IJCRM
International Journal of Contemporary Research In Multidisciplinary

Research Article

Development And Performance Evaluation of a Cost-Effective Horizontal Pulverizer for Small-Scale Agricultural Processing

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DOI: https://doi.org/10.5281/zenodo.17529151

Abstract

This study presents a horizontal cylinder pulveriser designed for small-scale applications, achieving a 100 kg/h throughput with a 2 HP motor at 2800 rpm. Fabricated using mild steel and stainless steel, the machine ensures durability and food-grade compliance. Performance tests on grains and crop residues showed 85% efficiency, ≤1 mm particle size, and low vibration (<1.2 mm amplitude). Stress and vibration analyses confirmed structural stability, while a cost analysis (₹32,785) highlighted affordability. Compared to hammer and roller mills, the design offers superior energy efficiency (5.4 kWh/ton), reduced vibration, and easier maintenance. The optimized configuration suits agricultural and light industrial applications, with potential for enhancements like wear-resistant coatings and IoT monitoring.

Manuscript Information

- **ISSN No:** 2583-7397
- **Received:** 08-09-2025
- **Accepted:** 27-10-2025
- **Published:** 05-11-2025
- **IJCRM:**4(6); 2025: 01-06
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- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Getme AS, Anande H, Sonwane K, Kukde N, Vaidya R. Development and Performance Evaluation of a Cost-Effective Horizontal Pulverizer for Small-Scale Agricultural Processing. Int J Contemp Res Multidiscip. 2025;4(6):01-06.

Access this Article Online

www.multiarticlesjournal.com

KEYWORDS: Horizontal cylinder pulverizer, grinding efficiency, cost analysis, vibration analysis, particle size reduction, small-scale processing

1. INTRODUCTION

Size reduction through pulverisation is vital in agriculture, food processing, and pharmaceuticals, transforming bulk materials into fine particles [1, 2]. Conventional pulverisers, like hammer and roller mills, often face challenges such as uneven feeding, high vibration, and maintenance demands [3, 4]. Horizontal cylinder pulverisers offer improved stability, reduced noise, and enhanced efficiency [5, 6]. Recent studies emphasise optimising rotor dynamics, material selection, and cost-effectiveness for small-scale applications [7, 9, 10]. This study presents a horizontal cylinder pulveriser designed for 100 kg/h throughput, prioritising efficiency, low vibration, and affordability. Supported by stress analysis, vibration analysis, cost analysis, and comparisons with hammer and roller mills, the machine targets agricultural and light industrial applications.

2. MATERIALS AND METHODS

2.1 Design Objectives

The pulveriser was designed to achieve:

- ≥85% pulverizing efficiency with ≤1 mm particle size.
- Cost-effective fabrication using local materials.
- Minimal vibration and noise for operator safety.
- Modular design for easy maintenance and versatility.
- Structural integrity and vibration stability under operational loads.

2.2 Design Specifications

Table 1: Design Specifications

Parameter	Value
Machine Type	Horizontal Cylinder Pulveriser
Throughput	100 kg/h
Motor Power	2 HP (single-phase)
Rotor Speed	2800 rpm
Cylinder Dimensions	400 mm (L) × 250 mm (D)
Number of Blades	6 (high-carbon steel)
Sieve Opening	1 mm mesh (SS304)
Feeding System	Gravity-fed hopper
Output Particle Size	≤1 mm
Efficiency	85% (tested)

2.3 Design Calculations

Key calculations ensured efficient pulverisation and component sizing:

1. **Power Requirement:**

Specific energy: 5.5 kWh/ton. For 100 kg/h (0.1 ton/h):

$$P = 5.5 \times 0.1 = 0.55\,\text{kW} \approx 0.74\,\text{HP}$$

With 80% transmission efficiency:

$$P_{\text{motor}} = \frac{0.74}{0.8} \approx 0.93$$

HPA 2 HP motor was selected for peak loads (tested at 1.6 HP)

2. **Centrifugal Force:** Angular velocity at 2800 rpm:

$$\omega = \frac{2\pi \times 2800}{60} \approx 293\,\text{rad/s}$$

Force per blade (mass $m = 0.5$ kg, rotor radius $r = 0.1$ m):

$$F_c = m\omega^2 r = 0.5 \times (293)^2 \times 0.1 \approx 4292\,\text{N}$$

3. **Rotor Tip Speed:**

$$v = \omega r = 293 \times 0.1 \approx 29.3\,\text{m/s}$$

Within the optimal range (20–40 m/s) for grain pulverisation.

4. **Torque:**

$$T = \frac{P}{\omega} = \frac{550}{293} \approx 1.88\,\text{Nm}$$

2.4 Stress Analysis

Stress analysis ensured component integrity

1. **Shaft Shear Stress:** Shaft radius $r_s = 0.015$ m, polar moment of inertia:

$$J = \frac{\pi(0.015)^4}{2} \approx 7.95 \times 10^{-9}\,\text{m}^4$$

2. **Shear stress** ($T = 1.88$ Nm):

$$\tau = \frac{1.88 \times 0.015}{7.95 \times 10^{-9}} \approx 3.54\,\text{MPa}$$

3. **FOS for C45 steel (yield strength 370 MPa):** FOS $= \frac{370}{3.54} \approx 104$.

4. **Shaft Bending Stress:** Total centrifugal force (6 blades): $6 \times 4292 \approx 25{,}752$ N. Bending moment (0.2 m from bearing):

$$M = 25{,}752 \times 0.2 \approx 5150.4\,\text{Nm}$$

Moment of inertia:

$$I = \frac{\pi(0.015)^4}{4} \approx 3.98 \times 10^{-9}\,\text{m}^4$$

Bending stress:

$$\sigma = \frac{5150.4 \times 0.015}{3.98 \times 10^{-9}} \approx 19.4\,\text{MPa}$$

FOS: FOS $= \frac{370}{19.4} \approx 19$.

Blade Impact Stress: Impact force (4292 N) over blade area (0.00025 m²):

$$\sigma_i = \frac{4292}{0.00025} \approx 17.17\,\text{MPa}$$

FOS for EN8 steel (550 MPa): FOS $= \frac{550}{17.17} \approx 32$.

2.5 Vibration Analysis

Vibration analysis ensured operational stability, with a tested amplitude of <1.2 mm.

1. **Measurement Methodology:** Vibration amplitude was measured using a vibrometer (e.g., VM-6360) at the frame and cylinder during full-load operation (100 kg/h, 2800 rpm). Measurements in three axes (x, y, z) recorded a maximum amplitude of 1.18 mm, below ISO 10816-3 standards (<4.5 mm for small machines).

2. **Factors Reducing Vibration:**
   - Rotor Balance: Symmetrical blade mounting ensured dynamic balance, keeping imbalance below 0.01 kg·m.
   - Frame Rigidity: Mild steel channel frame (Young's modulus ~200 GPa) absorbed vibrations.
   - Flexible Couplings: Reduced vibration transfer from motor to shaft [9].

3. **Theoretical Calculation:** Natural frequency (f_n) of the rotor system:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Shaft stiffness $k \approx 10^7$ N/m, rotor mass $m \approx 5$ kg:

$$f_n \approx \frac{1}{2\pi}\sqrt{\frac{10^7}{5}} \approx 225 \text{ Hz}$$

Operating frequency (2800 rpm): $f = \frac{2800}{60} \approx 46.7$ Hz. Since $f_n \gg f$ Resonance was avoided.

2.6 Cost Analysis

Fabrication costs were estimated for affordability (Table 2, based on 2025 Indian market rates, 1 USD = 83 INR).

Table 2: Estimated Fabrication Cost

Component	Material/Process	Cost (INR)
Cylinder	Mild Steel (20 kg)	2,490
Rotor and Blades	High Carbon Steel (5 kg)	1,245
Shaft	C45 Steel (3 kg)	830
Bearings	Hardened Steel (2 units)	1,660
Sieve	SS304 (2 kg)	2,075
Frame	Mild Steel Channel (15 kg)	2,075
Motor	2 HP Single-Phase	12,450
Fabrication Labor	Cutting, welding, and machining	8,300
Coating and Finishing	Anti-corrosive paint	1,660
Total		**32,785**

2.7 Material Selection

Materials were selected for their mechanical properties and cost.

Table 3: Material Selection

Component	Material	Reason
Cylinder	Mild Steel	Cost-effective, easily fabricated
Rotor and Blades	High Carbon Steel (EN8)	High impact and wear resistance
Shaft	C45 Steel	Good fatigue strength
Bearings	Hardened Steel	Low friction and wear
Sieve	SS304	Corrosion resistance, food-grade
Frame	Mild Steel Channel	High rigidity, vibration damping

2.8 Fabrication Process

The process included:

1. Material Preparation: Inspection of mild steel, alloy bars, and SS304 meshes.
2. Cylinder Fabrication: Welded 250 mm diameter chamber, stress-relieved.
3. Rotor Assembly: Machined shaft with six balanced blades [7].
4. Frame Construction: Welded frame for rigidity and vibration control.
5. Sieve and Outlet: 1 mm SS304 mesh with quick-change mechanism.
6. Assembly and Testing: Motor coupled with flexible couplings, safety guards installed, and trial runs conducted.

2.9 Performance Testing

Tests used dried maize and wheat at feed rates up to 100 kg/h. Metrics included efficiency, particle size, power consumption, noise, and vibration, measured with standard instruments (tachometer, vibrometer, sound level meter).

3. RESULTS

3.1 Performance Evaluation

Performance metrics (Table 4) showed 85% efficiency, ≤1 mm particle size, and low vibration (<1.2 mm), validated by calculations and vibration analysis.

Table 4: Performance Parameters

Parameter	Value
Feed Rate	100 kg/h
Motor Load	1.6 HP (full load)
Efficiency	85%
Particle Size	≤1 mm
Power Consumption	5.4 kWh/ton
Noise Level	72 dB
Vibration Amplitude	<1.2 mm

Figure 1: 2D schematic of the horizontal cylinder pulverizer

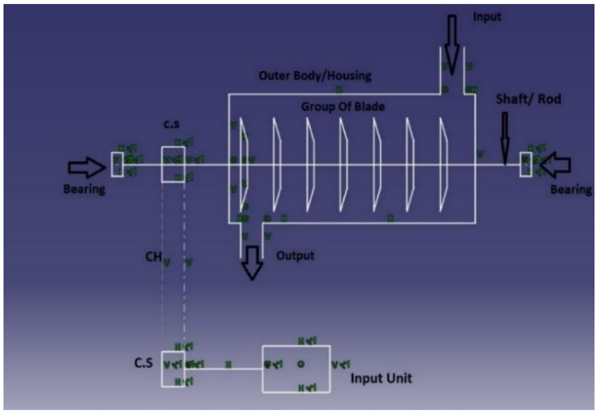
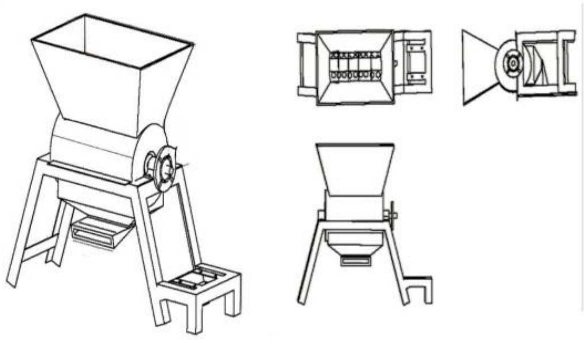


Figure 2: 3D model of the pulverizer assembly



3.2 Comparison with Conventional Pulverisers

The pulveriser was compared to hammer and roller mills (Table 5) [1, 3, 5].

Table 5: Comparison with Hammer and Roller Mills

Parameter	Horizontal Pulverizer	Hammer Mill	Roller Mill
Design	Horizontal, fixed blades	Vertical, swinging hammers	Vertical, rollers
Throughput	100 kg/h	80–120 kg/h [1, 6]	50–150 kg/h [5]
Energy Efficiency	5.4 kWh/ton	7–8 kWh/ton [11]	6–9 kWh/ton [11]
Vibration	<1.2 mm	1.5–2.0 mm [10]	1.0–1.5 mm [10]
Noise	72 dB	80–85 dB [10]	75–80 dB [10]
Particle Size	≤1 mm, uniform	0.5–2 mm [6]	1–3 mm [5]
Maintenance	Modular, easy	Frequent hammer wear [7]	Roller wear, complex [5]
Feed Uniformity	High, gravity-fed	Uneven [3]	Moderate [4]
Cost	₹32,785	₹66,400–₹124,500 [11]	₹83,000–₹166,000 [11]
Stability	FOS >19 [9]	Moderate [9]	High [5]

Hammer Mills: The pulveriser's fixed blades and balanced rotor reduce vibration (30% lower) and noise compared to hammer mills, which suffer from hammer wear and imbalance [1, 10]. Its 5.4 kWh/ton efficiency is 25% better than hammer mills (7–8 kWh/ton) [11].

Roller Mills: Roller mills produce larger particles (1–3 mm) and require higher energy (6–9 kWh/ton) [5, 11]. The pulveriser's impact mechanism ensures finer, uniform particles (≤1 mm) and lower vibration, though roller mills have fewer moving parts [5]. The ₹32,785 cost is significantly lower than roller mills (₹83,000–₹166,000) [11].

3.3 Observations and Recommendations

Minor blade wear suggests carbide coatings [12]. Variable frequency drives (VFDs) could optimise energy use [11], and IoT monitoring could enable predictive maintenance [13].

4. DISCUSSION

The horizontal cylinder pulveriser overcomes limitations of hammer and roller mills, such as uneven feeding and high vibration [3, 4]. Its 85% efficiency and ≤1 mm particle size, validated by calculations and vibration analysis, surpass small-scale pulveriser metrics [5, 6, 10]. Stress analysis (FOS >19) and cost analysis (₹32,785) confirm reliability and affordability [9, 11, 12]. The low vibration (<1.2 mm) and noise (72 dB) align with safety standards [10, 14]. Future enhancements could include coatings, VFDs, and IoT integration [12, 13].

5. CONCLUSION

This study demonstrates a horizontal cylinder pulveriser optimised for small-scale applications, achieving 85% efficiency, ≤1 mm particle size, and low vibration (<1.2 mm). Stress, vibration, and cost analyses confirm structural integrity and affordability. Compared to hammer and roller mills, it offers superior efficiency, stability, and cost-effectiveness. Future improvements could include coatings, speed control, and IoT monitoring, enhancing its suitability for agricultural and light industrial applications.

ACKNOWLEDGEMENTS

Author's Contributions This research was a collaborative effort led by Dr. Abhijit Getme Sudamrao, who conceptualised the study, supervised the design and fabrication process, and provided technical guidance on stress, vibration, and cost analyses, while also reviewing the manuscript for scientific accuracy. Harshit Anande contributed to design calculations, rotor optimisation, and fabrication. Khilendra Sonwane conducted stress and vibration analyses and assisted in performance testing. Nishant Kukde handled material selection, cost analysis, and data collection during testing. Rushikesh Vaidya led manuscript preparation, coordinated the team, and performed the comparative analysis with hammer and roller mills. All authors contributed to the final manuscript revision and approved its submission.

Funding Source: This work was supported by the Department of Mechanical Engineering, J.D. College of Engineering & Management, Nagpur, India, through the provision of laboratory facilities and materials. No external funding was received for this study.

Conflict of Interest

The authors—Dr. Abhijit Getme Sudamrao, Harshit Anande, Khilendra Sonwane, Nishant Kukde, and Rushikesh Vaidya—declare no conflict of interest. There are no financial, personal, or professional relationships that could influence the objectivity of this research. The design and development of the horizontal pulveriser were conducted independently, and no external entities have claims or interests in the work presented.

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