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# Design of Paper Foil and Laminating Machine as Lining Material for Paper Bags

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**Keywords**

Design; Foil Coating Machine; Paper Bag

**ABSTRAK**

*In order to enhance the contribution of MSMEs as a key driver of Indonesia's economic growth, the development of small- to medium-scale production machines is essential. This is particularly important as MSMEs face increasing competition and more complex customer demands. This study aims to design and develop a simple production machine using CAD software and Autodesk Inventor to improve productivity and quality in the paper bag manufacturing process. Currently, production is carried out manually, resulting in limited capacity and product quality. The machine being designed serves to perform the paper gluing and rolling processes with foil lamination. The design integrates the gluing and rolling mechanisms into a single unit equipped with an automatic rotating system. This setup significantly reduces production time, thereby increasing both capacity and quality compared to the manual process. Simulation analysis of force, stress, and safety factor was carried out assuming the frame receives a load of 120 N, based on conditions close to reality. The results show a maximum Von Mises stress of 97.91 MPa and a minimum of 0 MPa. The maximum displacement is 0.5844 mm, and the minimum is 0 mm. The safety factor at the top frame section is 2.55 ul. Meanwhile, for testing under a 12 kg load, the results show a maximum Von Mises stress of 108.8 MPa, a displacement of 0.6488 mm, and a safety factor of 2.3 ul.*

## 1. INTRODUCTION

The design process begins by recognizing a requirement, defining the issues and combining them, analyzing with optimization, evaluating, and making a decision to take action regarding the machine [1] and machine design is an integral part of the broader and general field of mechanical design. The design aims to create machines, tools, or systems to meet specific needs, typically involving moving parts, power transmission, and specific motion patterns [2]. In this research, we will be creating a paper roll machine. The definition of the rolling process refers to the set of mechanical operations involved in winding or rewinding a continuous sheet (web) of paper onto a roll, either during or after the paper manufacturing process. It ensures that paper is compactly and uniformly wound for storage, transportation, or further processing. The production of paper consists of two main phases: the creation of the paper sheet and its transformation into various final products. This transformation process, known as converting, includes multiple operations such as unwinding, rewinding, laminating, cutting, and packaging [3][4][5]. The quality of the produced product is one of the indicators that determine whether the machine is deemed suitable or not [6]. The machine to be designed is an adhesive and paper foil roller machine. The working system of this machine involves adhering paper and foil by pressing and rolling them simultaneously. Currently, the production process is still done manually, using a tool operated by the worker's hand with the rotation of the handle, which is time-consuming and results in suboptimal quality.

From previous research conducted by Hashimoto, Hiromu, Jeenkour, Puttha, et al. [7], in the manufacturing process, particularly those focused on the distribution of stress and friction forces occurring between layers of web in a wound paper roll, key sections discuss the constraints of design variables such as nip load and tangential stress. They also highlight experimental methods used to measure radial stress and evaluate the occurrence of slippage after the winding process. The research entitled "Optimization of taper winding tension in roll-to-roll web systems" by Wu Dehui highlights the importance of controlling winding tension and transport speed in the winding process, with the aim of improving efficiency in the manufacturing of web-based products [8].

From previous research where rolling systems were used as a reference with a similar concept, the design of this machine is developed by combining two functions: adhesion and rolling. With this machine it is expected to increase production capacity and improve the quality of its output so that it can compete with other small and medium enterprises. In a machine design, of course, mechanical systems and transmission systems are important to be taken into account properly and accurately in the planning process. The current design of the paper roll machine with integrated lamination has not been developed previously, as this machine is a combination of two existing machines. It is considered more innovative because it integrates the functions of rewinding and lamination automatically within a single unit. Its advantages include time efficiency, as there is no need to transfer materials between separate machines. It also features automatic synchronization between the lamination and rewinding speeds, which helps prevent defects such as bubbling or wrinkling. Additionally, it reduces production space requirements and labor costs.

## 2. METHODS

This research was conducted by following the complete research flow, as illustrated in Figure 1 below:

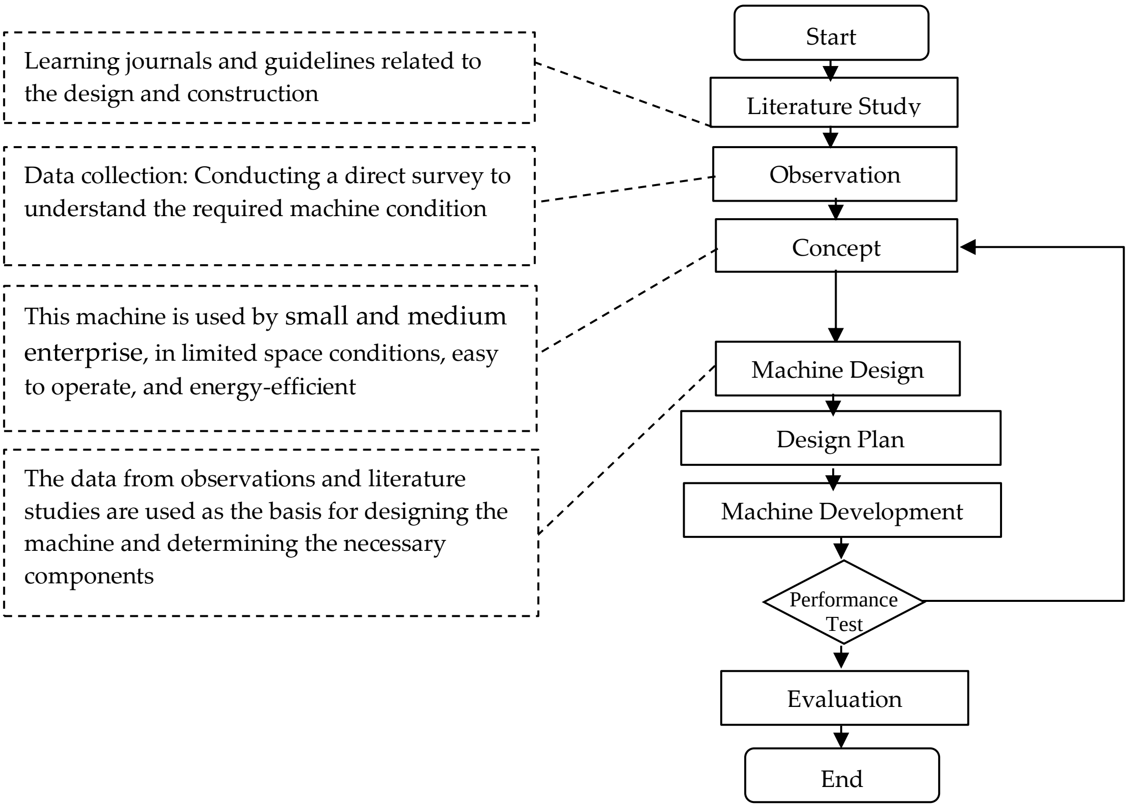



Figure 1. Research Flow

### 2.1 Literature Study

A literature review aims to gain a deep understanding of the topic, identify knowledge gaps, obtain perspectives, and support the development of solid arguments or methodologies in the ongoing research. This involves reading, reviewing, and synthesizing various existing sources, such as scientific journals, books, articles, and other scholarly works related to the subject of the research being conducted (machine design)

### 2.2 Observation

Field observation refers to the collection of data or information directly from the location or environment visually or through direct observation. It involves researching directly at the scene to gain a better understanding of the situation or observed phenomena.

### 2.3 Concept

The machine design concept includes identifying needs, understanding the functional and technical aspects of the desired machine, and considering technical and financial limitations in creating an efficient, safe, and goal-oriented design. In this stage, there is an exploration of ideas, conceptual modeling, initial analysis, and the development of a vision of how the machine will operate and meet the desired objectives.

### 2.4 Machine Design

The machine design concept includes identifying needs, understanding the functional and technical aspects of the desired machine, and considering technical and financial limitations in creating an efficient, safe, and goal-oriented design. In this stage, there is an exploration of ideas, conceptual modeling, initial analysis, and the development of a vision of how the machine will operate and meet the desired objectives.

### 2.5 Design Plan

Planning refers to the process of creating a structured plan or strategy to achieve goals. It involves identifying objectives, determining necessary steps or actions, allocating resources, and establishing a schedule or timeframe to achieve the desired outcomes.

### 2.6 Machine Development

The machine manufacturing process is carried out based on the initial planning that has been established and the results of calculations for the components used, including technical specifications, materials, and desired dimensional sizes. Some components are fabricated in the vocational faculty workshop, while others are obtained through purchases. Subsequently, assembly is conducted in accordance with the predetermined design.

### 2.7 Performance Test

Machine performance testing is conducted to evaluate the capabilities and performance of the machine and to ensure that it functions in accordance with the specified specifications and can perform its tasks effectively. The results of performance testing assist in determining whether the machine is ready for use in an operational environment and whether it meets the established standards.

### 2.8 Evaluation

In the machine manufacturing process, the evaluation stage involves assessing the performance of the manufactured machine. This includes performance testing, checking if the machine meets the specified specifications, and ensuring compliance with safety standards and reliability, as well as identifying areas where the machine may need improvement.

## 3. RESULT AND DISCUSSION

### 3.1 Machine Design

The initial design is created by visualizing the machine to be designed using Autodesk Inventor [9] [10] [11], and the result is obtained as follows:

The machine frame is planned to be constructed to provide the basic structure supporting machine components, such as the machine itself, transmission, and other systems that provide stability and strength to the installed parts. The initial step in machine design is, of course, designing the machine frame first by selecting a type of material that meets the design specifications. The strength of this machine frame is tested through static loading simulations to obtain a safe construction limit value for the frame. This loading simulation includes stress analysis features (finite element analysis (FEA) method). The frame simulation yields values for *displacement, von misses stress, and safety factor.*

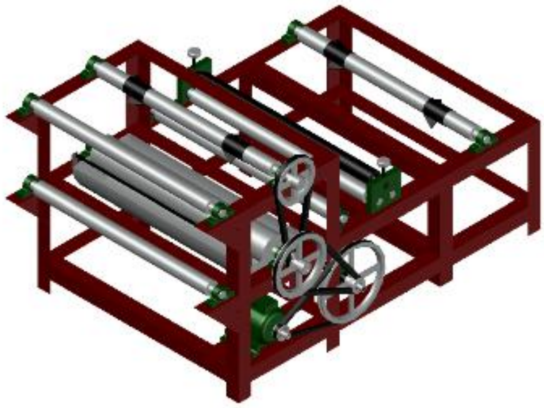


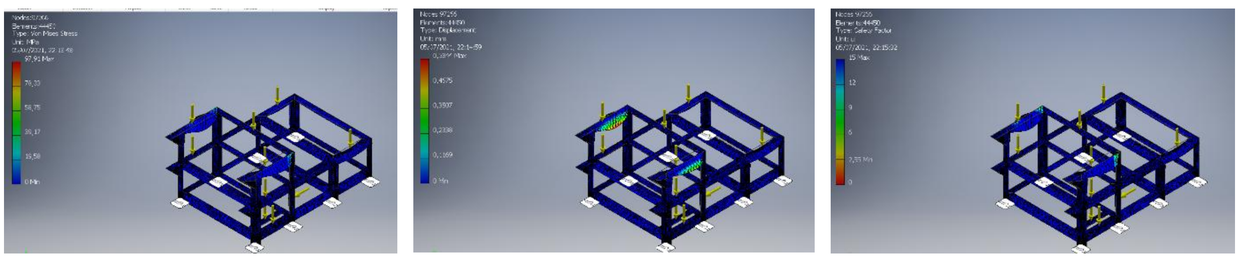
Figure 2. Design of foil-laminated paper machine

### 3.2 Frame Structure Design

The design of the frame structure for the paper foil laminating machine is carried out using AutoCAD [12] [13] with a frame structure model as follows.

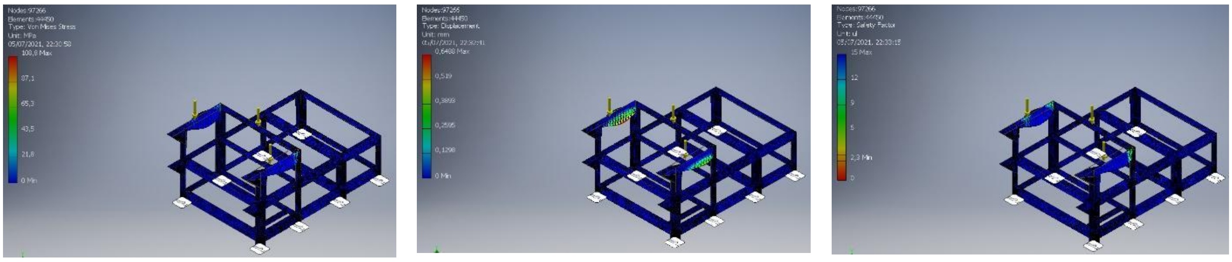
Figure 3. Main frame structure

Simulation analysis of forces, stress, and safety factors of the frame can be generated using Autodesk Inventor software by selecting the stress analysis toolbar. After selecting the stress toolbar, input the material specifications data according to the previous planning. Once the material is selected, choose static analysis and mesh view. It is assumed that the frame structure for the paper foil laminating machine is subjected to a load of 120 N, assumed as In Autodesk Inventor, frame data is inputted according to conditions close to reality, allowing for static analysis of the structure. Upon reaching this step, it can be determined if there are any errors in the analysis steps. If there are errors, editing needs to be done until correct. In this analysis, the frame structure can be seen in the image below to understand overall forces, stress, and safety factors.



(a) (b) (c)

Figure 4. (a) from the Von Mises testing results obtained a maximum stress value of 97.91 MPa and a minimum stress value of 0 MPa. (b) From the displacement testing results obtained, the largest displacement value was 0.5844 mm and the minimum displacement value was 0 MPa. (c) From the safety factor testing results, a safe value for the above frame is obtained at 2.55 ul.



(a) (b) (c)

Figure 5. (a) load stress 12 kg, (b) load displacement 12 kg, (c) load safety factor 12 kg. From the test results on a 12 kg load, the maximum values obtained are 108.8 MPa for Von Mises stress, 0.6488 mm for displacement, and 2.3 ul for the safety factor.

From the simulation results of the machine frame subjected to a 120 N load, the highest safe limit value is 2.94 (the safety factor value for dynamic loads is between 2.0-3.0 according to the book "Machine Element" by Dobrovolsky) [14]. A safety factor of 2.94 means that the maximum load the structure can withstand is nearly three times greater than the actual working load. This indicates that the design is on the safe side. A value of 2.94 falls into the conservative category, but it is still reasonable for mechanical systems that operate continuously, such as paper roll and lamination machines—especially when considering dynamic loads, vibrations, or material wear. With a relatively high safety factor, there is potential to use lighter materials or reduce the cross-sectional dimensions of certain components, as long as the minimum industry-standard safety factor (typically 1.5–2 for steel) is still maintained. However, such decisions must also take into account factors like cost, material availability, and ease of manufacturing.

### 3.3 Machine Element Design

The design calculations carried out include calculations for planned power, machine rotation speed, pulley and V-belt, as well as the shaft. The calculations for the pulley and V-belt components include speed ratio, pulley centrifugal tension, transmission ratio, belt speed, center distance between pulleys, belt length, actual center distance between pulleys, and the contact angle between the V-belt and the pulley. Shaft calculations are performed to determine the design power, torsional moment, shear stress, and shaft diameter.

Table 1. Design Calculations

| No | Parameter | Formula | Result |
|---|---|---|---|
| 1 | Power Calculation Plan (Pd) [2] | $Pd = fc\ x\ P$ | 0.15 $kW$ |
| 2 | Motor Rotation (N2) [15] | N1/N2 = D2/D2 | 240 $rpm$ |
| 3 | V-Belt Speed (v) [2] | $V$ = (π, D1, n1)/(60 .1000) | 3.19 $m/s$ |
| 4 | Circumference length (L) [2] | $L$ = (π)/2 ($D2 + D1$) + $2C$ + ((D2-D1)²)/4c | 42 *inches* |
| 5 | Shaft axis distance (C) [2] | $C$ = (b + √b2 - 8(D2 - D1))/8 | 295 mm |
| 6 | Contact angle (Θ) [2] | $\theta$ = 180 −(57 (Dp - dp))/c | 2.3 rad |
| 7 | Belt tension (Kg) [2] | $F1 - F2$ = T/R | 46.23 kg |
| 8 | Shaft Diameter ($\boldsymbol{ds}$) [2] | ds = [5,1/Ta┤ √($KmM$)2 + ├ (KtT)^2 ] 1/3 | 143 mm |
| 9 | Bearing lifespan [14] | $L10$ = 106/(60 n) (c/p)b | 18,777,090.99 hours (≈ 13 years, assuming a 5-day workweek with 6 hours per day) |

The calculation of machine elements, particularly in the transmission and mechanism systems, serves as the main foundation in the design and development of the machine prototype. The data obtained from these calculations ensure that each component can operate optimally and safely under the planned operating conditions, allowing them to be directly applied in the prototype manufacturing stage.

**3.4 Prototype**

The design and calculation of a foil-laminated paper machine have been successfully completed. This machine uses a driving motor with a power of 1/6 HP and a rotation speed of 2400 rpm, utilizing a transmission system with pulleys and V-belts. The shaft components are made from St90 material with a tensile strength of 90 kg/mm², and the motor shaft has a diameter of 20 mm. For the pulley system, a V-belt type A43 is used, and the bearings used are open-type pillow bearings model 6204.

Figure 6. Foil-laminated paper machine prototype

In the design process of a foil-laminated paper machine, there are several crucial design selection principles that significantly determine the success of the system being developed. The design choices not only consider technical aspects but also functional requirements and work efficiency, as well as user convenience and safety. The aspect of function and production process effectiveness serves as the primary foundation in the design selection. This machine is designed to integrate two processes that were previously carried out manually—namely, adhesion and winding—into a single, integrated system. Therefore, the design must accommodate an efficient workflow, with components that support each other to ensure the process runs smoothly and without interruption. The accuracy and consistency of the adhesion process is also a major concern. The adhesive must be applied evenly across the paper surface to ensure a neat, strong, and durable final product. This requires the selection of an adhesive system that is stable and well-controlled in terms of both pressure and glue distribution.

Furthermore, the alignment between the winding system and the foil layer is crucial, as foil—being a sensitive material—is prone to damage from pressure and wrinkling. The machine design must maintain consistent paper tension to ensure the winding result remains neat and does not damage the foil layer. This is closely related to the choice of roller types, tension control systems, and roller coating materials such as rubber or silicone. The machine design also takes into account ease of maintenance and operation. As the machine is intended for use in small- to medium-sized industries, it must be operator-friendly, easy to understand, and simple to maintain [16].

Table 2. Performance Data of Foil-laminated paper machine

| Performance Parameter | Manual Method | Prototype Machine |
|---|---|---|
| Operating Speed | Inconsistent | ± 5–15 sheets/min |
| Daily Output Productivity | ± 500–800 sheets/day | ± 6,000–9,000 sheets/day |
| Lamination Quality | Prone to wrinkles and uneven | Smooth and consistent |
| Adhesive Thickness Consistency | Variable (inconsistent) | Stable and even |
| Operator Involvement | High (fully manual) | Low (semi-automated) |

In the experiment, a total of 15 tests were conducted for cutting A4-size paper. There were 3 retests and 1 failure, which was caused by the need to readjust the position of the paper within the roll. This prototype demonstrates that the design is feasible and capable of achieving the desired results and output in terms of both productivity and quality. It also proves that the paper-cutting machine can be built with limited tools and at an affordable cost.

## 4. CONCLUSION

Based on the calculated planning of the machine components, several conclusions can be drawn. The design of the adhesive and foil paper rolling machine, which functions as a liner for paper bag material, has overall dimensions of 1200 x 800 x 650 mm. The machine frame uses a profile with a thickness of 50x50x2 mm. Through simulation analysis, the frame exhibited a Von Mises stress of 97.91 MPa, a displacement of 0.5844 mm, and a safety factor of 2.55 ul under the assumed operating conditions.

Further simulation under a maximum load of 12 kg resulted in a higher Von Mises stress of 108.8 MPa, a displacement of 0.6488 mm, and a reduced safety factor of 2.3 ul. These values are still within the acceptable range, as the highest safe limit is 2.94, and the recommended safety factor for dynamic loads is between 2.0 and 3.0, in accordance with the book Machine Elements by Dobrovolsky.

From the component calculations, a V-belt type A43 (with a length of 1066.8 mm) was selected for the transmission system. The shaft diameter was determined to be approximately 15 mm (rounded from a calculated value of 14.3 mm), and a pillow block bearing of type UCP204 was selected to support the shaft, based on the expected loads and performance requirements. In the future, this machine prototype can be improved through several developments, including the potential use of lighter materials or the reduction of cross-sectional dimensions in certain components, as long as the minimum industry-standard safety factor (typically 1.5–2 for steel) is maintained with proper considerations. Additionally, the addition of a cover box on moving parts is recommended to enhance safety

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