Analyzing Mechanical Defect Variability in Tablet Manufacturing: A Comprehensive Investigation of Machine Performance Consistency

Joar Manuel Santos Rolón
Master of Engineering in Manufacturing Engineering
Advisor: Rafael Nieves, PharmD.
Polytechnic University of Puerto Rico
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Abstract *— This study analyzes mechanical edge defects in the production of pharmaceutical tablets by analyzing performance variability across three rotary tablet compression machines. This investigation evaluates defect trends across ten production batches for each machine using statistical quality control methodologies, including control charts. The initial results indicate that Machine C exhibits the highest variability, mainly due to turret vibration, while both Machines A and C exhibit indications of undetected die wear. Following resolving these mechanical issues, all three machines exhibited enhancements in process stability and reduced defects. These findings accentuate the importance of integrating statistical monitoring with preventive maintenance to improve manufacturing consistency and ensure product quality within pharmaceutical operations.*

Key Terms *— Compression, Tablet Edge Defect, Maintenance.*

PROBLEM STATEMENT

This research seeks to evaluate the mechanical defect patterns associated with three tablet compression machines by analyzing edge defects in the production of pharmaceutical tablets. Despite operating under similar conditions, the defect rates differ among the machines, potentially indicating underlying mechanical inconsistencies or process variations. Through a systematic analysis of defect occurrences across multiple batches and statistical techniques such as control charts and Design of Experiments (DOE), this study aims to uncover trends, correlations, and potential root causes of the observed defects. The results will enhance the understanding of machine-specific defect patterns, supporting data-driven decision-making for process optimization and quality control in tablet manufacturing.

RESEARCH DESCRIPTION

This research delves into the patterns of mechanical defects in the production of pharmaceutical tablets by investigating edge defects associated with three distinct tablet compression machines. Despite being operated under similar conditions, these machines display different defect rates, which may indicate potential mechanical inconsistencies or variations in the production process. This study aims to uncover the underlying factors contributing to these inconsistencies by analyzing defect occurrences across multiple batches and applying statistical methods such as control charts and Design of Experiments (DOE).

The significance of this study rests in its potential to enhance quality control in tablet manufacturing. Mechanical defects can lead to increased waste, regulatory non-compliance, and compromised product integrity, adversely affecting production efficiency and cost-effectiveness. By analyzing defect patterns at the machine level, this research aims to provide valuable insights into process stability and performance. Such understanding will empower manufacturers to make informed maintenance, calibration, and process optimization decisions. Ultimately, by establishing a structured approach to defect analysis, this study improves manufacturing reliability and ensures consistent product quality in the pharmaceutical industry.

RESEARCH OBJECTIVES

This research aims to systematically analyze and evaluate mechanical defect patterns in the production of pharmaceutical tablets, explicitly focusing on edge defects associated with three distinct tablet compression machines. A primary objective is identifying trends and defects' variability by examining occurrences across multiple batches. Understanding whether specific machines consistently exhibit higher defect rates will aid in establishing patterns and uncovering potential root causes for these variations.

Additionally, this study seeks to assess the performance of each machine individually to determine its mechanical consistency and operational stability. Variations in defect rates among the machines may signal underlying mechanical issues or deviations in the process that warrant investigation to uphold high manufacturing standards. To facilitate this analysis, statistical quality control techniques, such as control charts, will be used to monitor defect trends and detect any abnormalities or shifts in the manufacturing process.

The study will employ Design of Experiments (DOE) methodologies to analyze the relationship between machine parameters and defect occurrence. By systematically adjusting specific factors, DOE can help identify potential root causes of defects and provide data-driven insights to enhance manufacturing performance. Understanding these relationships is crucial for improving manufacturing processes and ensuring product quality.

This research will significantly enhance quality control efforts and ensure strict compliance with pharmaceutical industry standards. The findings will equip manufacturers with critical insights into the mechanisms that lead to defects, empowering them to make decisive choices regarding machine maintenance, calibration, and process optimization. Ultimately, this study will strengthen defect monitoring, reduce production waste, and boost efficiency in tablet manufacturing without requiring direct modifications to the production process.

RESEARCH CONTRIBUTIONS

This research will advance the understanding and management of mechanical defect patterns in pharmaceutical tablet production. By examining edge defects across three tablet compression machines, this study will yield valuable insights into defect trends, machine-specific performance, and quality control measures. A significant contribution of this research is the identification of defect variability among the machines, which will enable manufacturers to determine whether specific equipment requires adjustments, maintenance, or process refinements to maintain consistent product quality.

An essential contribution is the application of statistical quality control tools, such as control charts, to systematically monitor defect trends across various batches. This method allows for the early detection of abnormalities in defect occurrences, equipping manufacturers with a proactive strategy to address mechanical inconsistencies before they escalate into substantial production challenges. Moreover, the Design of Experiments (DOE) will enhance the understanding of how machine parameters impact defect formation, providing a structured framework for identifying potential root causes.

This research will establish a data-driven framework to enhance quality control in tablet compression processes. By revealing the correlations between defect rates and machine performance, the study will facilitate the optimization of manufacturing workflows and improve predictive maintenance strategies. Furthermore, by identifying avenues for continuous improvement, these findings will help minimize production waste, lower manufacturing costs, and ensure adherence to pharmaceutical quality standards.

This study will be an essential reference for future research in pharmaceutical manufacturing

and defect analysis, offering a systematic approach applicable to various production environments. By contributing to the broader field of process optimization, this research will bolster the industry's efforts to improve efficiency, reduce variability, and uphold high-quality standards in tablet manufacturing.

LITERATURE REVIEW

Investigating mechanical defects in tablet compression machines requires understanding the principles of tablet compression, as these principles rule the conversion of powders into solid dosage forms. Critical parameters such as compression force, dwell time, and material flow are key in determining tablet integrity. Additionally, granule size, moisture content, and lubrication significantly affect the particle bonding process, influencing tablet hardness, disintegration, and the potential for defects. Without a firm grasp of these fundamentals, identifying the root causes of mechanical defects and implementing practical process improvements becomes challenging. Moreover, a thorough understanding of how compression equipment functions, specifically the roles of punches, dies, and pre-compression stages, enables researchers to analyze defects and optimize machine settings to enhance tablet quality.

Furthermore, understanding of mechanical defects in tablet formation during compression and adherence to regulatory compliance and quality control are crucial for effective research. Mechanical defects such as capping, lamination, chipping, and sticking may arise from formulation issues, improper machine settings, or tooling wear. Identifying and addressing these defects requires knowledge in quality control techniques, including in-process testing (IPT) and advanced monitoring technologies like Process Analytical Technology (PAT).

Moreover, regulatory agencies like the FDA [1], EMA, and ICH enforce strict Good Manufacturing Practices (GMP) to ensure that pharmaceutical products meet established safety and quality standards. Researchers must be well-versed in these regulations to ensure compliance and to design solutions that align with industry expectations. Without this regulatory knowledge, research on mechanical defects may overlook critical quality and safety concerns, limiting its practical applications in pharmaceutical manufacturing.

TABLET COMPRESSION MACHINE OVERVIEW

Tablet compression machines are essential to pharmaceutical manufacturing processes. These machines enable the production of tablets by compacting powdered formulations into solid dosage forms. They guarantee precise weight, uniform hardness, and consistent thickness, essential for compliance with regulatory and quality standards. The primary types of tablet compression machines include single-punch (eccentric) presses and rotary presses [2].

Single-punch presses are mainly used for small-scale production and research and development (R&D). They gather powder between a single upper and lower punch, making them well-suited for producing low-volume batches and executing formulation trials. These machines are user-friendly and easily adjustable, making them ideal for experimenting with different formulations before moving on to larger-scale production [3].

Rotary tablet presses are engineered for high-volume pharmaceutical production. These machines have multiple punches and die on a rotating turret, enabling continuous and rapid tablet manufacturing. Rotary presses offer significant advantages, such as enhanced efficiency and uniform distribution of compression force. They also come equipped with advanced automation features that enable real-time tablet weight, thickness, and hardness monitoring. Furthermore, these presses include mechanisms for rejecting defective tablets, which helps maintain consistent product quality [4].

Key parameters in tablet compression involve compression force, dwell time, pre-compression, and tablet ejection. Adequate control of these variables ensures that tablets comply with pharmacopeial standards for uniformity, disintegration, and dissolution. Advanced rotary presses are now equipped with automated control systems and data analytics capabilities, enabling manufacturers to optimize production processes and minimize variability. By effectively managing these factors, manufacturers can produce high-quality tablets that consistently meet established specifications.

Modern tablet compression machines are engineered to comply with Good Manufacturing Practice (GMP) standards, effectively minimizing contamination risks. They incorporate closed systems, dust extraction units, and stainless-steel construction. In addition, the integration of Process Analytical Technology (PAT) fosters real-time adjustments to maintain quality and efficiency.

Tablet compression machines are essential in pharmaceutical manufacturing, enabling efficient, scalable, and high-quality tablet production. Several factors influence the selection of the appropriate machine, including production volume, formulation characteristics, and regulatory standards. This decision is essential for small-scale research and development (R&D) environments and large-scale commercial production facilities.

MECHANICAL DEFECTS ON TABLETS DURING COMPRESSION

Mechanical defects in tablets can occur during the compression process within pharmaceutical manufacturing. These issues may originate from factors such as formulation properties, machine settings, or the wear and tear of tooling. Such defects can significantly compromise the quality of the tablets, leading to increased rejection rates and production inefficiencies. Common mechanical defects include capping, lamination, chipping, sticking, picking, and variations in weight.

Capping is when a tablet's top or bottom layer detaches from its main body. This issue can result from inadequate bonding between particles, excessive air entrapment, or improper compression force. Common remedies involve adjusting the compression force, refining the formulation with suitable binders, and reducing excessive powder content.

Lamination separates a tablet into multiple layers, often caused by excessive pressure, high turret speed, or inadequate granule flow. Unlike capping, which usually involves a split at the top or bottom, lamination results in splits throughout the tablet. To mitigate the risk of lamination, it is crucial to maintain appropriate granule moisture content, decrease compression speed, and fine-tune pre-compression settings.

Chipping occurs when small fragments break off from the edges of tablets. It typically results from worn punches, improper die alignment, or inadequate binding agents within the formulation. Maintaining well-functioning tooling, optimizing compression force, and enhancing the formulation's flow properties are essential to mitigate chipping issues.

Sticking and picking are interconnected issues in tablet manufacturing, where powder adheres to the punches or dies, resulting in surface defects. "Sticking" occurs when the entire tablet attaches to the tooling, while "picking" involves the accumulation of material in the lettering or logo areas of the punch face. These challenges often originate from excessive moisture, inadequate lubrication, or insufficient drying of granules. To effectively reduce these defects, it is crucial to employ proper lubrication, use anti-adherent agents, and maintain optimal humidity levels within the production environment.

Weight variation is a critical issue that can arise from inconsistent powder flow, improper feeder adjustments, or punch penetration depth variations. These factors can adversely affect tablet uniformity and dosage accuracy. To achieve consistent weight, it is crucial to regularly calibrate

the tablet press, optimize powder flow properties, and use effective die-filling techniques.

Addressing mechanical defects requires implementing comprehensive equipment maintenance, process optimization, and formulation adjustments. Contemporary tablet compression machines are equipped with real-time monitoring systems and automatic rejection mechanisms that enable the detection and mitigation of defects. This capability is crucial for ensuring compliance with established pharmaceutical quality standards.

Regulatory Compliance and Quality Control for Mechanical Defects in Tablets

Regulatory compliance within the pharmaceutical industry ensures that tablets meet established safety, efficacy, and quality standards. Regulatory bodies such as the U.S. Food and Drug Administration (FDA) [1], the European Medicines Agency (EMA), and the International Council for Harmonisation (ICH) provide guidelines for tablet manufacturing, including the management of mechanical defects. Following Good Manufacturing Practices (GMP) and adhering to Quality by Design (QbD) principles are essential steps to minimize defects and preserve the integrity of the product.

Quality control (QC) and quality assurance (QA) processes are crucial for identifying and addressing mechanical defects, such as capping, lamination, chipping, sticking, picking, and weight variation [5]. Routine in-process testing (IPT) during tablet compression ensures products conform to specified standards. Manufacturers use a range of testing methods, including weight variation tests, hardness tests, friability tests, and disintegration/dissolution testing, to assess the quality of their tablets.

Manufacturers employ Process Analytical Technology (PAT) to adhere to regulatory standards, facilitating real-time monitoring of critical quality attributes (CQAs) [6]. Automated tablet compression machines, with pressure sensors, vision inspection systems, and data logging software, assist in early defect detection, lowering batch rejection rates [6]. Regulatory guidelines stipulate that all manufacturing deviations, including mechanical defects, must be documented and investigated through Corrective and Preventive Actions (CAPA) to avoid recurrence.

Regulatory inspections ensure pharmaceutical companies comply with established Standard Operating Procedures (SOPs) in tablet manufacturing. These SOPs encompass critical aspects such as machine calibration, preventive maintenance, and environmental controls. Non-compliance can lead to warnings, product recalls, or even production shutdowns. Consequently, it is crucial to maintain validated processes, provide comprehensive employee training, and implement strong quality control systems to ensure regulatory approval and product safety.

By adopting strict quality control measures and comprehensive regulatory compliance frameworks, pharmaceutical manufacturers can effectively reduce mechanical defects, enhance the reliability of their products, and guarantee that tablets adhere to internationally recognized quality standards.

Relevant Literature

In the study "Early Detection of Capping Risk in Pharmaceutical Compacts" by Xiaochi Xu [7] et al., published in the International Journal of Pharmaceutics in December 2018, the researchers investigated a common mechanical defect known as capping. The study's objective was to establish a nondestructive method for predicting the risk of capping by analyzing the internal mechanical properties of tablets before any visible defects arise. Using a contact ultrasonic method, researchers transmitted waves through tablets compressed at different forces and speeds, analyzing waveforms to assess stiffness and integrity. X-ray imaging confirmed internal cracks and defects.

The findings revealed that ultrasonic analysis is highly effective in detecting early signs of capping by monitoring changes in mechanical properties

related to porosity and tensile strength. Tablets compressed at higher speeds and pressures demonstrated significant variations in wave propagation, which were linked to an increased risk of capping. This approach allows manufacturers to make real-time adjustments to compression parameters, thereby minimizing defects.

The study concluded that integrating ultrasonic monitoring within continuous manufacturing processes enhances quality control and reduces variability. It underscores the critical importance of real-time monitoring in the production of pharmaceutical tablets to ensure uniform product quality and mitigate mechanical defects.

In the 2016 study titled "The Effect of Mechanical Strain on the Properties of Lubricated Tablets Compacted at Different Pressures," Pallavi Pawar [8] and her colleagues explored how different levels of shear strain during powder blending affect the compaction process and the mechanical properties of pharmaceutical tablets. The study's objective was to understand the influence of blending conditions on tablet integrity, particularly concerning porosity, bonding efficiency, and the potential emergence of mechanical defects such as capping and lamination.

Employing a Couette shear cell and an instrumented compactor simulator, the researchers found that increased shear strain led to a decline in particle bonding efficiency and an increase in elastic recovery. This, in turn, elevated the risk of mechanical defects like capping and lamination. Notably, tablets produced from high-shear blends exhibited weakened tensile strength and greater structural relaxation following compression [9].

The study concluded that controlling shear strain during blending is crucial to preserve tablet quality, as excessive strain can undermine mechanical stability [9]. By optimizing blending conditions, manufacturers can reduce the likelihood of defects and ensure consistent production of pharmaceutical tablets.

METHODOLOGY

The study employs a methodology that analyzes the variability of edge defects in tablets produced by three different tablet compression machines. It contains data collection, statistical analysis, and control charts for visualizing defect trends across various production batches. This approach evaluates machine performance, supporting enhancements in quality control within pharmaceutical manufacturing.

Data will be collected from ten production batches for each of the three tablet compression machines (A, B, and C) to ensure statistical accuracy. Each batch will yield approximately 1,250,000 tablets, from which a random sample of 500 defects will be extracted and analyzed per drum per batch, totaling around 9,000 evaluated tablets. This sampling approach ensures a representative dataset, minimizing potential biases and enabling accurate machine comparisons. The defect counts from each batch are carefully recorded and organized into structured datasets for further analysis.

The study employs control charts (C-charts) to analyze defect variability and evaluate machine performance. This statistical tool is especially effective for monitoring defect counts in processes with large, stable sample sizes. The C-charts facilitate the tracking of edge defects per batch over time, providing an understanding of the stability and consistency of each machine’s output.

The key statistical components that will be analyzed include the mean defect count per machine, which indicates the average number of defects recorded across the ten batches. The standard deviation is calculated to assess variability, providing insight into the consistency of defect counts for each batch. Upper Control Limits (UCL) and Lower Control Limits (LCL) are established based on the overall mean and standard deviation to define the expected range of defect counts. By applying these calculations, the study identifies out of control points batches where defect

counts exceed expected limits indicating potential problems with machine stability and consistency.

Defect trends for each machine are visualized through C-charts, displaying the defect count per batch over time and the mean and control limits. These charts are critical in detecting deviations or shifts in defect trends. When a machine consistently produces batches that approach or exceed the upper control limit (UCL), it may indicate the presence of a specific cause for variation that requires further investigation. Furthermore, defect counts for each batch are organized into tables, enabling direct comparisons between machines and identifying which machines demonstrate greater stability or higher defect rates.

The mean and standard deviation of defect counts are calculated for each machine to assess variability. By analyzing the defect distributions among the machines, it is possible to identify and trace performance differences. For further analysis, unique cause variations are identified by flagging batches exceeding control limits. Potential root causes, including machine settings, component wear, and operator handling, are then evaluated. A comparative analysis will then be conducted, ranking the machines according to their defect rates and stability metrics.

This methodology ensures a routine evaluation of tablet defect trends across machines. Using statistical quality control tools, such as control charts, the study identifies variations in defect counts, allowing for data-driven decisions in process improvement. The findings will emphasize the importance of monitoring defect trends, enabling targeted interventions to optimize machine performance and reduce defects in pharmaceutical manufacturing.

RESEARCH SCHEDULE

The proposed research schedule can be seen in the following table:

Table 1

Machine Tablets Edge Defects per Batch

Activity	Description	Estimated Duration	Estimated Completion Date
Project Planning & Research Design	Define research objectives, scope, and methodology.	2 weeks	Week 2
Data Collection	Collect edge tablet defects data from 10 batches per machine.	4 weeks	Week 6
Data Organization	Structure the dataset for statistical analysis.	1 week	Week 7
Statistical Analysis	Calculate means, standard deviations, and control limits. Develop Control Charts (C-Charts).	2 weeks	Week 9
Interpretation	Generate graphics and interpret the edge tablet defect trends across machines.	1 week	Week 10
Identification of Variations	Identify patterns and out of control points. Investigate potential causes of defect trends.	2 weeks	Week 12
Comparative Analysis	Compare machine performances based on statistical findings.	2 weeks	Week 14
Results Discussion	Analysis and discussion of findings.	2 weeks	Week 16
Report Documentation	Generate the final report.	2 weeks	Week 18
Revision	Proofread, refine, and feedback incorporation.	1 week	Week 19
Submission of Final Report	Submit the research study.	-	Week 19

RESULTS AND DISCUSSION

This chapter presents the findings from the analysis of edge defect data collected from three tablet compression machines, machines A, B, and C, across ten production batches for each machine. Statistical tools, specifically control charts (C-charts), were employed to evaluate the variability in defect counts and the consistency of machine performance. The results provide practical insight into the root causes of mechanical defects, emphasizing machine-specific issues and operator oversight.

The average number of edge defects per 500 sampled tablets per batch drums indicated significant differences among the three machines. Machine A exhibited a mean of tablet edge defect count of 42.7, Machine B recorded the lowest count at 36.9, and Machine C had the highest average at 51.2. Standard deviation analysis further highlighted the degree of variability, with Machine B showing the least variation ($\sigma \approx 3.7$), Machine A exhibiting moderate variation ($\sigma \approx 4.3$), and Machine C presenting the greatest variability ($\sigma \approx 5.8$). These metrics were subsequently used to construct control charts that visually represent the stability of each machine's output across batches.

Table 2

Machine Tablets Edge Defects per Batch

Batch	Machine A	Machine B	Machine C
Batch 1	45	36	50
Batch 2	43	37	52
Batch 3	40	35	54
Batch 4	41	34	53
Batch 5	39	38	48
Batch 6	44	37	51
Batch 7	47	36	55
Batch 8	46	35	57
Batch 9	42	37	49
Batch 10	38	39	60

The C-chart for Machine B revealed a clustered set of defect counts within the control limits, indicating a stable and well-maintained process. This machine consistently produced tablets with minimal variation in edge defects, suggesting effective maintenance, calibration, and adherence to consistent operator practices. Conversely, Machine C displayed significant process instability, with two batches exceeding the upper control limit. A detailed investigation identified that Machine C was subjected to excessive vibration in its turret assembly, resulting in misalignment. This directly contributed to increased edge defects such as chipping and lamination, especially during peak production.

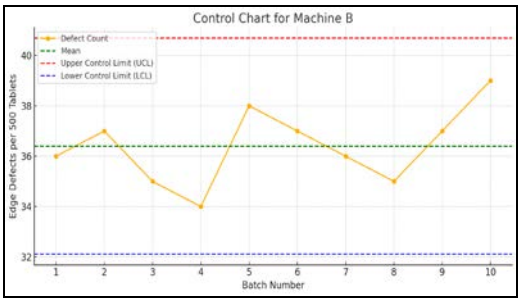

Figure 1

Machine B Tablets Edge Defects per Batch

While commonly operating within control limits, Machine A did present one batch that slightly exceeded the upper control threshold. An evaluation revealed slight undetected die wear affecting both Machines A and C. Manufacturing operators did not initially recognize this wear, leading to minor inconsistencies in tablet shape and compression dynamics. Although these issues were less severe than those caused by the turret misalignment observed in Machine C, the unnoticed die wear contributed to the variations in edge defects recorded across certain batches.

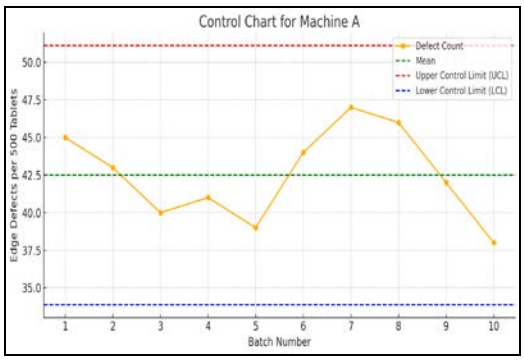

Figure 2

Machine A Tablets Edge Defects per Batch

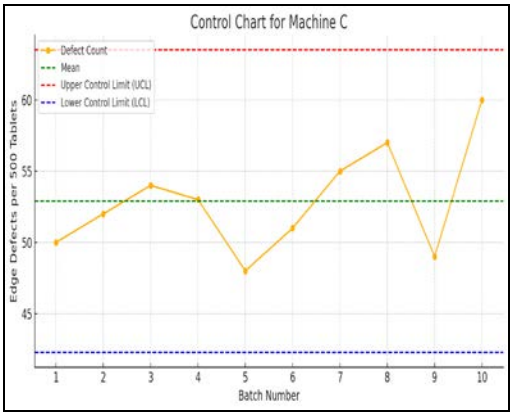

Figure 3

Machine C Tablets Edge Defects per Batch

A comparative analysis of the three machines revealed that Machine B provided the best average defect rate and process consistency performance. Conversely, Machine C exhibited the highest level of mechanical instability, mainly attributed to the identified turret vibration. This issue underscores the necessity for regular mechanical diagnostics and vibration monitoring in high-speed rotary presses. Machine A's moderate performance also highlighted the need for more rigorous die inspection training and protocols, as early signs of wear can be easily overlooked during routine operations.

Table 3
Machine Tablets Edge Defects per Batch after Mechanical Issues Resolution

Batch	Machine A	Machine B	Machine C
Batch 1	40	36	45
Batch 2	39	35	44
Batch 3	38	34	43
Batch 4	37	33	42
Batch 5	36	34	41
Batch 6	38	35	43
Batch 7	39	36	44
Batch 8	37	34	42
Batch 9	36	33	41
Batch 10	35	32	40

These findings highlight the importance of integrating statistical monitoring tools with targeted mechanical assessments to ensure the quality of pharmaceutical products. The control charts facilitated variability identification and supported the investigation into its underlying causes. The excessive vibration in Machine C and the die wear in Machines A and C are examples of how mechanical issues and human oversight can merge to influence product outcomes.

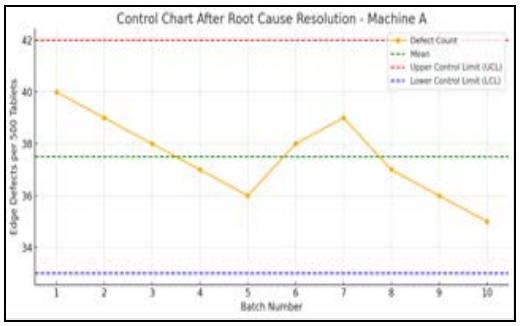

Figure 4
Machine B Tablets Edge Defects per Batch

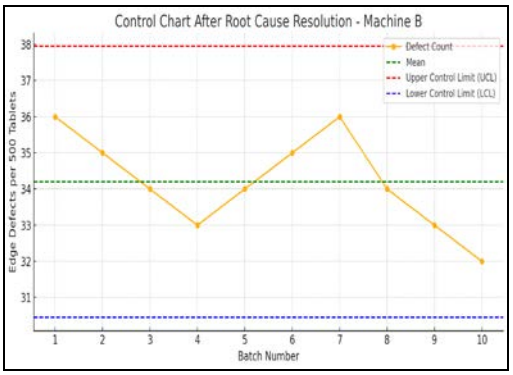

Figure 5
Machine B Tablets Edge Defects per Batch

Following resolving mechanical issues, turret vibration, and die wear, the revised control charts and tables display significant performance improvements across all three machines.

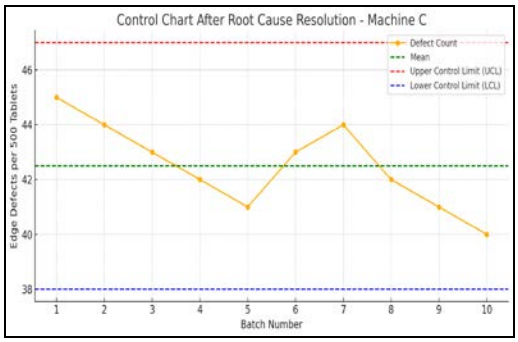

Figure 6
Machine C Tablets Edge Defects per Batch

For machine A, after managing previously undetected die wear, there has been a reduction in defect count and enhanced stability. The results from the control charts fall within the established control limits, demonstrating robust process stability. Machine B consistently delivers low defect counts and exhibits minimal variability, indicating no interventions are needed. Its reliable performance solidifies its status as a model machine. Lastly, for machine C, there has been an improvement in defect rates after resolving the issues related to turret vibration and die wear. The decreased variability suggests that the corrective maintenance actions have successfully fixed machine performance.

The corrective measures have reduced edge defects for Machines A and C, while Machine B has maintained reliable performance. The control charts indicate that all batches operate well within control limits, reflecting improved process control and equipment reliability. These findings underscore the importance of integrating root-cause analysis with statistical monitoring. Furthermore, the process improvement highlights the need for proactive maintenance and operator training, especially in the early detection of mechanical wear. These results support a continuous quality improvement strategy in pharmaceutical tablet manufacturing.

In conclusion, the results show that mechanical defects in tablet compression are closely linked to machine condition and operator awareness. Machine B demonstrated robust process control and should be considered the operational model. Meanwhile, the challenges identified in Machines A and C point to improved maintenance protocols and enhanced operator training. This chapter reinforces the value of statistical process control in conjunction with mechanical diagnostics, highlighting the critical role of proactive quality assurance in pharmaceutical manufacturing.

CONCLUSION

In conclusion, the analysis of edge defects across three tablet compression machines has demonstrated that mechanical inconsistencies, such as turret vibration in Machine C and undetected die wear in Machines A and C, contributed to high and variable defect rates. The implementation of statistical quality tools, particularly control charts, decisively identified these variations and investigated their root causes. All three machines demonstrated improved stability and reduced defect counts following targeted corrective actions. Machine C showed the most noticeable improvement. These findings highlight the importance of integrating data-driven monitoring with proactive maintenance and heightened operator awareness to sustain high-quality pharmaceutical tablet production.

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