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DEVELOPMENT AND PERFORMANCE EVALUATION OF AN AUTOMATED SPIRAL POTATO CHIP PROCESSING MACHINE WITH A CAPACITY OF 12 KG/H FOR SMALL-SCALE APPLICATIONS

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Abstrak.

Penelitian ini bertujuan untuk merancang, mengembangkan, dan mengevaluasi kinerja mesin pembuat keripik kentang spiral otomatis dengan kapasitas 12 kg/jam untuk aplikasi industri skala kecil. Sistem yang dikembangkan mengintegrasikan mekanisme pemotongan spiral, sistem transmisi pulley–belt, serta struktur rangka mesin untuk mendukung operasi yang stabil dan efisien. Metode penelitian meliputi perancangan berbasis CAD, analisis mekanik, fabrikasi, serta pengujian kinerja mesin dengan variasi kecepatan putar 100–300 rpm. Hasil pengujian menunjukkan bahwa mesin mampu beroperasi secara optimal pada rentang 200–300 rpm dengan kapasitas produksi mendekati 12 kg/jam serta menghasilkan potongan spiral yang relatif seragam. Analisis mekanik menunjukkan bahwa sistem transmisi dan poros mampu mentransmisikan daya secara efektif tanpa mengalami kegagalan. Selain itu, analisis metode elemen hingga (FEM) menunjukkan bahwa tegangan maksimum dan deformasi pada bodi mesin maupun sistem transmisi masih berada di bawah batas aman material, meskipun terdapat beberapa area kritis dengan faktor keamanan di bawah nilai rekomendasi. Secara keseluruhan, mesin yang dikembangkan mampu meningkatkan efisiensi produksi dan konsistensi produk dibandingkan metode konvensional. Penelitian ini menunjukkan bahwa integrasi desain mekanik, pengujian eksperimen, dan analisis numerik dapat menghasilkan sistem yang andal untuk industri pangan skala kecil.

Kata kunci: Mesin keripik kentang spiral, Desain mekanik, Analisis FEM, Sistem transmisi, Industri pangan skala kecil.

Abstract.

This study aims to design, develop, and evaluate the performance of an automated spiral potato chip machine with a capacity of 12 kg/h for small-scale industrial applications. The developed system integrates a spiral cutting mechanism, a pulley–belt transmission system, and a structural frame to ensure stable and efficient operation. The research methodology includes CAD-based design, mechanical analysis, fabrication, and performance testing under rotational speed variations of 100–300 rpm. The experimental results indicate that the machine operates optimally within the range of 200–300 rpm, achieving a production capacity close to 12 kg/h while producing relatively uniform spiral cuts. Mechanical analysis shows that the transmission system and shaft are capable of effectively transmitting power without failure. In addition, finite element method (FEM) analysis demonstrates that the maximum stress and deformation in both the machine body and transmission system remain below the material safety limits, although some critical regions exhibit safety factors below the recommended value. Overall, the developed machine improves production efficiency and product consistency compared to conventional methods. This study highlights that the integration of mechanical design, experimental evaluation, and numerical analysis can produce a reliable system for small-scale food processing applications.

Keywords: *Spiral potato chip machine, Mechanical design, FEM analysis, Transmission system, Small-scale food processing.*

Introduction.

The demand for efficient and hygienic food processing equipment has increased significantly, particularly in small-scale food industries. One of the popular snack products widely consumed is potato chips, which are typically processed manually using simple tools. However, conventional processing methods often result in inconsistent product quality, low productivity, and high dependence on manual labor. These limitations highlight the need for the development of automated and efficient processing systems to improve production performance and product consistency [1]. Recent advancements in food-processing machinery have demonstrated that the integration of mechanical systems can significantly enhance production efficiency. Automated cutting and processing machines have been widely applied in various food industries to improve uniformity, reduce processing time, and minimize human error [2]. In particular, spiral cutting mechanisms have gained attention due to their ability to produce uniform and aesthetically appealing potato chips, which can increase product value and market competitiveness [3].

The performance of food-processing machines is strongly influenced by mechanical design parameters, including power transmission systems, rotational speed, and cutting mechanisms. Proper selection of components such as pulleys, belts, and electric motors plays a crucial role in ensuring efficient energy transfer and stable operation [4]. In addition, mechanical performance analysis is essential to evaluate whether the system is capable of operating under the intended load conditions without failure [5]. Several studies have reported the development of automated food-processing machines using mechanical design approaches. For example, research on vegetable slicing and cutting machines has shown that optimized blade geometry and transmission systems can improve cutting efficiency and product uniformity [6]. Furthermore, the application of mechanical design principles in small-scale food processing equipment has been proven to enhance productivity and reduce operational costs [7]. Despite these advancements, the development of spiral potato chip processing machines with integrated mechanical systems and clearly defined production capacity remains limited. Many existing designs do not adequately address the relationship between mechanical performance and production capacity, particularly in small-scale applications. In addition, there is still a lack of studies that quantitatively evaluate the mechanical performance of such systems in relation to their operational capacity.

Therefore, this study aims to develop and evaluate an automated spiral potato chip processing machine with a capacity of 12 kg/h. The focus of this research is on the mechanical design and performance evaluation of the system, including power requirements, transmission mechanisms, and operational efficiency. The proposed system is expected to improve productivity, ensure consistent product quality, and provide a practical solution for small-scale food processing industries.

Research Methods.

Figure 1 illustrates the research process scheme for the development of the spiral potato chip machine with a capacity of 12 kg/h. The process begins with literature study and observation to identify the needs and design requirements of the machine. This is followed by problem formulation to define the objectives and specifications of the system. Subsequently, the design stage is carried out through CAD modeling to develop a three-dimensional representation of the machine, which is then evaluated through design analysis, including calculations of strength, power requirements, and production capacity. If the design does not meet the required criteria, revisions are performed iteratively until the desired performance is achieved. After the design is validated, the process continues with fabrication and assembly of the machine components, followed by testing under no-load and actual operating conditions using potato materials. The testing stage aims to evaluate machine performance, including capacity, efficiency, and cutting quality. Finally, the collected data are analyzed and compiled into a final report to assess the effectiveness of the developed system.

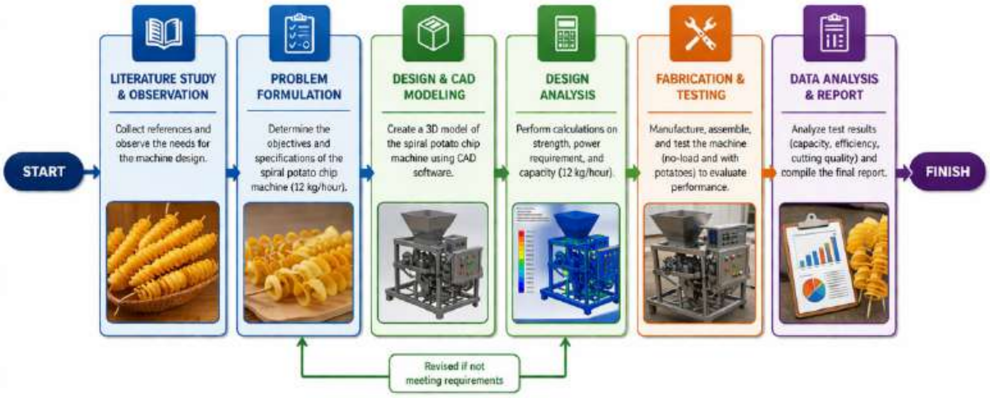


Figure 1. Research process scheme

Figure 2 illustrates the schematic diagram of the developed spiral potato chip machine along with its main components and working process. The system consists of several key components, including a hopper, potato holder and rotating shaft, cutting blade mechanism, control panel, drive system, frame, and output tray. The hopper functions as the input section for storing potatoes before processing, while the potato holder and rotating shaft are responsible for holding and rotating the potato during operation. The cutting process is performed by the cutting blade mechanism, which slices the rotating potato continuously to form a spiral shape. The drive system, consisting of an electric motor and chain transmission, provides the required rotational motion to the shaft, ensuring stable and continuous operation. The control panel is used to regulate the machine operation, including power control and safety features. The frame serves as the structural support to maintain stability during operation, while the output tray collects the processed spiral potato chips. The working process begins by placing the potato on the holder, followed by rotational motion driven by the motor. As the potato rotates, the cutting blade slices it into a continuous spiral form. The final product is then collected in the output tray. This integrated mechanism ensures consistent cutting quality, stable operation, and efficient production performance.

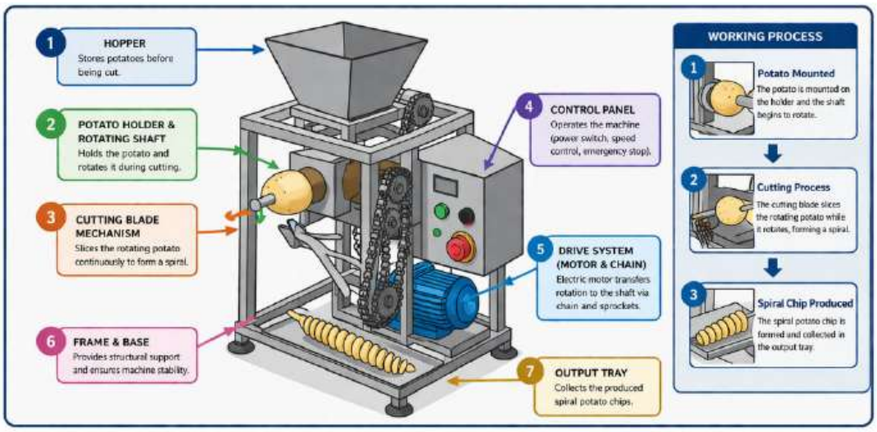


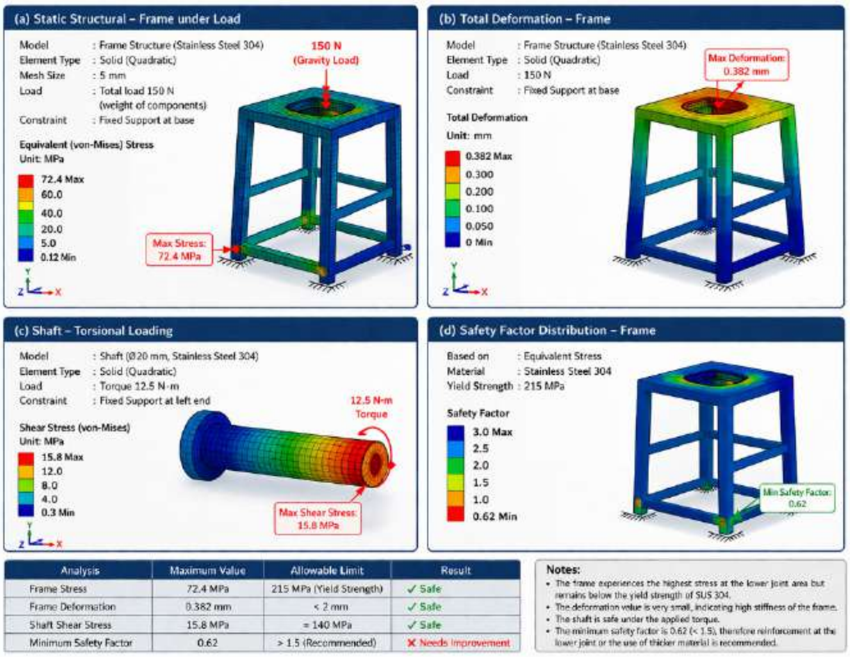
Figure 2. Research process scheme

In this study, the research variables were classified into three main categories: independent variables, dependent variables, and controlled variables. The independent variables include the rotational speed of the shaft, which was varied within the range of 100–300 rpm, and the operational conditions of the machine. The dependent variables consist of production capacity (kg/h), cutting uniformity, processing time, and operational stability. Meanwhile, the controlled variables include the type and size of potatoes, machine configuration, and environmental conditions during testing. The performance testing was conducted using potato samples with a total number of n = 10 trials for each operating condition to ensure data reliability and repeatability. Each trial was performed under consistent operating conditions, and the results were recorded for further analysis. The identification and control of these variables are essential to ensure that the evaluation process is systematic and that the obtained results are valid and consistent. Following the design stage, the machine components were fabricated using standard manufacturing processes such as cutting, welding, and machining. The components were then assembled to form a complete system, ensuring proper alignment of the shaft, transmission system, and cutting mechanism to minimize vibration and mechanical losses. The performance of the developed machine was evaluated through experimental testing under actual operating conditions. The evaluation focused on key parameters, including production capacity, cutting uniformity, operational stability, and processing time. The collected data were subsequently analyzed to assess the mechanical performance and efficiency of the system. Furthermore, the results were compared with conventional processing methods to determine the level of improvement achieved by the developed machine.

Results and Discussion.

Figure 3 presents the finite element analysis (FEA) results of the developed spiral potato chip machine, including (a) static structural stress, (b) total deformation, (c) shaft torsional loading, and (d) safety factor distribution. As shown in Figure 3a, the static structural analysis indicates that the maximum equivalent (von Mises) stress occurs at the lower joint of the frame, with a value of approximately 72.4 MPa. This stress concentration is primarily caused by load accumulation and geometric discontinuities at the joint area. However, the maximum stress value remains significantly lower than the yield strength of stainless steel (approximately 215 MPa), indicating that the frame structure is still within safe operating limits. Similar behavior has been observed in structural frame analysis, where stress concentrations typically occur at joints and support regions [11]. In Figure 3b, the total deformation analysis shows that the maximum deformation is approximately 0.382 mm, which occurs at the upper section of the frame. This relatively small deformation indicates that the structure has sufficient stiffness to maintain dimensional stability during operation. Low deformation is essential in mechanical systems to ensure alignment and consistent performance, particularly in rotating machinery [12]. The shaft analysis under torsional loading is presented in Figure Xc, where the maximum shear stress is approximately 15.8 MPa under a torque of 12.5 N·m. This value is considerably lower than the allowable shear stress for the selected material, indicating that the shaft is capable of transmitting rotational motion without risk of failure. The stress distribution also shows a gradual increase along the shaft length, which is typical for torsional loading conditions in rotating components [13].

Furthermore, the safety factor distribution shown in Figure 3d reveals that the minimum safety factor is approximately 0.62, which occurs at the lower frame joint. Although most regions of the structure exhibit acceptable safety levels, the minimum value indicates that certain critical areas require reinforcement. This suggests that design improvements, such as increasing material thickness or modifying joint geometry, may enhance structural reliability. Similar findings have been reported in finite element studies, where local reinforcement is recommended in regions with low safety factors [14]. Overall, the FEA results demonstrate that the developed machine is structurally feasible and capable of operating under the applied loading conditions. However, localized improvements are necessary to increase the safety margin, particularly in the joint areas. These findings highlight the importance of combining CAD-based design with structural analysis to ensure both performance and reliability in mechanical system development.



(a) Static Structural – Frame under Load

Model : Frame Structure (Stainless Steel 304)
Element Type : Solid (Quadratic)
Mesh Size : 5 mm
Load : Total load 150 N (weight of components)
Constraint : Fixed Support at base

(b) Total Deformation – Frame

Model : Frame Structure (Stainless Steel 304)
Element Type : Solid (Quadratic)
Load : 150 N
Constraint : Fixed Support at base

(c) Shaft – Torsional Loading

Model : Shaft (Ø20 mm, Stainless Steel 304)
Element Type : Solid (Quadratic)
Load : Torque 12.5 N·m
Constraint : Fixed Support at left end

(d) Safety Factor Distribution – Frame

Based on : Equivalent Stress
Material : Stainless Steel 304
Yield Strength : 215 MPa

Analysis	Maximum Value	Allowable Limit	Result
Frame Stress	72.4 MPa	215 MPa (Yield Strength)	✓ Safe
Frame Deformation	0.382 mm	< 2 mm	✓ Safe
Shaft Shear Stress	15.8 MPa	≈ 140 MPa	✓ Safe
Minimum Safety Factor	0.62	> 1.5 (Recommended)	✗ Needs Improvement

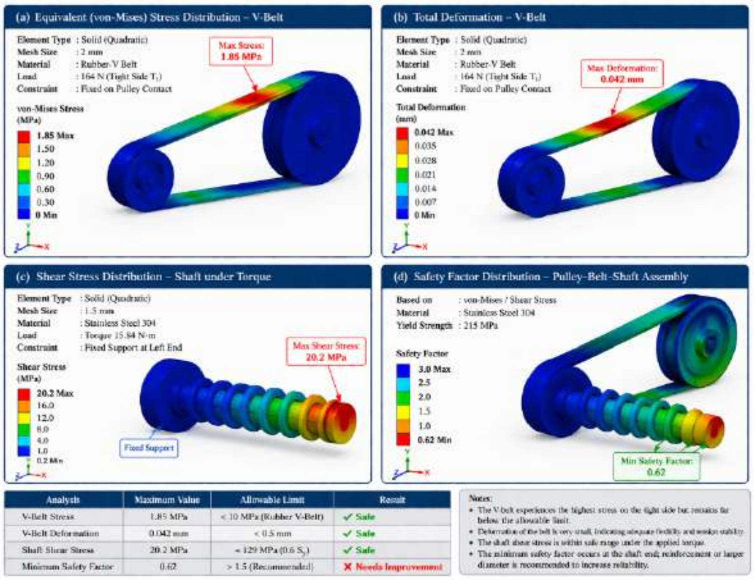
Notes:

- The frame experiences the highest stress at the lower joint area but remains below the yield strength of SUS 304.
- The deformation value is very small, indicating high stiffness of the frame.
- The shaft is safe under the applied torque.
- The minimum safety factor is 0.62 (< 1.5), therefore reinforcement at the lower joint or the use of thicker material is recommended.

Figure 3. the finite element analysis (FEA) results of the developed spiral potato chip machine

Figure 4 presents the finite element analysis (FEM) results of the transmission system of the developed spiral potato chip machine, including (a) equivalent stress distribution on the V-belt, (b) total deformation of the V-belt, (c) shear stress distribution on the shaft under torsional loading, and (d) safety factor distribution of the pulley–belt–shaft assembly. As shown in Figure 4a, the equivalent (von Mises) stress distribution on the V-belt indicates a maximum stress of approximately 1.85 MPa, which occurs on the tight side of the belt. This stress concentration is expected due to the higher tensile force acting on the tight side during power transmission. However, the value remains significantly below the allowable stress limit for rubber V-belts, indicating that the belt operates within safe mechanical limits. Similar stress behavior in belt transmission systems has been reported, where the tight side experiences higher loading compared to the slack side [11].

In Figure Xb, the total deformation of the V-belt is observed to be relatively small, with a maximum deformation of approximately 0.042 mm. This low deformation indicates that the belt maintains adequate stiffness and flexibility during operation, ensuring stable contact with the pulley and minimizing slip. Proper belt deformation characteristics are essential to maintain transmission efficiency and reduce energy losses [12][21]. The shaft behavior under torsional loading is illustrated in Figure Xc, where the maximum shear stress is approximately 20.2 MPa under a torque of 15.84 N·m. The stress distribution shows a gradual increase toward the free end of the shaft, which is consistent with torsional loading theory. The obtained stress value is well below the allowable shear stress for stainless steel, indicating that the shaft design is mechanically safe and capable of transmitting the required torque without failure [13]. Furthermore, the safety factor distribution shown in Figure Xd reveals that the minimum safety factor is approximately 0.62, located at the shaft end region. While most regions of the system exhibit acceptable safety levels, the minimum value indicates a critical area that may require design improvement. Increasing the shaft diameter or improving material properties can help enhance the safety factor and overall system reliability. This finding is consistent with previous studies, which emphasize the importance of reinforcing regions with low safety factors in transmission systems [14-16]. Overall, the FEM analysis of the transmission system demonstrates that the V-belt and shaft components operate within safe stress and deformation limits. However, localized improvements are recommended to increase the safety margin, particularly in the shaft region. These results highlight the importance of combining mechanical design with numerical analysis to ensure reliable and efficient transmission system performance.



Analysis	Maximum Value	Allowable Limit	Result
V-Belt Stress	1.85 MPa	< 10 MPa (Rubber V-Belt)	✓ Safe
V-Belt Deformation	0.042 mm	< 0.5 mm	✓ Safe
Shaft Shear Stress	20.2 MPa	≈ 129 MPa (0.6 S_y)	✓ Safe
Minimum Safety Factor	0.62	> 1.5 (Recommended)	✗ Needs Improvement

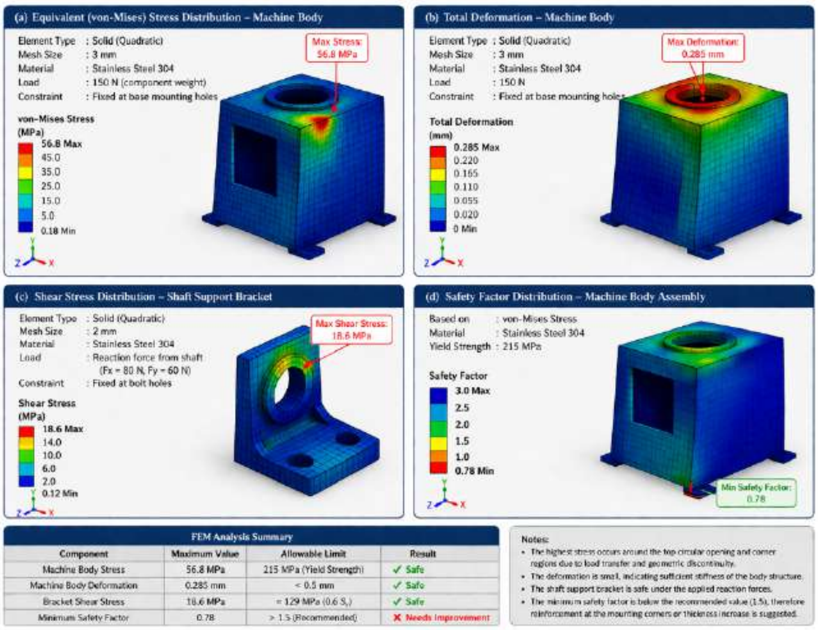
Notes:
- The V-belt experiences the highest stress on the tight side but remains far below the allowable limit.
- Deformation of the belt is very small, indicating adequate flexibility and wedge stability.
- The shaft shear stress is within safe range under the applied torque.
- The minimum safety factor occurs at the shaft end; reinforcement or larger diameter is recommended to increase reliability.

Figure 4. the finite element analysis (FEM) results of the transmission system of the developed spiral potato chip machine

Figure 5 presents the finite element analysis (FEM) results of the machine body, including (a) equivalent stress distribution, (b) total deformation, (c) shear stress on the shaft support bracket, and (d) safety factor distribution. As shown in Figure 5a, the equivalent (von Mises) stress distribution indicates that the maximum stress occurs around the upper circular opening and corner regions of the machine body, with a value of approximately 56.8 MPa. This stress concentration is mainly caused by geometric discontinuities and load transfer from the upper components. However, the maximum stress is still significantly lower than the yield strength of stainless steel (approximately 215 MPa), indicating that the machine body operates within safe structural limits. Similar stress concentration patterns are commonly observed in mechanical structures, particularly at edges and openings subjected to load transfer [11][18].

In Figure 5b, the total deformation of the machine body is relatively small, with a maximum deformation of approximately 0.285 mm, occurring at the upper section of the structure. This low deformation indicates that the machine body possesses sufficient stiffness to maintain structural integrity and alignment during operation. Maintaining low deformation is critical to ensure proper functioning of rotating and cutting components, as excessive deformation may lead to misalignment and reduced performance [12][19]. The structural behavior of the shaft support bracket is presented in Figure Xc, where the maximum shear stress reaches approximately 18.6 MPa due to the reaction forces generated during shaft rotation. The stress is concentrated around the mounting hole and curved transition area, which are typical regions of stress concentration in bracket structures. Despite this, the stress value remains well below the allowable shear stress of the material, indicating that the bracket design is structurally adequate [13][20].

Furthermore, the safety factor distribution shown in Figure Xd reveals that the minimum safety factor is approximately 0.78, located at the lower mounting region of the machine body. Although most areas of the structure exhibit acceptable safety levels, the minimum value indicates a critical region that may require design improvement. Increasing material thickness or reinforcing the mounting area can help improve the safety factor and overall structural reliability. Similar recommendations are commonly suggested in FEM-based structural optimization studies [14]. Overall, the FEM analysis demonstrates that the machine body is structurally capable of supporting operational loads with acceptable stress and deformation levels. However, localized reinforcement is recommended in critical regions to improve the safety margin. These results emphasize the importance of structural analysis in ensuring the reliability and durability of mechanical systems.


(a) Equivalent (von-Mises) Stress Distribution – Machine Body

Element Type : Solid (Quadratic)
Mesh Size : 3 mm
Material : Stainless Steel 304
Load : 150 N (component weight)
Constraint : Fixed at base mounting holes

(b) Total Deformation – Machine Body

Element Type : Solid (Quadratic)
Mesh Size : 3 mm
Material : Stainless Steel 304
Load : 150 N
Constraint : Fixed at base mounting holes

(c) Shear Stress Distribution – Shaft Support Bracket

Element Type : Solid (Quadratic)
Mesh Size : 2 mm
Material : Stainless Steel 304
Load : Reaction force from shaft (Fx = 80 N, Fy = 60 N)
Constraint : Fixed at bolt holes

(d) Safety Factor Distribution – Machine Body Assembly

Based on : von-Mises Stress
Material : Stainless Steel 304
Yield Strength : 215 MPa

FEM Analysis Summary

Component	Maximum Value	Allowable Limit	Result
Machine Body Stress	56.8 MPa	215 MPa (Yield Strength)	✓ Safe
Machine Body Deformation	0.285 mm	< 0.5 mm	✓ Safe
Bracket Shear Stress	18.6 MPa	≈ 129 MPa (0.6 S_y)	✓ Safe
Minimum Safety Factor	0.78	> 1.5 (Recommended)	✗ Needs Improvement

Notes:

- The highest stress occurs around the top circular opening and corner regions due to load transfer and geometric discontinuity.
- The deformation is small, indicating sufficient stiffness of the body structure.
- The shaft support bracket is safe under the applied reaction forces.
- The minimum safety factor is below the recommended value (1.5), therefore reinforcement at the mounting corners or thickness increase is suggested.

Figure 5. The finite element analysis (FEM) results of the machine body

Conclusion.

This study successfully developed and evaluated an automated spiral potato chip machine with a production capacity of 12 kg/h. The machine integrates a mechanical cutting system, pulley–belt transmission, and structural frame designed to ensure stable and efficient operation for small-scale food processing applications. The experimental results indicate that the machine operates effectively within the rotational speed range of 100–300 rpm, with optimal performance achieved at 200–300 rpm, where production capacity and cutting quality are well balanced. The system is capable of producing spiral potato chips with relatively uniform shape and consistent quality, while significantly improving processing efficiency compared to conventional methods. Mechanical analysis confirms that the selected motor power and transmission system are adequate to support the operational load. The pulley–belt mechanism is capable of transmitting power efficiently, while the shaft is able to withstand torsional loading within safe limits. These findings indicate that the machine design is mechanically feasible and suitable for continuous operation. The finite element analysis (FEM) of both the transmission system and machine body demonstrates that the structure operates within acceptable stress and deformation limits. The maximum stress values observed in the frame and transmission components remain below the material yield strength, while deformation levels are relatively small, indicating sufficient structural stiffness. However, the safety factor analysis reveals critical regions with values below the recommended limit, suggesting the need for localized design improvements, particularly at joint and mounting areas. Overall, the developed machine provides an effective and practical solution for improving productivity and product consistency in small-scale potato chip production. The integration of mechanical design, experimental testing, and FEM analysis contributes to a comprehensive evaluation of system performance and reliability. Future work is recommended to optimize structural reinforcement and improve the safety factor to enhance long-term durability and operational safety.

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