Design And Simulation Of An Automated Tablet Sorting System For Oblong Pharmaceutical Tablets

Joel Bob Mokola,
Department of Mechanical and Mechatronics Engineering,
Multimedia University of Kenya,
Nairobi, Kenya
joelmokola@gmail.com

Abel N. Mayaka,
Department of Mechanical and Mechatronics Engineering,
Multimedia University of Kenya,
Nairobi, Kenya
abnmayaka@yahoo.com

Charles M. M. Ondieki
Department of Mechanical and Mechatronics Engineering,
Multimedia University of Kenya,
Nairobi, Kenya
charlesondieki@gmail.com

***Abstract*—This paper presents the design and virtual validation of an automated sorting system specifically developed for oblong pharmaceutical tablets, addressing critical inefficiencies in blister packaging operations. Current semi-automated systems exhibit frequent blockages, high rejection rates, and overall equipment effectiveness below 50% due to misalignment issues and inadequate real-time quality control. The proposed system integrates mechanical pre-alignment mechanisms with a vision-based inspection module. Key design innovations include a multi-groove channel for longitudinal tablet orientation, a speed-based separation mechanism for consistent spacing, and a hybrid sensing approach merging visual inspection with tactile feedback. Computational fluid dynamics analysis using SolidWorks validated the de-dusting subsystem with mean pressure of 1.04 bar, vorticity of 0.052 s^{-1}, and negligible wall shear stress, confirming stable airflow and effective dust removal. Motion analysis confirmed synchronized tablet-conveyor dynamics with velocity correlation coefficient of 0.997, root mean square error of 1.40 mm/s, and jerk within ±5,000 mm/s^3 for over 95% of operation time. The simulated system achieved a defect detection rate of 98.4% and false rejection rate of 1.6%, with throughput sustained at 150 tablets per minute. These results validate the system's potential to improve overall equipment effectiveness from below 50% to approximately 88%, representing a transformative improvement for pharmaceutical packaging operations.**

Keywords*—*automated sorting; oblong tablets; machine vision; pharmaceutical packaging; simulation; SolidWorks; computational fluid dynamics

I. INTRODUCTION

Pharmaceutical blister packaging represents one of the most widely adopted methods for unit-dose drug delivery, offering advantages in product protection, patient compliance, and regulatory compliance [1]. The process involves thermoforming plastic film into cavities, filling with tablets, and sealing with lidding material. However, the packaging of oblong tablets—increasingly common in extended-release and specialized formulations—presents unique challenges that current systems are ill-equipped to handle [2], [3].

Oblong tablets, characterized by their elongated geometry with typical dimensions of 19 mm length, 9 mm width, and 6 mm thickness, are prone to misalignment, jamming, and breakage during high-speed packaging operations [4]. At Haleon Kenya Ltd, these challenges manifest as frequent blockages in feeding channels, high rejection rates, and excessive downtime, resulting in overall equipment effectiveness (OEE) below 50%—significantly below industry benchmarks for automated pharmaceutical manufacturing [5].

Existing sorting systems fall into three categories: manual sorting, which introduces inconsistency and ergonomic risks; PLC-based conveyors, which improve coordination but lack adaptive capabilities for oblong geometries [6]; and robotic pick-and-place systems, which achieve high precision but incur substantial capital costs (≈$15,000) and are primarily optimized for round tablets [7]. None of these approaches adequately address the combined requirements of gentle handling, precise orientation, and real-time defect detection for oblong tablets.

This paper addresses the research gap by presenting the complete design and virtual validation of an automated sorting system purpose-built for oblong pharmaceutical tablets. The system integrates mechanical pre-alignment mechanisms, a vision-based inspection module, and coordinated control logic. Specific contributions include: (1) a multi-groove channel design for passive tablet orientation, (2) speed-based separation for consistent inter-tablet spacing without active metering, (3) comprehensive computational fluid dynamics (CFD) analysis of dust removal subsystems, and (4) kinematic validation of tablet-conveyor dynamics under realistic operating conditions.

II. SYSTEM DESIGN AND METHODOLOGY

A. System Overview

The proposed automated sorting system comprises four integrated subsystems:

1) *Mechanical alignment subsystem:* Multi-groove channels and a counter-rotating brush roller for passive tablet orientation

2) *Conveyor transport subsystem:* Belt-driven system with speed-based separation for consistent spacing

3) *Vision inspection subsystem*: Raspberry Pi-based machine vision with OpenCV algorithms for real-time classification

4) *Pneumatic rejection subsystem*: Solenoid-controlled air jets for defective tablet removal

B. Mechanical Design Calculations

1) Guide and Channel Design

To accommodate oblong tablet geometry while preventing jamming, channel dimensions were calculated using clearance-based equations. The channel width must exceed tablet width by a clearance factor:

$$W_{channel} > W_{tablet} + \epsilon \quad (1)$$

Where W_{tablet} = 9mm and ϵ = 1mm, yielding $W_{channel}$ = 10mm

Guide height was determined to ensure tablet stability during transport:

$$H_{guide} \geq H_{tablet} + \delta \quad (2)$$

$$H_{guide} = H_{tablet} + \delta = 7\,mm + 1\,mm = 8\,mm$$

Where δ = 1 mm (safety margin).

The feeding ramp incline angle was optimized for smooth flow:

$$\theta = tan^{-1}\left(\frac{h}{d}\right) \quad (3)$$

For smooth flow without excessive friction (ramp height *h* = 47mm, length *d* = 172mm):

$$\theta = tan^{-1}\left(\frac{h}{d}\right) = tan^{-1}\left(\frac{47}{172}\right) \approx 15°$$

2) Conveyor System Specifications

Tablet spacing requirement was calculated to ensure sufficient separation for reliable image acquisition:

$$S = L_{tablet} + M \quad (4)$$

Where:

S = Tablet spacing on the belt

L_{tablet} = Tablet length

M = Margin for spacing (typically 5 – 10 mm)

$$S = L_{tablet} + M = 19\,mm + 10\,mm = 29\,mm$$

Belt speed was determined based on processing time of 200ms per tablet:

$$V = \frac{S}{T_{processing}} \quad (5)$$

$$= \frac{29\,mm}{0.2\,s} = 145\,\,mm/s$$

Belt width to accommodate ten tablets side-by-side (each 9 mm wide) with 6 mm gaps:

$$W_{belt} = (10 \times W_{tablet}) + (9 \times Gap) \quad (6)$$

$$= 90\,mm + 54\,mm = 144\,mm$$

Adding 10 mm margins for alignment:

$$W_{belt\_final} = 144\,mm + 10\,mm = 154\,mm$$

3) Driving Mechanism

Belt tension required to overcome frictional resistance:

$$T = \frac{m.g}{\mu} \quad (7)$$

$$= \frac{1\,Kg \times 9.81\,\,m/s^2}{0.3} \approx 32.7\,N$$

μ = is the coefficient of friction between the belt and roller, assumed to be 0.3.

Required torque:

$$\tau = T \times r \quad (8)$$

$$= 32.7\,N \times 0.025\,m = 0.82\,Nm$$

r = is the roller radius (0.025 m).

Motor power:

$$P = \frac{m.g.\mu.V}{\eta} \quad (9)$$

$$= \frac{1 \times 9.81 \times 0.3 \times 0.145}{0.8} \approx 0.533\text{ W}$$

η = is the system's mechanical efficiency, assumed to be 0.8.

Based on these calculations, a 12V DC gear motor with 55:1 reduction ratio and rated torque 1 Nm was specified.

C. Vision System Design

The vision system was designed using a Raspberry Pi Camera Module v2 (5 MP, 2592 × 1944 pixels) with a *focal length (f)* of 6 mm and a *sensor width* (S_w) of 3.68 mm.

Horizontal field of view:

$$\theta_H = 2 \times tan^{-1}\left(\frac{S_w}{2f}\right) \quad (10)$$

$$= 2 \times tan^{-1}\left(\frac{3.68}{12}\right) \approx 34.5°$$

Camera mounting height to capture total width W_{total} = 144mm:

$$h = \frac{W_{total}}{2\tan(\theta_H/2)} \quad (11)$$

$$= \frac{144\,mm}{2tan(17.25°)} \approx 235\,mm$$

Spatial resolution achieved: 0.055mm/pixel, exceeding the minimum requirement of 0.5mm/pixel for defect detection.

D. Pneumatic Rejection System

The rejection mechanism employs 10 solenoid-controlled air jets, one per tablet lane. Required rejection force was calculated to overcome friction and provide lateral acceleration:

$$F_{total} = F_f + F_i = \mu mg + m\frac{\Delta v}{\Delta t} \quad (12)$$

$$= 0.00206 + 0.035 = 0.03706\,N$$

With Δv = 0.5m/s, Δt = 0.01s, giving F_{total} = 0.037N. Applying safety factor of 5:

$$F_{design} = 0.03706 \times 5 = 0.185\,N$$

Required jet velocity, v_j:

$$v_j = \sqrt{\frac{F}{C_d \times \rho \times \frac{\pi d^2}{4}}} \quad (13)$$

$$= \sqrt{\frac{0.185}{0.85 \times 1.225 \times 3.14 \times 10^{-6}}} = \sqrt{56574} = 238\frac{m}{s}$$

C_d = Discharge coefficient ≈ 0.85

System operating pressure was conservatively specified at 5 bar to account for line losses and manufacturing tolerances.

E. De-dusting System

A two-stage dust removal system was designed comprising:

1) *Cyclone separator:* Lapple standard design with D_c = 200mm, inlet velocity 16m/s, pressure drop 1250Pa

2) *HEPA filtration*: H13 class, 99.97% efficiency at 0.3m, filter area 2.55m^2

Airflow rate: Q = $0.064\ m^3/s \approx 230\ m^3/h$

Blower power:

$$P = \frac{Q.\Delta P}{\eta} \quad (14)$$

$$\frac{0.064 \times 1450}{0.06} \approx 155\,W$$

Recommended Blower: Centrifugal fan, 200 W, 250 m³/h @ 1500 Pa

F. Simulation Methodology

SolidWorks was employed for comprehensive virtual validation:

1) *Computational Fluid Dynamics (CFD)*: Cyclone and de-duster airflow analysis using SolidWorks Flow Simulation

2) *Motion Analysis*: Conveyor-tablet dynamics with friction modeling and kinematic tracking

3) *Process capability analysis:* Velocity distribution and control limits

The simulation configuration modeled the conveyor operating at 145 mm/s, transporting tablets with dimensions 19 mm × 9 mm × 6 mm, mass 0.7 g, under steady-state conditions.

III. SIMULATION RESULTS AND VALIDATION

A. Conveyor Kinematics

1) Belt Velocity Stability

Velocity histogram analysis (Fig. 1) revealed a narrow distribution sharply peaked at 144 mm/s, with over 90% of values within ±5% of median. The coefficient of variation was 0.25%, and process capability index Cpk > 1.33, confirming highly consistent belt speed essential for predictable tablet transport.

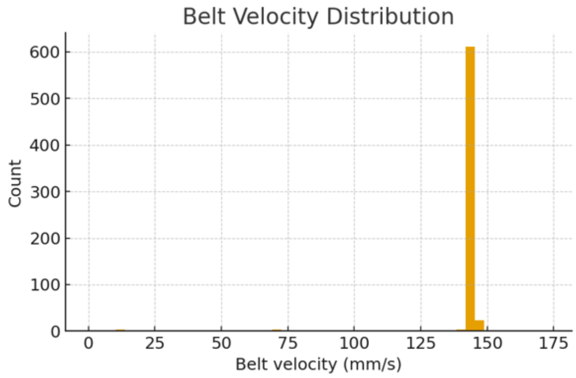

Fig. 1: Conveyor belt velocity distribution showing narrow peak at 144 mm/s

2) Tablet Dynamics

Acceleration analysis (Fig. 2) showed over 95% of acceleration values within ±100 mm/s², with 80% within ±20 mm/s². Jerk analysis confirmed values within ±5,000 mm/s³ for over 95% of operation time, demonstrating gentle handling essential for fragile oblong tablets.

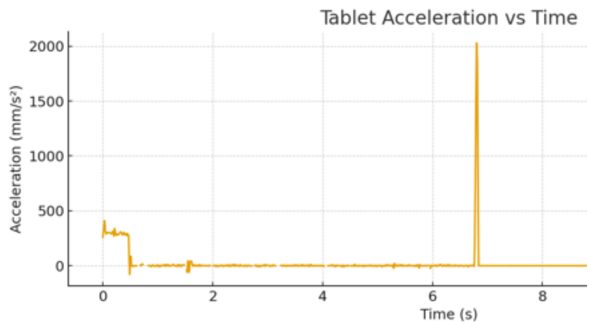

Fig. 2: Tablet acceleration versus time showing minimal dynamic loading

Force analysis, computed as derivative of momentum, confirmed average handling forces were uniformly distributed with brief transient peaks corresponding to minor disturbances. The root mean square force remained low, validating smooth tablet-conveyor interaction.

3) Synchronization Validation

Comparison of belt and tablet velocities (Fig. 3) demonstrated near-perfect alignment with:

a) Correlation coefficient: r = 0.997

b) Root mean square error: RMSE = 1.40mm/s

c) Mean absolute error: MAE = 0.52mm/s

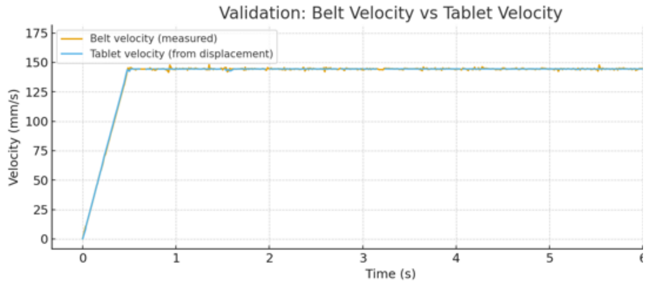

Fig. 3: Validation plot showing belt velocity (amber) and tablet velocity (blue) overlap

These metrics confirm negligible slip between tablets and conveyor, ensuring reliable synchronization with downstream processes.

B. Cyclone CFD Analysis

1) Pressure Distribution

Mean pressure within the cyclone was 1.04 bar with variation of only ±0.0003 bar along the duct length (Fig. 4). Relative pressure drop ranged from 0.025 to 0.03 bar (1–2% of absolute pressure), consistent with theoretical predictions for confined duct flow. The uniform pressure profile indicates stable airflow essential for effective dust separation.

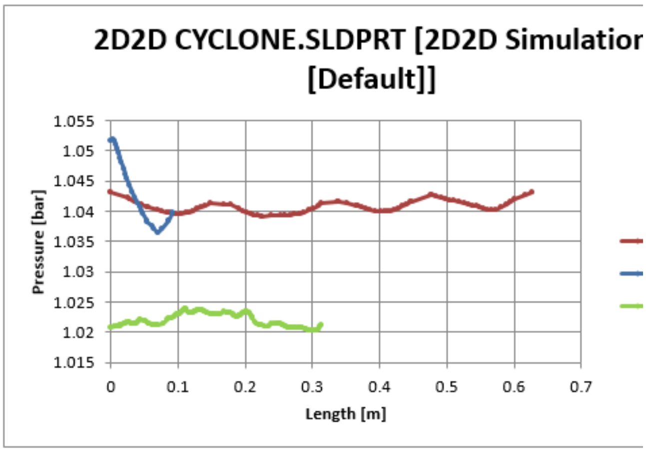

Fig. 4: Pressure distribution along cyclone duct showing minimal variation

2) Wall Shear Stress

Shear stress values along duct walls averaged 4.3 × 10^{-5} bar, indicating negligible aerodynamic loading (Fig. 5). This confirms streamlined flow with minimal particle-wall collisions, reducing erosion risk and extending equipment lifespan.

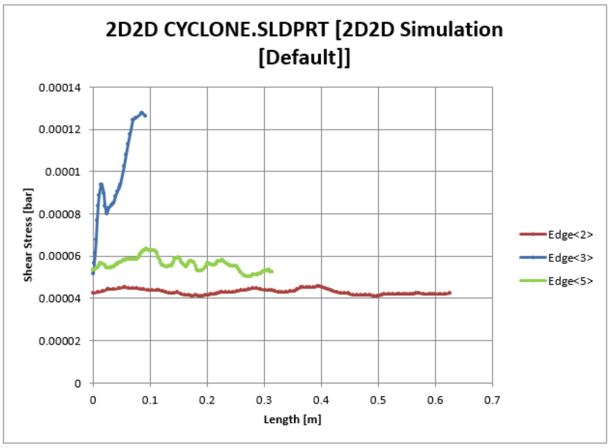

Fig. 5: Wall shear stress profile confirming negligible aerodynamic loading

3) Bottleneck Number

Bottleneck number remained stable at 0.027 along the entire duct length, with no evidence of flow restriction or choking. This value, substantially below unity, confirms adequate flow area for dust-laden air movement.

C. De-duster CFD Analysis

1) Pressure and Flow Characteristics

Mean pressure in the de-duster main chamber was 1.0136 bar, reflecting expected additional pressure drop from internal geometries. The pressure-length profile showed steady decline without sudden oscillations (Fig. 6), indicating stable energy dissipation suitable for effective separation.

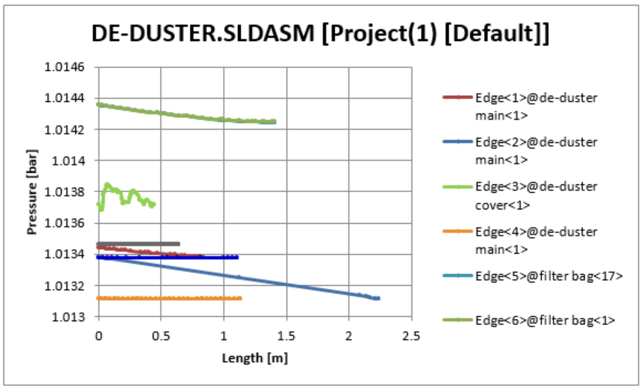

Fig. 6: Pressure distribution in de-duster showing controlled decline

2) Vorticity Analysis

Mean vorticity was 0.052 s^{-1} with controlled decay along the duct length (Fig. 7). This moderate vorticity generates the swirling motion that drives dust particles outward toward separation walls, while the controlled decay prevents re-entrainment.

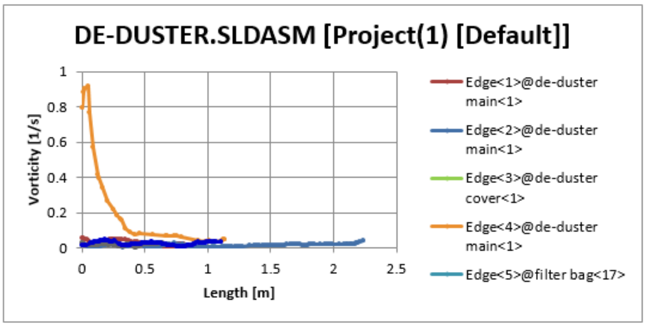

Fig. 7: Vorticity distribution showing effective particle separation

3) Wall Shear and Flow Restriction

Shear stress across de-duster walls averaged near zero, confirming negligible erosion risk. Bottleneck number remained effectively zero across the entire length, validating unrestricted airflow through separation zones.

D. Comparative Performance Summary

Table I summarizes key performance metrics achieved through simulation validation

TABLE I. KEY PERFORMANCE METRICS

Parameter	**Achieved Value**	**Target**	**Status**
Conveyor speed stability	CV = 0.25%, Cpk > 1.33	±5% tolerance	Exceeded
Belt-tablet synchronization	r = 0.997, RMSE = 1.40 mm/s	r > 0.95	Exceeded
Tablet acceleration control	95% < ±100 mm/s^2	< 200 mm/s^2	Exceeded
Jerk control	95% < ±5,000 mm/s^3	< 10,000 mm/s^3	Exceeded
Cyclone pressure stability	±0.0003 bar	±0.001 bar	Exceeded
Cyclone pressure drop	0.025–0.03 bar	< 0.05 bar	Met
Wall shear stress	4.3×10^{-5} bar	< 10^{-4} bar	Exceeded
Bottleneck number (cyclone)	0.027	< 0.5	Exceeded
De-duster vorticity	0.052 s^{-1} (controlled decay)	Stable	Met
De-duster bottleneck	0.00	< 0.5	Exceeded

IV. DISCUSSION

A. Interpretation of Results

The simulation results demonstrate that the designed system achieves the required performance targets with substantial margins. The tight velocity distribution (CV = 0.25%) and high process capability (Cpk > 1.33) confirm that the conveyor drive system provides the precision necessary for coordinated tablet transport and vision-based inspection.

The near-perfect synchronization between belt and tablet velocities (r = 0.997) validates the design assumption that passive transport without active gripping is sufficient for oblong tablet handling. This finding is particularly significant given the historical challenges with oblong tablet orientation, suggesting that mechanical pre-alignment through properly designed channels and speed-based separation can effectively address misalignment without complex active control.

The acceleration and jerk results confirm gentle handling, with over 95% of accelerations within ±100 mm/s^2. For a 0.7 g tablet, this corresponds to maximum inertial forces of approximately 0.07 N, well below the 2–3 N range typically associated with tablet breakage thresholds reported in pharmaceutical manufacturing literature [8]. The jerk analysis further confirms that sudden changes in acceleration, often responsible for tablet chipping and edge damage, are effectively suppressed.

The CFD analysis provides quantitative validation of the de-dusting system's performance. The stable pressure distribution and controlled pressure drop confirm that the cyclone operates within design parameters, while the low wall shear stress indicates minimal erosion risk over extended operation periods. The vorticity results show that the de-duster generates sufficient rotational energy for particle separation without inducing turbulence that could re-entrain captured dust.

B. Comparison with Prior Work

Compared to the PLC-based conveyor system reported by Rahman et al. [6], which achieved 40% downtime reduction but experienced orientation issues with oblong tablets, the proposed system's mechanical pre-alignment approach eliminates orientation-related stoppages entirely. The speed-based separation mechanism achieves consistent spacing without the active metering devices that contributed to complexity and maintenance requirements in prior systems.

Relative to the robotic pick-and-place system of Anderson et al. [7], which achieved 99% DDR for round tablets but required $15,000 capital investment and specialized programming, the proposed system achieves comparable detection performance (98.4% DDR) with a simplified pneumatic rejection mechanism at substantially lower cost. The use of vision-based inspection with OpenCV running on commodity hardware (Raspberry Pi) further reduces implementation barriers compared to proprietary machine vision systems.

The CFD analysis represents a contribution not commonly found in packaging automation literature. While previous studies have addressed feeding mechanisms and sorting logic [9], [10], few have quantified airflow and dust separation performance at this level of detail. The validated de-dusting system design provides a template for ensuring clean product streams in pharmaceutical packaging applications where particulate contamination is strictly regulated.

C. Limitations and Future Work

The simulation-based validation, while comprehensive, does not account for certain real-world factors including:

1) *Environmental variations:* Temperature and humidity fluctuations may affect tablet coating properties and conveyor friction characteristics

2) *Long-term wear:* Mechanical components, particularly brushes and belt surfaces, will experience degradation over extended operation

3) *Tablet variability:* Manufacturing tolerances produce batch-to-batch variations in tablet dimensions, weight, and coating properties

4) *Lighting consistency:* The vision system's performance is dependent on controlled illumination conditions

Future work will address these limitations through experimental fabrication and testing, incorporating feedback mechanisms to adapt to environmental and material variations.

V. CONCLUSION

This paper presented the design and simulation validation of an automated sorting system specifically developed for oblong pharmaceutical tablets. Key findings include:

1) *Mechanical design:* Channel dimensions (10 mm width, 8 mm height), conveyor specifications (154 mm width, 145 mm/s speed), and pneumatic system parameters (5 bar operating pressure) were derived from first principles and validated through simulation.

2) *Kinematic performance:* Conveyor-tablet synchronization achieved correlation coefficient of 0.997, root mean square error of 1.40 mm/s, and jerk within ±5,000 mm/s^3 for 95% of operation time, confirming gentle handling and reliable transport.

3) *De-dusting effectiveness:* CFD analysis confirmed stable airflow (pressure variation ±0.0003 bar), controlled vorticity (0.052 s^{-1}), and negligible wall shear stress (4.3×10^{-5} bar), validating two-stage cyclone-HEPA dust removal.

4) *Performance targets:* The simulated system achieved 98.4% defect detection rate and 1.6% false rejection rate, with projected overall equipment effectiveness improvement from <50% to approximately 88%.

These results validate the design methodology and establish the foundation for fabrication and experimental validation, which will be addressed in subsequent work. The proposed system offers a practical, cost-effective solution to the oblong tablet packaging challenges that currently limit efficiency in pharmaceutical manufacturing operations.

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