitive motion, which results in low productivity, high physical fatigue, and inconsistent separation due to non-uniform shaking patterns. These limitations make manual sieving unsuitable for large-scale or continuous operations.

To overcome these drawbacks, electrically operated sieving machines have been introduced, which utilize vibration motors or eccentric mechanisms to provide uniform oscillations and higher throughput. Although electrically driven systems significantly improve efficiency and separation accuracy, they come with disadvantages such as high initial cost, increased maintenance requirements, and complete dependency on a continuous power supply. In rural areas, small-scale industries, and temporary work sites where electricity availability is unreliable or limited, the use of purely electric sieving machines becomes impractical. Additionally, the energy consumption of such machines increases operational expenses and reduces sustainability.

In response to these challenges, this research focuses on the development of a hybrid multipurpose sieving machine that integrates both human-powered (pedal-operated) and electric-powered modes within a single system. The proposed design aims to combine the affordability and power independence of manual systems with the efficiency and consistency of electric machines. Special emphasis is placed on energy efficiency, ergonomic operation, and user adaptability, ensuring reduced operator fatigue and improved comfort during prolonged use. The machine is designed with interchangeable mesh screens and a stable vibration mechanism, allowing it to be used across multiple working environments and applications.

By offering dual-mode operation, the developed system ensures uninterrupted sieving performance regardless of power availability, making it a practical, cost-effective, and sustainable solution for agricultural processing units, small-scale industries, and laboratory applications.

II. LITERATURE REVIEW

The literature survey focuses on reviewing existing research, designs, and developments related to sieving machines, including manual, pedal-operated, electrically driven, and hybrid systems. Sieving is a widely used mechanical separation process, and numerous studies have been carried out to improve its efficiency, reduce human effort, and enhance adaptability for different applications.

Several researchers have studied manual and pedal-operated sieving machines as economical solutions for rural and small-scale industries. Pedal-operated systems typically use a crank-slider or chain and sprocket mechanism to convert human leg motion into reciprocating or oscillatory motion of the sieve tray. Studies by Joseph et al. and Kumar et al. highlight that pedal-driven sieving machines significantly reduce manual labour compared to hand sieving and improve productivity while remaining independent of electrical power. These machines are particularly suitable for agricultural applications such as grain cleaning and sand separation in remote locations. However, literature also points out that continuous pedalling may lead to operator fatigue during prolonged use, and the achievable output is limited by human effort.

Electrically operated sieving machines have been extensively researched due to their high efficiency and consistent performance. Researchers such as Ramesh and Prasad have demonstrated that vibratory sieving machines using electric motors and eccentric mechanisms provide uniform vibration, higher throughput, and better separation accuracy compared to manual methods. These machines are widely used in construction, pharmaceutical, and food-processing industries. Key design parameters discussed in literature include vibration frequency, amplitude, mesh size, tray mass, and motor speed. Although electric sieving machines offer superior performance, studies also report disadvantages such as high initial cost, increased power consumption, and complete dependency on continuous electricity supply, making them less suitable for rural or small-scale users.

Comparative studies between manual, pedal-operated, and electrically driven sieving systems indicate that mechanical sieving methods are approximately two to three times more efficient than traditional hand sieving in terms of throughput and time efficiency. Research findings emphasize that consistent vibration significantly improves separation quality and reduces material loss. Ergonomics and operator safety are also highlighted as critical factors, especially for pedal-operated systems, where improper design can increase fatigue and discomfort.

Recent literature has also explored vibration analysis and dynamic modelling of sieving machines. Authors have modelled the sieve tray as a vibrating system to study natural frequency, resonance conditions, and response under forced excitation. These studies help optimize vibration parameters to maximize sieving efficiency while minimizing

structural stress and noise. Proper dynamic tuning ensures smooth operation and prolongs machine life. However, many small-scale designs lack detailed vibration optimization due to simplicity and cost constraints.

Multi-layer and multipurpose sieving machines have been proposed to increase versatility. Research shows that machines with interchangeable mesh trays or multi-deck arrangements allow separation of materials into different size fractions in a single operation, improving productivity and reducing handling time. Modular designs enable the same machine to be used for agricultural products, construction materials, and laboratory samples by simply changing the sieve mesh.

Despite extensive research on individual pedal-operated and electric sieving machines, the literature reveals a clear gap in integrated dual-mode systems that combine both human-powered and electric-powered operation in a single machine. Few studies focus on roller-guided vibration systems that replace traditional spring mechanisms to provide smoother and more controlled motion. Additionally, limited research addresses the ergonomic optimization and cost-effective fabrication of hybrid sieving machines suitable for both rural and industrial environments.

Based on the reviewed literature, there is a strong need for a low-cost, energy-efficient, and multipurpose dual-mode sieving machine that ensures reliable performance under varying power conditions. The present research aims to bridge this gap by developing a hybrid pedal and electric operated sieving machine with improved ergonomics, interchangeable meshes, and smooth roller-based vibration, offering a practical and sustainable solution for small-scale industries and agricultural applications.

III. PROPOSED SYSTEM (AI-ASSISTED SYSTEM)

The proposed system is an AI-assisted multipurpose dual-mode sieving machine designed to improve material separation efficiency while ensuring operational flexibility, energy efficiency, and user adaptability. The system integrates a mechanically robust sieving unit with basic AI-assisted decision and monitoring support, enabling optimized operation under varying material and power conditions. The primary objective of the proposed system is to combine human-powered (pedal-operated) and electric motor-driven mechanisms with intelligent assistance to enhance performance, reduce manual effort, and improve reliability.

IV. SYSTEM ARCHITECTURE

The system consists of a rigid mild steel frame supporting a sieve tray mounted on a roller-guided vibration mechanism. This roller system ensures smooth and controlled reciprocating motion with minimal friction compared to traditional spring-based arrangements. The sieve tray is designed to accommodate interchangeable mesh screens, allowing separation of materials of different particle sizes such as sand, grains, and powdered substances.

Two modes of operation are integrated within a single mechanical structure:

1. Pedal-Operated Mode (Manual Mode)

In this mode, human leg motion is converted into mechanical oscillation using a crank, chain, and connecting rod mechanism. The roller-guided tray moves in a controlled reciprocating manner, enabling effective sieving without electrical power. This mode ensures uninterrupted operation in off-grid or power-deficient environments.

2. Electric Motor-Operated Mode (Automatic Mode)

When electrical power is available, an electric motor drives the same oscillatory mechanism through a belt and pulley or eccentric cam system. This mode provides uniform vibration, higher throughput, and consistent separation quality with minimal human effort.

AI-Assisted Functional Features

Artificial Intelligence is incorporated at a **supportive and supervisory level**, rather than replacing the mechanical operation. AI tools are used for:

- **Operational Parameter Recommendation:**

Based on material type, mesh size, and desired output, AI-assisted logic suggests optimal operating mode (pedal or electric), vibration speed, and recommended processing duration.

- **Performance Monitoring:**
Simple sensors (speed, vibration frequency, and load) can be used to collect operational data. AI-assisted analysis helps identify inefficient operating conditions, excessive vibration, or overload scenarios.
- **Maintenance Prediction Support:**
By observing patterns such as increased vibration, irregular motion, or reduced output, AI-assisted models can recommend maintenance actions such as lubrication of rollers, mesh replacement, or belt tension adjustment.
- **Energy Optimization Guidance:**
AI-assisted recommendations help minimize energy consumption by advising pedal operation for low-volume tasks and electric mode for bulk processing, thereby improving overall sustainability.

Working Principle

The system operates on the principle of controlled reciprocating vibration. Motion generated either through pedalling or motor rotation is transferred to the sieve tray, which moves back and forth over rollers. Fine particles pass through the mesh while coarser particles remain on the tray. AI-assisted feedback enhances operational efficiency by guiding the user toward optimal operating conditions.

Advantages of the AI-Assisted Proposed System

- Dual-mode operation ensures continuous functionality
- Improved efficiency through AI-guided parameter selection
- Reduced operator fatigue and optimized energy usage
- Enhanced machine reliability and preventive maintenance
- Suitable for rural, industrial, and laboratory applications

Expected Outcome

The proposed AI-assisted multipurpose sieving system is expected to deliver improved separation efficiency, reduced operational cost, and enhanced adaptability. By combining mechanical engineering principles with AI-assisted monitoring and optimization, the system provides a practical, intelligent, and sustainable solution for modern material separation challenges.

V. DESIGN AND MODELLING

The design and modelling of the proposed AI-assisted multipurpose dual-mode sieving machine were carried out with the objective of achieving high separation efficiency, mechanical stability, ergonomic operation, and adaptability to both manual and electric modes of operation. The system was designed by integrating fundamental mechanical engineering principles with computer-aided design (CAD) tools to ensure accuracy, reliability, and ease of fabrication.

Design Considerations

The following key factors were considered during the design stage:

- Dual-mode operation (pedal and electric)
- Smooth and controlled vibration of the sieve tray
- Reduction of friction and mechanical losses
- Structural strength and vibration stability
- Ergonomic comfort for the operator
- Ease of maintenance and low manufacturing cost
- Compatibility with AI-assisted monitoring and optimization

Frame Design

The main frame forms the backbone of the sieving machine and is fabricated using mild steel angle sections due to their high strength, durability, and ease of welding. The frame is designed to withstand dynamic loads generated during continuous vibration without excessive deformation. Finite spacing between members ensures rigidity while minimizing overall weight. The frame geometry also allows easy mounting of the motor, pedal mechanism, rollers, and sieve tray.

Sieve Tray and Mesh Design

The sieve tray is designed as a removable unit fitted with interchangeable wire mesh screens of varying sizes. This modular approach enables the machine to be used for multiple materials such as sand, grains, and powdered substances. The tray dimensions are optimized to ensure adequate screening area while maintaining stable motion during operation. Stainless steel mesh is preferred for corrosion resistance and long service life.

Roller-Guided Motion System

Unlike conventional spring-mounted systems, the proposed design employs a roller-guided reciprocating mechanism. Rollers supported by bearings with housing guide the linear movement of the sieve tray. This design reduces friction, minimizes vibration losses, and provides controlled oscillation. The roller system also improves durability and reduces maintenance requirements, making it suitable for prolonged use.

Pedal Mechanism Design

The pedal-operated system is designed using a bicycle-type crank, chain, and sprocket arrangement. Human pedaling motion is converted into rotary motion, which is then transferred to a crank and connecting rod mechanism to generate reciprocating movement of the sieve tray. The crank radius and stroke length are selected to produce sufficient vibration amplitude while ensuring ergonomic comfort and reduced operator fatigue.

Electric Drive Design

In electric mode, a single-phase electric motor is used to drive the system through a belt and pulley or eccentric cam mechanism. The motor speed is selected to achieve optimal vibration frequency without inducing resonance in the structure. Pulley ratios allow speed adjustment, enabling the system to handle different materials effectively. The electric drive shares the same transmission path as the pedal mechanism, ensuring seamless switching between modes.

Shaft and Bearing Selection

The main shaft is designed to transmit torque from both the pedal and motor systems. Bearings with housing are selected to support the shaft and rollers, ensuring smooth rotation and reduced wear. Standard bearing sizes are used for ease of replacement and cost efficiency.

CAD Modelling

The complete assembly of the sieving machine is modeled using CAD software such as SolidWorks / CATIA / AutoCAD. Individual components including the frame, sieve tray, rollers, crank mechanism, shaft, and motor mount are modeled separately and then assembled to verify alignment, clearance, and motion. CAD modelling helps identify potential interference, optimize component dimensions, and reduce fabrication errors.

AI-Assisted Design Support

Artificial Intelligence tools are used at the design stage to:

- Optimize component dimensions based on load and vibration requirements
- Analyze motion behavior and recommend suitable vibration parameters
- Improve structural layout for better stability and reduced material usage
- Assist in documentation, design validation, and error minimization

AI-BASED PERFORMANCE MONITORING

Artificial Intelligence techniques are applied for intelligent analysis of experimental data. The AI module performs:

- Real-time monitoring of pressure, speed, and torque
- Efficiency prediction using regression-based models
- Identification of optimal operating pressure and speed ranges
- Performance trend visualization for decision support

This approach reduces manual analysis errors and enables data-driven optimization.

VI. EXPERIMENTAL SETUP AND PROCEDURE**A. Experimental Setup**

The experimental setup of the AI-assisted multipurpose dual-mode sieving machine was developed to evaluate its performance under both pedal-operated (manual) and electric motor-operated conditions. The setup was designed to analyse sieving efficiency, vibration behaviour, ease of operation, and overall system reliability for different types of materials.

The machine consists of a rigid mild steel frame supporting the sieve tray, roller-guided motion system, pedal mechanism, electric motor drive, and transmission components. The sieve tray is mounted on bearing-supported rollers, which provide smooth and controlled reciprocating motion. Interchangeable wire mesh screens of different sizes are used depending on the material under test.

The pedal mechanism includes a bicycle-type crank, chain, sprocket, and connecting rod assembly, allowing human effort to generate oscillatory motion. The electric drive system consists of a single-phase electric motor connected to the main shaft through a belt and pulley arrangement. Both drive systems are connected to a common shaft, enabling easy switching between modes.

For experimental observation, materials such as sand, grains, and powdered substances were selected due to their common industrial and agricultural applications. Measuring instruments such as a stopwatch, weighing balance, and tachometer were used to record time, material throughput, and operating speed. AI-assisted analysis tools were used to organize experimental data and identify optimal operating conditions.

B. Experimental Procedure

The experimental procedure was carried out in a systematic manner to ensure accurate and repeatable results.

1. Initial Inspection and Setup

All mechanical components were inspected for proper alignment, lubrication, and secure fastening. The appropriate sieve mesh was selected based on the material to be tested and mounted on the sieve tray.

2. Material Loading

A known quantity of material was weighed and uniformly fed onto the sieve tray to ensure consistent testing conditions.

3. Pedal Mode Testing

- The machine was operated in pedal mode by continuous pedalling at a comfortable speed.
- The oscillatory motion of the sieve tray was observed.
- The time required for complete sieving was recorded.
- The quantity of separated material was measured to determine throughput and efficiency.

4. Electric Mode Testing

- The electric motor was switched on and allowed to reach steady speed.
- Sieving was performed using the same quantity and type of material.
- Vibration uniformity, noise level, and sieving time were observed and recorded.

5. Vibration Observation

The vibration behaviour of the sieve tray was monitored visually and analytically to ensure smooth motion without excessive resonance. AI-assisted tools helped compare vibration response under both operating modes.

6. Data Recording and Analysis

Parameters such as sieving time, output rate (kg/hr), separation quality, and ease of operation were recorded. The collected data was analysed to compare performance between pedal and electric modes.

7. Safety and Shutdown

After each test cycle, the machine was switched off, cleaned, and inspected for wear or loosening of components. Safety guards ensured safe operation throughout the experiments.

C. Observations and Reliability

The experimental setup demonstrated stable performance under both modes of operation. The roller-guided system ensured smooth reciprocating motion with minimal vibration loss. Pedal mode provided effective operation in off-grid conditions, while electric mode delivered higher throughput and uniform separation. Repeated trials confirmed consistent and reliable results.

VII. CONCLUSION

The design, development, and experimental evaluation of the AI-assisted multipurpose dual-mode sieving machine have been successfully carried out. The proposed system effectively addresses the limitations of conventional manual and fully electric sieving machines by integrating pedal-operated and electric motor-operated mechanisms within a single compact structure. This dual-mode capability ensures continuous operation under varying power availability, making the machine suitable for rural, semi-urban, and small-scale industrial environments.

The use of a roller-guided reciprocating motion system instead of traditional spring-based mechanisms resulted in smoother vibration, reduced mechanical losses, and improved operational stability. Experimental testing confirmed that the machine provides higher sieving efficiency, reduced processing time, and consistent separation quality compared to manual sieving methods. Pedal operation minimized dependency on electrical power while maintaining acceptable productivity, whereas electric mode offered higher throughput with minimal human effort.

AI assistance played a supportive role in design optimization, operational parameter selection, and performance analysis, contributing to improved reliability and efficiency without altering the core mechanical functionality. The system is economical, easy to fabricate using locally available materials, and requires minimal maintenance.

Overall, the developed multipurpose sieving machine demonstrates a practical, energy-efficient, and sustainable solution for material separation. The project highlights the successful integration of mechanical engineering principles with AI-assisted tools, making it suitable for agricultural processing units, construction applications, laboratories, and small-scale industries.

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