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Shaft Design for an Onion Slicing Machine Using AISI 1020 Material

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ABSTRACT

This study presents the design and basic mechanical calculation of a shaft for an onion slicing machine using AISI 1020 material. The study focuses on the shaft because it transmits rotation from the electric motor to the slicing blade through a pulley and V-belt system. The design process used literature study, material selection, 2D and 3D CAD modelling, shaft calculation, quality control, and finishing evaluation. The driving unit was a single-phase AC motor with 200 W power, 220 V voltage, 50 Hz frequency, and 2800 rpm rotation speed. The selected shaft has a length of 320 mm and an applied diameter of 20 mm. The calculation produced a design power of 0.24 kW, a design moment of 83.485 kg.mm, a shaft torque of 1.63 N.m, an allowable shear stress of 52.08 N/mm2, an actual shear stress of 1.03 N/mm2, a minimum shaft diameter of 6.22 mm, and a shaft speed of 1.88 m/s. The 20 mm shaft diameter was retained to match the inner diameter of the slicing blade and pulley. The study remains limited to dimensional design and analytical shaft calculation. It does not include full finite element analysis, fatigue testing, corrosion testing, or machine performance testing under continuous production conditions. The result can support the early-stage design of a compact onion slicing machine for small-scale food processing because it provides a safe shaft dimension and a simple power transmission configuration. The paper converts a student design report into a concise engineering manuscript that highlights the relationship between motor power, shaft torque, material selection, and component compatibility in a small onion slicing machine.

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1. INTRODUCTION

Onion (Allium cepa L.) is one of the most widely consumed horticultural commodities worldwide and serves as an essential ingredient in households as well as the food processing industry. In many countries, onions are processed into value-added products such as fried onions, dehydrated onion flakes, onion powder, and seasoning ingredients to extend shelf life and increase market value. The growing demand for processed onion products has encouraged small and medium-sized enterprises (SMEs) to improve production efficiency while maintaining product quality. Among the various processing stages, slicing is one of the most important operations because slice thickness directly affects moisture removal, frying time, texture, color, and overall product uniformity (Fellows, 2017; Singh & Heldman, 2014).

In Indonesia, onion slicing is still predominantly performed manually using conventional kitchen knives, particularly by household industries and small-scale producers. Although manual slicing requires relatively low investment costs, it presents several limitations, including high labor dependency, operator fatigue, inconsistent slice thickness, low production capacity, and limited process repeatability. These limitations become increasingly significant when production volume rises or market demand fluctuates. Furthermore, inconsistent slice geometry may reduce product quality and decrease processing efficiency during subsequent frying or drying operations. Therefore, the adoption of appropriate mechanical slicing technology has become increasingly important for improving productivity and ensuring consistent product quality (Mujumdar, 2015; Fellows, 2017).

Mechanical onion slicing machines have been developed to overcome these challenges by integrating electric motors, rotating blades, transmission systems, and feeding mechanisms into compact production equipment. Previous studies have demonstrated that such machines significantly improve slicing capacity and operational efficiency. Effendi and Khumaidi (2018) designed a multipurpose onion slicing machine driven by an electric motor with a target production capacity of approximately 55 kg/hour. Baskara et al. (2018) developed a vertical onion slicing machine that achieved a slicing capacity of 56.21 kg/hour with a slicing efficiency of 89%. Likewise, Hermawan et al. (2018) reported that pulley diameter substantially influences blade rotational speed and consequently affects machine productivity and slicing performance. These studies indicate that machine performance depends not only on blade geometry but also on the effectiveness of the mechanical transmission system that transfers power from the motor to the cutting mechanism.

Among the transmission components, the shaft plays a particularly critical role because it transmits rotational power and torque from the electric motor through the pulley system to the cutting blade. During operation, the shaft is subjected to combined mechanical loading, including torsional moments, bending forces, dynamic loading, and vibration generated by continuous cutting cycles. An improperly designed shaft may experience excessive shear stress, excessive deflection, fatigue failure, or misalignment, ultimately reducing slicing accuracy, increasing vibration, shortening bearing life, and lowering overall machine reliability. Consequently, shaft design must satisfy both strength and rigidity requirements while maintaining compatibility with the selected pulley dimensions, blade configuration, bearing arrangement, and motor characteristics (Budynas & Nisbett, 2020; Khurmi & Gupta, 2019).

Mechanical shaft design generally follows established machine design principles involving the determination of transmitted power, design power, transmitted torque, allowable shear stress, actual working stress, minimum shaft diameter, and rotational speed. Appropriate material selection also becomes an important consideration because mechanical properties such as yield strength, ductility, machinability, and cost influence both safety and

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manufacturing feasibility. AISI 1020 medium-low carbon steel is widely used in rotating machine components due to its balanced combination of adequate mechanical strength, good weldability, excellent machinability, and economical manufacturing cost, making it suitable for moderate power transmission applications (Budynas & Nisbett, 2020; Callister & Rethwisch, 2020).

Although previous investigations have successfully developed onion slicing machines with satisfactory production capacities, most studies primarily emphasize machine fabrication and production performance while providing only limited discussion regarding systematic shaft design calculations. Detailed engineering analyses concerning transmitted torque, allowable stress, shaft sizing methodology, and material selection remain relatively scarce in the published literature. As a result, there is still a need for a comprehensive shaft design procedure that can serve as a practical engineering reference for the development of compact onion slicing machines suitable for small-scale food industries.

Therefore, this study aims to design and analyze the shaft of a compact onion slicing machine using AISI 1020 steel as the shaft material. The design analysis includes the determination of motor power, design power, transmitted torque, allowable shear stress, actual shear stress, minimum shaft diameter, and shaft rotational speed based on established machine design principles. The novelty of this study lies in presenting a systematic shaft design methodology that integrates power transmission analysis, mechanical strength calculations, and material selection into a single engineering design framework for a compact electric onion slicing machine. The results are expected to provide practical design guidelines for researchers, machine manufacturers, and small-scale food processing industries in developing reliable, safe, and cost-effective onion slicing equipment.

2. METHODS

This study used an engineering design approach. The object was a small onion slicing machine consisting of a frame, electric motor, motor pulley, V-belt, driven pulley, pillow block, shaft, hopper input, slicing blade, and output channel. The design data were obtained from the student scientific writing report and converted into a journal manuscript format.

The design procedure consisted of six stages. First, literature study identified the working principle of onion slicing machines and shaft design requirements. Second, the shaft material was selected. Third, 2D and 3D models were prepared using SolidWorks 2018. Fourth, shaft calculations were carried out. Fifth, quality control checked the connection among the shaft, pulley, V-belt, and blade. Sixth, finishing confirmed machine readiness before use.

The driving motor was a single-phase AC motor with 200 W power, 220 V voltage, 50 Hz frequency, 1.1 A current, and 2800 rpm rotational speed. The shaft design used AISI 1020 material with a planned shaft length of 320 mm and a planned shaft diameter of 20 mm.

The calculation began by determining the design power using Pd = fc x P, where Pd is design power, fc is correction factor, and P is motor power. The design moment was calculated using T = 9.74 x 10^5 x Pd/n1, where T is the design moment and n1 is motor rotation. Shaft torque was calculated from design power and motor rotation. The allowable shear stress was calculated from tensile strength and safety factors. The actual shear stress used the applied torque and planned shaft diameter. The minimum shaft diameter was then compared with the diameter required by the blade and pulley.

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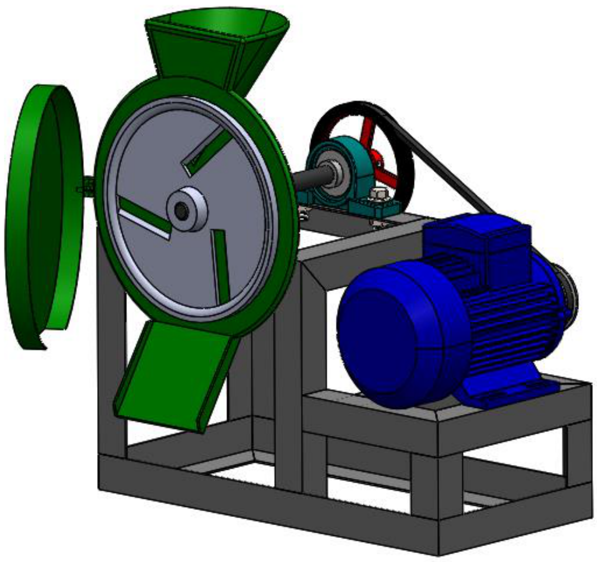

Figure 1. Three-dimensional design of the onion slicing machine.

Table 1. Main components and functions of the machine

No.	Component	Function
1	Frame	Machine support and component mounting base
2	Motor pulley	Transfers rotation from motor shaft to V-belt
3	Single-phase motor	Primary power source
4	V-belt	Transmits rotation between pulleys
5	Driven pulley	Transfers rotation to main shaft
6	Pillow block	Supports shaft rotation
7	Shaft	Transmits rotation to slicing blade
8	Hopper input	Feeds peeled onion into the cutting zone
9	Blade	Slices onion by rotary cutting action
10	Output channel	Guides sliced onion to the collection area

3. RESULTS

The calculation produced the shaft dimensions and mechanical design parameters needed for the onion slicing machine. Table 2 shows the motor specification, Table 3 shows the material data used for the shaft, and Table 4 summarizes the calculation results.

Table 2. Specification of the single-phase AC motor

Property	Value
Voltage	220 V
Frequency	50 Hz
Speed	2800 rpm
Output power	200 W or 0.2 kW
Current	1.1 A

Table 3. Chemical composition used for AISI 1020 shaft material

Material	C (%)	Si (%)	Mn (%)	Mo (%)	P (%)	Cr (%)
AISI 1020	0.20-0.30	0.15-0.35	0.50-0.70	0.20-0.30	0.035	0.90-1.40

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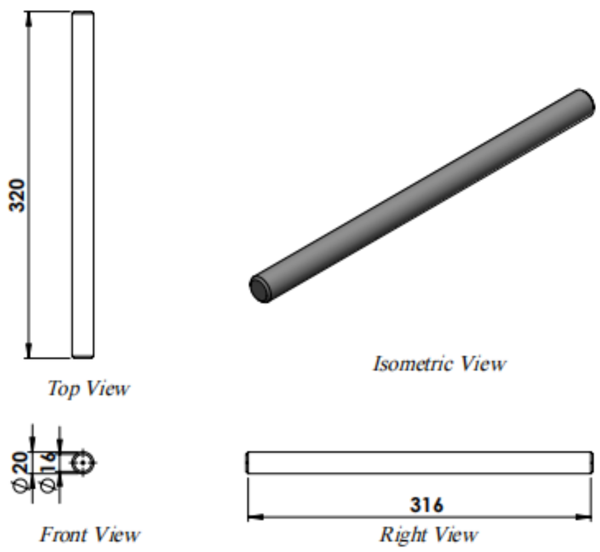

Figure 2. Two-dimensional shaft drawing for the onion slicing machine.

Table 4. Shaft calculation results

Parameter	Result	Design note
Motor power, P	0.2 kW	Input power from electric motor
Correction factor, fc	1.2	Selected design correction factor
Design power, Pd	0.24 kW	Pd = fc x P
Motor rotation, n1	2800 rpm	Motor speed used in calculation
Design moment, T	83.485 kg.mm	Calculated using Pd and n1
Shaft torque	1.63 N.m	Torque acting on the shaft
Allowable shear stress	52.08 N/mm2	Based on tensile strength and safety factors
Actual shear stress	1.03 N/mm2	Calculated using 20 mm shaft diameter
Minimum calculated diameter	6.22 mm	Minimum diameter from shaft design equation
Applied shaft diameter	20 mm	Selected to match blade and pulley bore
Shaft length	320 mm	Final design dimension
Pulley size	Outer diameter 254 mm; inner diameter 20 mm	Driven pulley dimension
Shaft speed	1.88 m/s	Calculated from angular speed and shaft radius

The result indicates that the actual shear stress on the designed 20 mm shaft is lower than the allowable shear stress. The actual shear stress is 1.03 N/mm2, while the allowable value is 52.08 N/mm2. This relationship indicates that the shaft dimension is safe for the calculated torsional load.

The minimum calculated shaft diameter was 6.22 mm. However, the final design used a 20 mm diameter because the bore diameter of the slicing blade and driven pulley also requires 20 mm. This decision provides dimensional compatibility and increases the margin of safety in the shaft design.

The shaft speed was calculated as 1.88 m/s. This speed supports the rotary cutting mechanism because the blade rotates through the shaft and cuts onion supplied from the hopper input. The pulley and V-belt system provides a simple power transmission layout for a compact food processing machine.

4. DISCUSSION

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The design result confirms the important role of the shaft in the onion slicing machine. The shaft does not only act as a rotating bar. It also connects the power transmission system to the cutting mechanism. When the motor rotates, the motor pulley drives the V-belt, the driven pulley rotates the shaft, and the shaft moves the blade. A stable shaft therefore supports continuous blade rotation and helps maintain the slicing process.

The use of a 20 mm shaft diameter gives a practical advantage. The calculated minimum value is smaller than the applied diameter, but the design must also consider assembly compatibility. A shaft diameter that matches the pulley and blade bore reduces the need for additional adapters and decreases the risk of loose connections. This decision follows a common engineering practice where standard part compatibility and safety margin influence final dimensions.

The calculated stress condition also supports the design. The actual shear stress is far below the allowable shear stress. This means that, under the motor power and rotation used in this design, the shaft should be able to transmit the required torque without exceeding the material strength limit. Similar studies on small slicing machines also emphasize the importance of motor power, pulley transmission, blade speed, and blade position for production capacity and slice uniformity (Baskara et al., 2018; Hermawan et al., 2018; Tampubolon et al., 2025).

The selected AISI 1020 shaft material gives adequate strength for the calculated load. However, onion processing belongs to a food-processing environment, so corrosion resistance and hygiene must receive attention. Food-contact parts should use food-grade material, especially stainless steel, or require surface protection if carbon steel parts are located near the product zone. This point becomes important because onion moisture and processing residue can accelerate corrosion.

This study has clear limitations. The analysis focuses on shaft calculation and design compatibility. It does not yet measure slicing capacity, slice thickness distribution, vibration, fatigue life, bearing load, corrosion behavior, or long-term operating reliability. Further research should add finite element analysis, prototype testing, hygiene evaluation, and performance testing using several onion feed rates.

5. CONCLUSION

This study designed a shaft for an onion slicing machine using AISI 1020 material. The final shaft dimension is 320 mm in length and 20 mm in diameter. The driven pulley has an outer diameter of 254 mm and an inner diameter of 20 mm.

The shaft calculation produced a design power of 0.24 kW, a design moment of 83.485 kg.mm, a shaft torque of 1.63 N.m, an allowable shear stress of 52.08 N/mm2, an actual shear stress of 1.03 N/mm2, a minimum shaft diameter of 6.22 mm, and a shaft speed of 1.88 m/s. The selected 20 mm shaft diameter is safe for the calculated load and matches the pulley and blade bore diameter.

Future work should test the prototype under real onion slicing conditions. The next analysis should include slicing capacity, slice thickness uniformity, vibration, shaft fatigue, bearing performance, and corrosion resistance of components located near food-contact zones.

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7. AUTHORS' NOTE

The author declares that there is no conflict of interest regarding the publication of this article. The author confirms that the manuscript was prepared from the original scientific writing report and should be checked again with a plagiarism detection tool before journal submission.

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