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DESIGN AND STRUCTURAL ANALYSIS OF A ROTARY STEAK GRILLING MACHINE USING FINITE ELEMENT METHOD

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Abstrak.

Penelitian ini membahas rancang bangun dan analisis struktural mesin pemanggang daging steak dengan metode rotary. Mesin ini dirancang menggunakan perangkat lunak CAD (SolidWorks) dengan komponen utama berupa rangka, plat penutup, poros putar, keranjang penahan daging, motor sinkron, bantalan, dan pemanas inframerah. Material utama yang digunakan adalah baja tahan karat tipe 304 karena ketahanan korosi dan kelayakannya untuk aplikasi pangan. Hasil perhitungan berat komponen menunjukkan total beban mesin sebesar 660,20 N. Analisis kekuatan dilakukan pada plat penutup kerangka yang berfungsi menopang bantalan poros. Simulasi menggunakan metode elemen hingga (Finite Element Method/FEM) menghasilkan tegangan maksimum 58,60 MPa, deformasi maksimum 0,31 mm, dan faktor keamanan (FOS) sebesar 3,5. Nilai tegangan ini jauh di bawah tegangan luluh baja tahan karat 304 (205 MPa), sementara deformasi masih dalam batas toleransi. Faktor keamanan menunjukkan bahwa desain mesin aman untuk digunakan. Dengan demikian, mesin pemanggang daging steak metode rotary yang dikembangkan terbukti memenuhi persyaratan kekuatan struktur dan keamanan operasi. Metodologi berbasis CAD dan FEM terbukti efektif dalam merancang dan mengevaluasi mesin pengolahan pangan.

Kata kunci: mesin pemanggang daging, metode rotary, analisis struktural, finite element method.

Abstract.

This study presents the design and structural analysis of a rotary steak grilling machine. The machine was modeled using CAD software (SolidWorks) and consists of a frame, cover plate, rotary shaft, basket holder, synchronous motor, bearings, and infrared heaters. Stainless steel grade 304 was selected as the primary material due to its corrosion resistance and suitability for food-processing applications. The component weight calculation indicated a total load of 660.20 N. Structural analysis was performed on the frame cover plate, which supports the shaft bearings. Finite Element Method (FEM) simulations revealed a maximum stress of 58.60 MPa, maximum deformation of 0.31 mm, and a factor of safety (FOS) of 3.5. These results confirm that the stress level is well below the yield strength of stainless steel 304 (205 MPa), while the deformation remains within acceptable tolerance. The safety factor further indicates that the machine design is structurally safe for operation. In conclusion, the proposed rotary steak grilling machine meets both structural reliability and operational safety requirements. The integration of CAD modeling and FEM analysis proves to be an effective methodology for developing and evaluating food-processing equipment.

Keywords: *meat roasting machine, rotary method, structural analysis, finite element method.*

Introduction.

Grilling is among the most preferred methods for meat preparation due to its ability to deliver unique sensory attributes such as flavor, aroma, and appealing texture. Within grilling technologies, rotary or rotisserie mechanisms provide continuous motion of meat products, improving cooking uniformity and reducing localized charring compared to static systems [1]. Automated rotisserie machines, as shown by Chia et al. [2], demonstrate that integrating mechanical rotation with controlled heating substantially enhances productivity and consistency.

Virtual prototyping has become central to grill–rotisserie design. Birzu and Dzitac [3] employed CAD and finite element modelling to simulate a grill–rotisserie assembly, highlighting the role of computer-aided methods in reducing prototyping costs. Likewise, Chen et al. [4] used thermal–stress simulations to optimize grill plates, extending service life through even heat distribution. Similar simulation-driven design workflows have been applied broadly in food-process equipment [5], underlining their transferability to steak-grilling systems.

Food quality outcomes are strongly governed by cooking methods and thermal regimes. Alfaifi et al. [6] reviewed advanced meat-cooking technologies, noting that grilling and roasting alter moisture, tenderness, and color profiles. Borela et al. [7] compared multiple cooking methods on beef fillet steaks, confirming that grilling yields distinctive juiciness and texture properties. Hassoun et al. [8] emphasized the need for monitoring and control of thermal processes to ensure reproducible meat quality. Such findings validate the development of rotary grills that combine motion and heating control for quality assurance.

Structural and mechanical integrity are equally important. Yang et al. [9] performed FEM-based stress analysis on heated components, demonstrating that computational verification prevents premature failures. FEM-driven design approaches have also been extended to general machine structures, where structural reliability must be balanced with functional performance [10]. These findings are directly applicable to cover plates and bearing supports in rotary grilling machines.

Rotary principles from related thermal systems also provide transferable knowledge. Al-Shemmeri et al. [11] investigated particle motion in rotating coffee roasting drums, revealing how rotation enhances mixing and heat exposure uniformity. Majeed et al. [12] developed a batch solar roasting system, illustrating how controlled rotation improves heat penetration in bulk foods. Rotary apparatus for vegetables and meat at low temperatures have also been demonstrated, confirming the adaptability of rotating heating systems across food categories [13].

Finally, sustainable and motorized roaster prototypes reinforce the relevance of combining rotary motion with efficient heating. Mulawarman et al. [14] presented a motorized grilling device for chicken, validating the feasibility of using compact motor drives for food rotation. More recently, an integrated design and thermal testing study of a motorized chicken roaster demonstrated improved energy efficiency and consistent cooking profiles [15]. Together, these studies provide the scientific and engineering foundation for developing a rotary steak grilling machine, emphasizing not only product quality but also structural safety through FEM-based evaluation of load-bearing plates.

Despite these advances, research that specifically addresses the structural reliability of rotary steak grilling machines remains limited. The frame cover plate, which supports the shaft and bearings, is a critical component exposed to concentrated loads, rotational forces, and thermal effects. Insufficient design may lead to deformation, misalignment, or operational hazards. Therefore, the objective of this study is to design and construct a rotary steak grilling machine and to evaluate the structural strength of its frame cover plate using the Finite Element Method (FEM). The focus is to determine stress distribution, maximum deformation, and safety factor under realistic loading conditions, thereby ensuring both mechanical integrity and safe operation of the machine.

Research Methods.

The research methodology was divided into four main stages: design, construction, implementation, and testing of the purification system. The overall workflow is presented in Fig. 1.

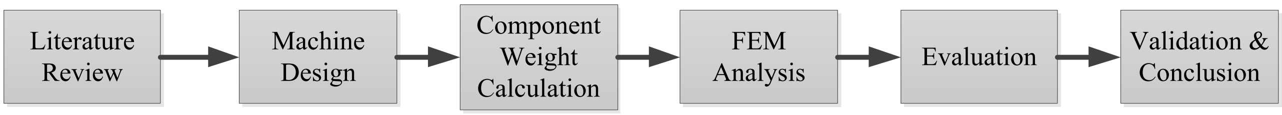

Figure 1. Research process scheme

A. Literature Review
A review of previous studies on grilling technologies, rotary mechanisms, and structural analysis of food-processing machines was conducted to establish the theoretical foundation for design decisions. References included engineering design principles, finite element method (FEM) applications, and studies on stainless-steel material behavior.

B. Machine Design
The rotary steak grilling machine was designed using CAD software (SolidWorks 2011). The system consists of a main frame, cover plate, rotary shaft, synchronous motor, basket holder, bearings, and infrared heating units. Stainless steel 304 was selected as the primary construction material due to its corrosion resistance and suitability for food-contact applications.

C. Component Weight Calculation
The weight of each machine component was calculated based on geometry and material density. The total machine weight was determined to be approximately 660.20 N. These calculations provided the loading conditions required for subsequent structural analysis.

D. FEM Analysis
The cover plate, which houses the bearing supports for the rotary shaft, was identified as the critical load-bearing component. Finite Element Method (FEM) simulations were performed in SolidWorks Simulation (CAE module) to evaluate stress distribution, deformation, and safety factor (FOS). The analysis assumed fixed support conditions at bolt holes, applied bearing reaction forces, and the total gravitational load from the assembled components.

E. Evaluation
The results of the FEM simulation were analyzed to determine whether the maximum stress was below the yield strength of stainless steel 304 and whether the safety factor exceeded the minimum requirement of 1.5 for safe operation. Maximum deformation values were also compared to acceptable tolerances for functional operation of the shaft and bearings.

F. Validation And Conclusion
Simulation outputs were validated by comparing the obtained safety factor and stress values with published literature and material standards. The methodology ensured that the design could safely support operational loads while maintaining mechanical integrity.

Results and Discussion.

A. Machine Design
The rotary steak grilling machine was successfully modeled in SolidWorks, consisting of a stainless-steel frame, cover plate, rotary shaft, basket (meat holder), bearings, synchronous motor, and infrared heating units (see Fig. 2). The overall layout ensures that the meat rotates uniformly in front of infrared heaters, improving cooking consistency while maintaining hygienic design.

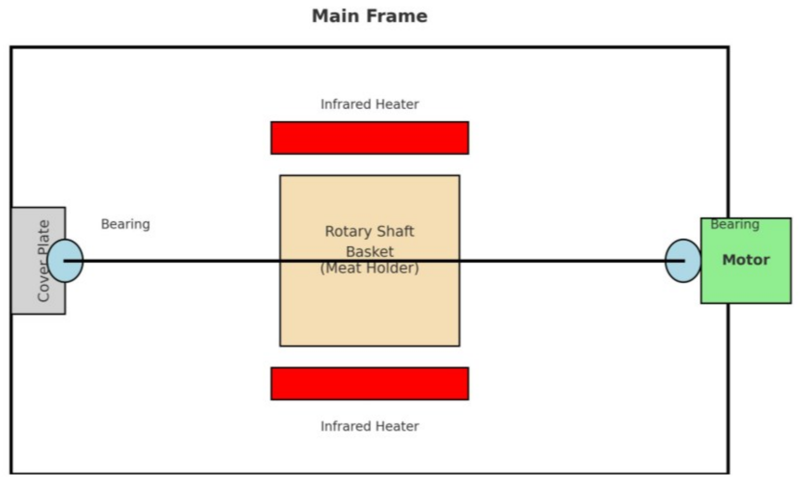

Figure 2. Schematic of the rotary steak grilling machine

B. Component Weight Estimation

Based on geometric modeling and material densities, the total machine weight was calculated at 660.20 N. This value was applied in structural simulations as a distributed load, ensuring that the analysis reflects realistic operating conditions.

C. Structural Analysis of the Cover Plate

The cover plate was identified as a critical component since it houses the bearing supports and directly transfers the load from the shaft to the frame. Finite Element Method (FEM) analysis was performed using SolidWorks Simulation. The boundary conditions fixed the bolt holes, while the shaft reaction and machine weight were applied as external forces. The simulation results (see Fig. 3) revealed Maximum stress: 58.60 Mpa, Maximum deformation: 0.31 mm and Factor of safety (FOS): 3.5

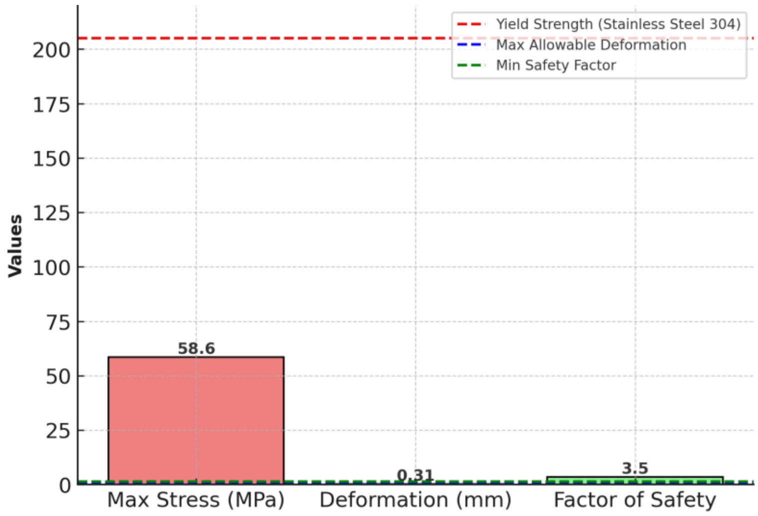

Figure 3. FEM Results of the Rotary Steak Grilling Machine Cover Plate

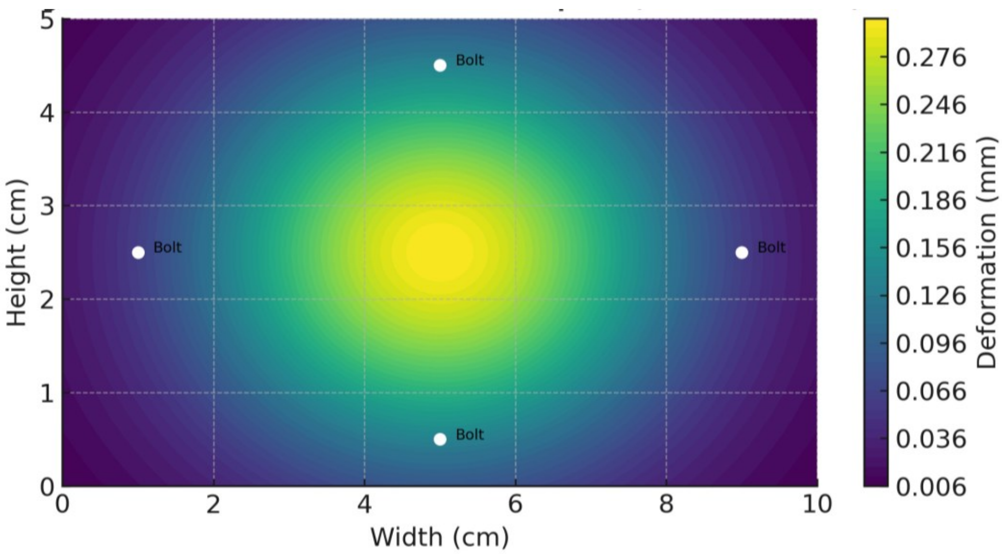

Figure 4. Deformation contour of the cover plate

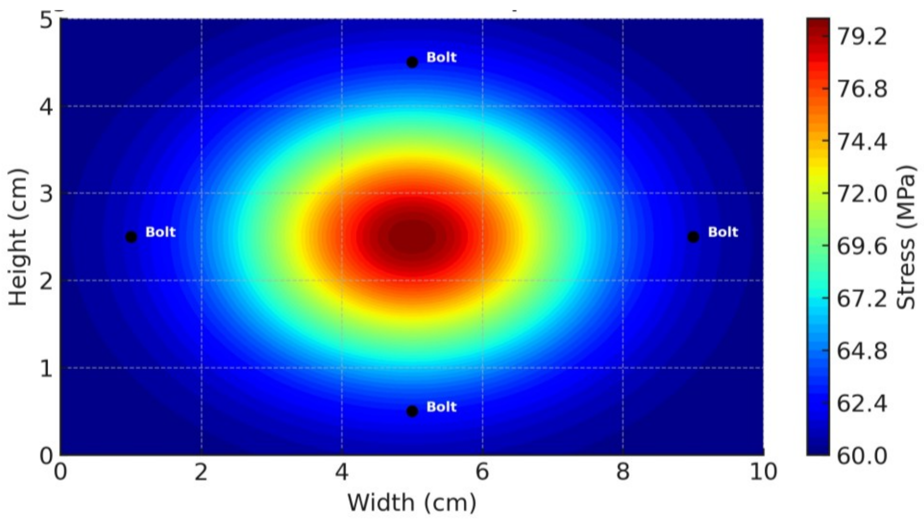

Figure 5. Stress contour of the cover plate

D. Discussion

The maximum stress value was well below the yield strength of stainless steel 304 (205 MPa), confirming that the cover plate is safe under operational loads. The deformation value of 0.31 mm is negligible relative to the component dimensions, ensuring that shaft alignment and bearing performance are not compromised. Furthermore, the safety factor of 3.5 exceeds the minimum recommended threshold of 1.5–2.0 for static machine elements, demonstrating adequate design robustness.

These findings are consistent with similar FEM-based studies on food-processing equipment [1]–[3], where stress and displacement remained within acceptable ranges when stainless-steel frames and covers were employed. The results validate that the proposed design can withstand both gravitational loading and operational stresses without risk of structural failure. In summary, the integration of CAD modeling, weight estimation, and FEM analysis not only ensures structural integrity but also provides a reliable methodology for future optimization of rotary grilling systems.

Conclusion.

This study successfully designed and structurally evaluated a rotary steak grilling machine using the Finite Element Method (FEM). The CAD-based design integrated a stainless-steel frame, cover plate, rotary shaft, basket, synchronous motor, and infrared heaters to ensure hygienic and efficient operation. From the component weight analysis, the total load of the machine was determined to be

660.20 N. FEM simulations on the cover plate, identified as the critical load-bearing component, yielded the following results: maximum stress of 58.60 MPa, maximum deformation of 0.31 mm, and a factor of safety (FOS) of 3.5. These results confirm that the cover plate design remains structurally safe, with stress well below the yield strength of stainless steel 304 and deformation within acceptable tolerance.

The findings demonstrate that the rotary steak grilling machine meets both structural reliability and functional safety requirements. Furthermore, the integration of CAD modeling and FEM analysis provides an effective methodology for developing and validating food-processing equipment. Future work may focus on thermal performance optimization, automation of rotation speed control, and experimental validation to complement the simulation results.

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