TRANSMISSION SYSTEM PROTOTYPE AS SPEED OPTIMIZATION IN THE POWER DRIVE MECHANISM OF THE MAKER S4000 MACHINE AT PT DM

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ABSTRAK

Mesin *maker S4000* di PT DM mengalami permasalahan pada proses pemotongan batang rokok akibat ketidaksesuaian kecepatan antara motor servo pada proses penyaluran dan pemotongan. Ketidaksinkronan ini menyebabkan hasil potongan tidak presisi dan meningkatkan jumlah produk cacat. Permasalahan tersebut menunjukkan perlunya sistem yang mampu menyelaraskan kecepatan putaran antara kedua proses secara mekanis. Penelitian ini bertujuan untuk merancang sistem transmisi roda gigi sebagai solusi untuk menyelaraskan kecepatan antara proses penyaluran dan pemotongan. Analisis masalah dilakukan dengan metode *Failure Mode and Effect Analysis* (FMEA). Metode perancangan dilakukan metode VDI 2221, yang mencakup analisis kebutuhan fungsional, pengembangan beberapa alternatif konsep, evaluasi rasio transmisi, serta pemilihan komponen mekanis yang sesuai. Analisis kekuatan struktur dilakukan melalui simulasi menggunakan *Finite Element Analysis* (FEA). Purwarupa sistem dibuat menggunakan *3D printing* sebagai media verifikasi desain. Hasil penelitian menunjukkan bahwa sistem transmisi mampu menyalurkan putaran secara sinkron sehingga menghasilkan panjang rokok yang konsisten. Simulasi FEA menyatakan sistem aman terhadap beban kerja. Purwarupa berhasil divalidasi secara visual dan fungsional, serta menjadi dasar evaluasi sebelum implementasi aktual.

Kata kunci: Mesin *Maker S4000*, Sistem Transmisi, Rokok, Metode VDI 2221, FEA

ABSTRACT

The S4000 maker machine at PT DM faces issues during the cigarette rod cutting process due to a mismatch in speed between the servo motors in the feeding and cutting processes. This lack of synchronization results in imprecise cuts and an increase in defective products. This problem indicates the need for a system capable of mechanically synchronizing the rotational speeds between the two processes. This study aims to design a gear transmission system as a solution to synchronize the speeds between the feeding and cutting processes. Problem analysis was conducted using the Failure Mode and Effect Analysis (FMEA) method. The design process follows the VDI 2221 method, which includes functional requirement analysis, development of several conceptual alternatives, evaluation of transmission ratios, and selection of suitable mechanical components. Structural strength analysis was carried out through simulations using Finite Element Analysis (FEA). A system prototype was created using 3D printing as a design verification tool. The results show that the transmission system is capable of delivering synchronized rotation, resulting in consistent cigarette rod lengths. The FEA simulation indicates the system is safe under working loads. The prototype was successfully validated both visually and functionally, serving as a basis for evaluation prior to actual implementation.

Keywords: S4000 Maker Machine, Transmission System, Cigarette, VDI 2221 Method, FEA

INTRODUCTION

The cigarette industry in Indonesia has experienced rapid development, from initially only a home industry to a large number of sectors on a national and multinational scale. The Central Statistics Agency (BPS) explained that regarding the increase in cigarette consumption in the Indonesian people in 2024, smokers in Indonesia can consume an average of 87.45 cigarettes per week. This data has increased from the previous one in 2023 which was at an average consumption rate of 85.42 cigarettes per week [1].

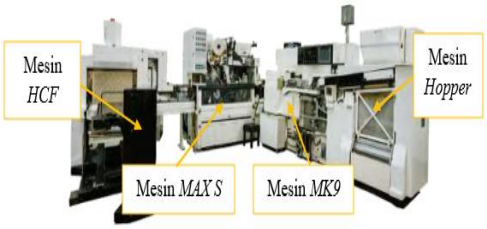
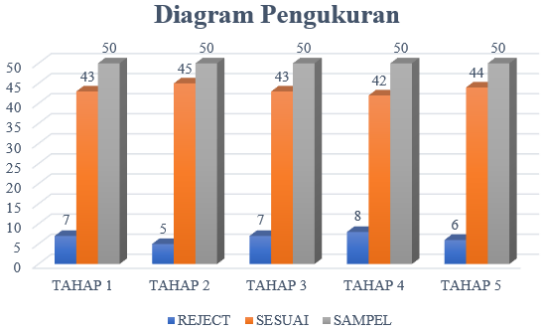


Figure 1 S4000 Maker Machine

Cigarette machines are tools used as a means of production in the tobacco product processing industry. The cigarette machine product produced by PT DM is the S4000 maker machine, which can be seen in Figure 1. The S4000 maker machine has several types of machines according to their functions. The production process on this machine is carried out starting from the process of assembling components to the test run process when the components have been assembled thoroughly. The purpose of the test run is to ensure that all parts of the machine can work optimally according to their function.



Gambar 2 Diagram Pengukuran

The test run process carried out by the S4000 maker machine is carried out for 8 hours a day, this is done to show the quality of the cigarette bars according to the specifications. The process of checking the quality of cigarette bars is carried out by measuring the length of cigarette bars. Measurements were made using a dial caliper measuring device, and were carried out in 5 stages with different times, the sample of each measurement taken amounted to 50 rods, shown in Appendix 1. The measurement of cigarette length results in cigarettes in the category of reject (product defects), due to the length size that does not correspond to tolerance. The measurement results showed rejected cigarettes with an average of 5 – 8 sticks from the total samples measured, shown in Figure 2.

The difference in length in the test run process is caused by the MK9 machine in the trial making cigarette sticks, there are a series of printers, tape drums and cut offs that have a role in making cigarette sticks. The printer series has a function to distribute cigarette paper on cigarette paper to be filled with tobacco. The cigarette paper that has been filled with tobacco will be driven by a series of tape drums to carry out the forming process or the formation of cigarette sticks to produce cigarette rod protrusion, then channeled to the cutting process. The cut off series has a function to carry out the process of cutting cigarette rods.

Cigarettes with the reject category are caused by the precise process of cutting cigarette rods on the MK9 engine. This is due to the rotational speed of the servo motor that drives the tape drum as a distribution of cigarette rods to the cutting process that is not in harmony with the rotational speed of the servo motor that drives the cut off for the cutting process, because it exceeds the permissible tolerance ±2 rpm. The misalignment of the rotation speed of the two servo motors is due to the increase or decrease of the speed of one servo motor, but the other servo motor does not automatically make the speed adjustment. The main problem lies in the controller system that regulates the servo motor, where the speed commands from the control software are not accurately synchronized between the tape drum drive servo motor and the cut off drive servo motor. This mismatch causes a difference in rotational speed between the two motors, because when there is a change in load or fluctuation in electric current in one motor, the controller system does not automatically make adjustments to the other motors. As a result, the process of cutting cigarette rods becomes imprecise and reduces the consistency of the length of the produced cigarettes.

This research was conducted to design a speed synchronization mechanism in the process of distributing and cutting cigarette sticks. The transmission system aims to produce a rotational speed that is aligned between the cigarette rod rod thrust driven by the tape drum against the cut off as the cigarette rod cutting place, thus resulting in a consistent measurement of cigarette length according to the size.

SYSTEM DESIGN

The design and research process includes a sequence of activities, from the beginning to becoming a product. Figure 3 shows the sequence of research stages used in the VDI 2221 method.

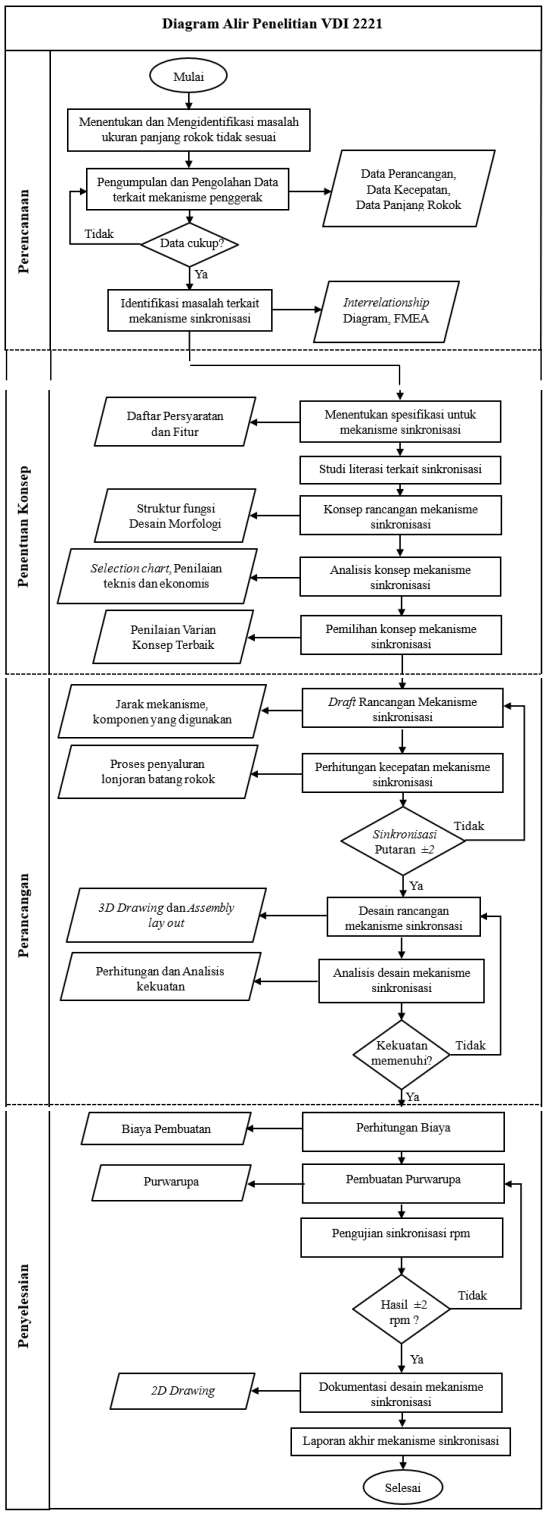


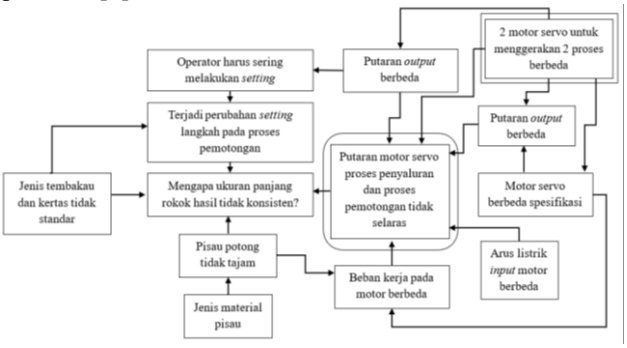
Figure 3 Flowchart

The research flow diagram is compiled to describe the systematic flow of the stages of activities carried out during the design process. This diagram covers the main steps from problem identification, data collection and analysis, formulation of design needs, development of alternative concepts, evaluation and selection of concepts, to the stages of detailed design and prototyping. The methodology used refers to the VDI 2221 standard, which allows a structured approach in the development of transmission systems. VDI 2221 is used as a guide to develop technical and economical products in practice as well as contribute to the needs of design education [2]. With this flowchart, the research process can be monitored sequentially and systematically, and facilitate the verification process of each stage towards the final design goal.

1. Planning

The process began by identifying the main problem with the S4000 maker machine, namely the mismatch of the length of the cigarette rod caused by the asynchronous speed between the tape drum and the cut off. The planning process is carried out by collecting and processing data related to the drive mechanism, including servo motor rotation speed data, cigarette length data from tests, and technical information from machine design documentation.

The data that has been obtained is evaluated to determine the adequacy of the information needed in the analysis of the problem. If the data is considered insufficient, the data collection process is repeated to meet the needs of the analysis. The next stage is an in-depth identification of the main cause of the problem using the Interrelationship Diagram and Failure Mode and Effect Analysis (FMEA) approach. Interrelationship Diagrams are used to identify and describe the cause-and-effect relationship between various factors in a complex problem [3].



Gambar 4 *Interrelationship* Diagram

The Failure Mode and Effect Analysis (FMEA) method is used to identify and prevent a

problem in a system [4]. The results of this planning stage are the basis for determining the direction of the design of the transmission system as a mechanical solution to the problem of rotation synchronization. The proposed improvement, the use of one drive motor to avoid synchronization problems, a transmission system is needed to harmonize the speed of the distribution of cigarette rods with the process of cutting cigarette rods.

2. Concept Determination

The design specification serves as a reference in the design and analysis process of the power drive mechanism of the S4000 maker machine at PT DM.

Tabel 1 Daftar Fitur

Daftar Fitur		
1	Geometri	Dimensi maksimal : 1000 x 500 x 500 mm
2	Kinematik	Gerak linear dan gerak rotasi
3	Statik, Dinamik, Elasto Mekanik	Berat alat : mampu diangkat 1 orang
4	Energi	Temperatur kerja : tidak ada tuntutan
5	Material	Sesuai dengan perencanaan
6	Ergonomi	Tidak memerlukan tempat yang luas
7	Manufaktur	Tidak ada proses pembuatan khusus Tidak ada norma khusus
8	Perakitan	Tidak ada proses perakitan khusus
9	Penggunaan dan Pemeliharaan	Perawatan mudah tanpa alat bantu khusus Pengoperasian mudah tanpa keahlian khusus
10	Biaya	Semurah mungkin
11	Termin	Agustus 2025

The literacy study was carried out by collecting previous research related to the process as a reference for the final project and books as the basis for research theory related to the prototype of the transmission system as speed optimization in the power drive mechanism of the S4000 maker machine at PT DM.

Tabel 2 Daftar Persyaratan

Daftar Persyaratan			
No	Persyaratan	Kuantifikasi	Keterangan
1	**Persyaratan Utama**		
1.1	Konsistensi ukuran panjang rokok pada hasil produksi		IV
1.2	Mampu menggerakkan rangkaian dengan kenentuan kecepatan	*Printer* = 1152 rpm (± 2) *Tape Drum* = 272 rpm (± 2)	IV
1.3	Dimensi *Body*	700 x 350 x 250 mm	III
1.4	Pertimbangan perancangan tidak merubah komponen yang sudah ada		IV
2	**Persyaratan Umum**		
2.1	Pemilihan komponen	*Standard part*	IV
2.2	Metode pelumasan		III
2.3	Material kuat, ringan dan mampu menahan beban	Umur pakai, hanya memerlukan 1 mekanik perakitan	III
3	**Keinginan / Harapan**		
3.1	Kemudahan perakitan		III
3.2	Kemudahan perawatan		III
3.3	Tidak bising		II

The function structure is assumed to be a product or system being designed, and the formulation of the diagram is the flow of energy, materials, and signals.

Figure 5 Main Function Structure of MK9 Machine

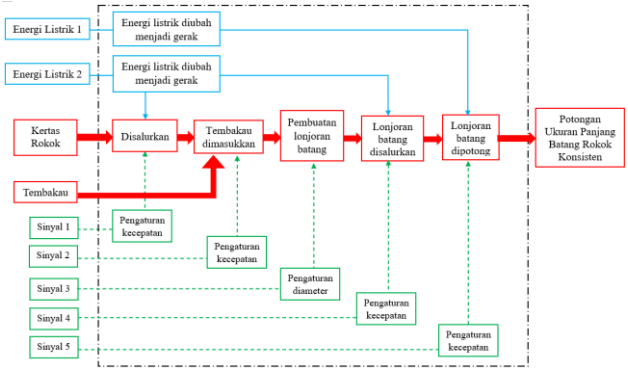


Figure 6 MK9 Machine Function Structure

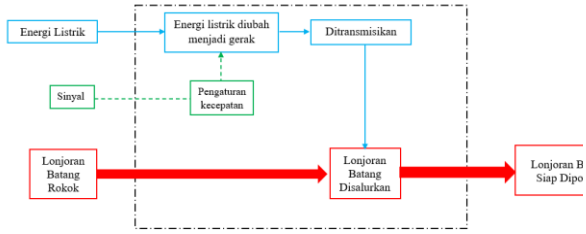


Figure 7 Design Function Structure

The concept variant principle serves to combine alternative solutions for each sub-function that have been included in the parameters with various choices of variation mechanisms included in the column.

Tabel 3 Morfologi Desain

Parameter	Alternatif 1	Alternatif 2	Alternatif 3
Energi listrik diubah menjadi gerak			
	Motor Servo	Motor Listrik	
Pengaturan Kecepatan			
	Servo *controller*	VFD (*Variable Frequency Drive*)	
Ditransmisikan			
	Gearbox	*Chain*	
Pelumasan (Sub-fungsi Ditransmisikan)			
	Rendam	Oles	Tetes
Lonjoran batang disalurkan			
	Pusher Mechanism	*Rotating Drum* dan *Belt*	*Compressed Air Mechanism*

The results of the selection of the best solution for the design of the transmission system on the S4000 maker machine will be combined to build the concept of the conceptual design

Table 4 Variant Alternative Selection

Parameter	Alternatif 1	Alternatif 2	Alternatif 3
Energi listrik diubah menjadi gerak			
	Motor Listrik	Motor Servo	Motor Listrik
Pengaturan Kecepatan			
	VFD (*Variable Frequency Drive*)	Servo *controller*	VFD (*Variable Frequency Drive*)
Ditransmisikan			
	Pulley dan *Belt*	Sistem Transmisi Mekanik	*Chain*
Pelumasan (Sub-fungsi Ditransmisikan)			
		Rendam	Oles
Lonjoran batang disalurkan			
	Pusher Mechanism	*Rotating Drum* dan *Belt*	*Compressed Air Mechanism*

The technical assessment criteria consist of 7 main aspects that reflect the functional and mechanical characteristics of the designed transmission system. Each aspect is given a weight with a value range of 0 to 4, adjusted to the level of urgency and its effect on the overall performance of the system.

Table 5 Technical Assessment of Variants

No	Fitur Evaluasi Sistem (Kriteria Evaluasi Teknis)	Nilai/*Score* Varian (*Range*: 0-4)		
		Var. 1	Var. 2	Var. 3
1	Pencapaian Fungsi Penyelarasan Putaran	2	4	2
2	Kemampuan menggerakkan rangkaian dengan kecepatan yang ditentukan	2	3	2
3	Kemampuan dalam menyalurkan lonjoran batang rokok	2	4	2
4	Kemudahan Perakitan	2	3	2
5	Keamanan Konstruksi	3	3	2
6	Kebutuhan Ruang	2	3	2
7	Kemudahan Perawatan	3	3	2
Jumlah		16	23	14
Nilai Teknis(x)		0.58	0.83	0.5
Persentase		58%	83%	50%
Peringkat		2	1	3

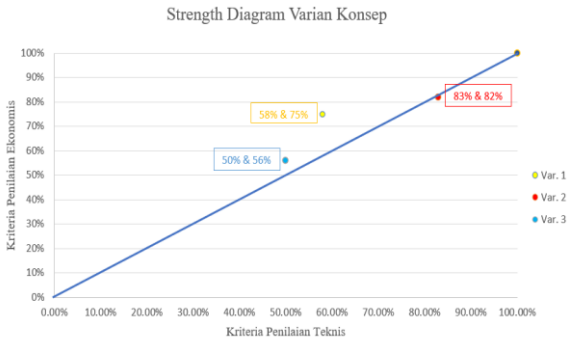
The economic assessment consists of 4 aspects, this assessment is carried out by considering the costs used during the manufacture of the engine, with a range of values given between

0 to 4, the highest value is given to the variant that has the highest economic value in its manufacture.

No	Fitur Evaluasi Sistem (Kriteria Evaluasi Ekonomis)	Nilai/*Score* Varian (*Range*: 0-4)		
		Var. 1	Var. 2	Var. 3
1	Biaya Bahan Baku Material	3	3	2
2	Biaya *Standard Part*	4	4	3
3	Biaya Permesinan	3	3	2
4	Biaya Operasional	2	3	2
Jumlah		16	17	13
Nilai Ekonomis (x)		0.75	0.82	0.56
Persentase		75%	82%	56%
Peringkat		2	1	3

Tabel 6 Penilaian Ekonomis Varian

The strength diagram shows that concept variant 2 is the best concept, as it has the value and rank closest to the positive diagonal line. The concept of variant 2 as a selected concept is realized into a design plan at the design process stage.



Gambar 8 *Strength* Diagram Varian Konsep

3. Design

Measurements are carried out in real time using measuring tools, resulting in data with appropriate accuracy. The specifications listed are data that already exist on the S4000 maker machine and have not changed.

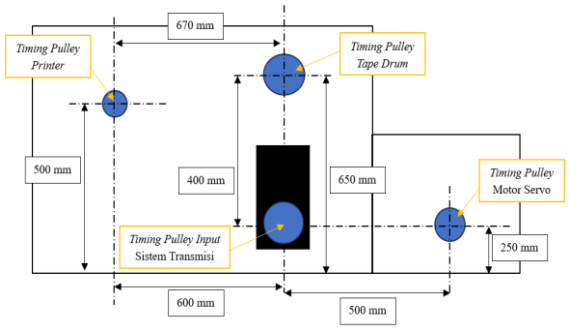


Figure 8 Design Dimensions

This design includes the selection of gear sizes, shaft dimensions, and other supporting components, all of which are based on technical and economic calculations.

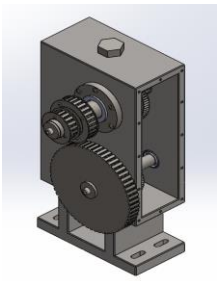


Figure 9 Front View Mechanism Design

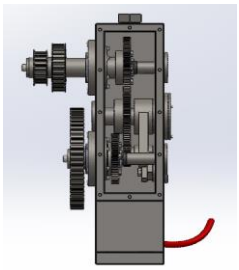


Figure 10 Side View Mechanism Design

Lubrication is required in the transmission system to reduce direct contact between the two working components [5]. In this system, SW90 oil (SAE 90) is used which has high viscosity and is able to form a stable protective layer. The oil was chosen because it is able to adhere firmly to the surface of the gear, and contains extreme pressure (EP) additives that function to protect components from wear and corrosion.

4. Completion

Calculation of the estimated cost needed to make a transmission system construction on the S4000 maker machine at PT DM. It is based on the cost of standard parts, material price, and process/machining cost. The overall construction of the transmission system has a total of 182 components.

The prototype results show that the transmission system configuration can be validated visually and mechanically, thus providing a functional picture of the system's performance,

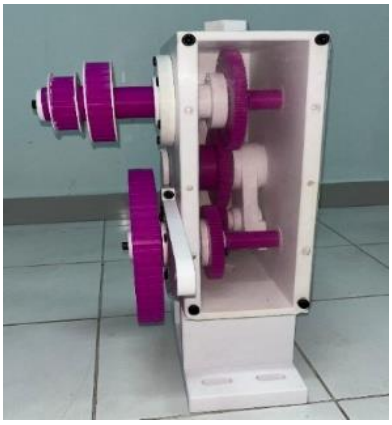
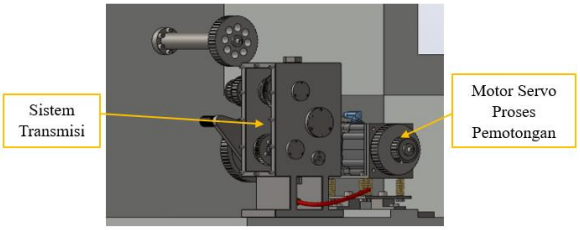


Figure 11 Prototype Mechanism

RESULTS AND DISCUSSION

The analysis has been carried out with modifications to the distribution system by adding a gear-based transmission system unit driven directly by a cutting servo motor. The servo motor that drives the cut off unit remains working directly, while the channeling process is streamed through a mechanical transmission circuit. This integration ensures that the rotation between the dispensing and cutting processes is in one synchronous source of motion, resulting in a more stable relative speed and improving the accuracy of cigarette bar length as standard.



Gambar 12 Rancangan Penggerak Daya

Calculations are carried out to determine the technical parameters of the cigarette rod distribution system using a tape drum. The analysis includes the linear speed based on the rotation of the tape drum, the channeling force due to friction between the rod and the surface of the tape drum, and the time it takes for the cut off process to produce the standard length of the rod. The calculation results are used to ensure the synchronization of motion between components and the stability of the production process.

Results of Mechanism Calculation Analysis

Linear Speed of Distribution Process:

$$v = \frac{2\pi r \times n}{60}$$
$$v = \frac{2.\pi.0.135 \times 272}{60}$$
$$v = \frac{230{,}667}{60}$$
$$v = 3{,}844\ m/s \quad (1)$$

Gaya Normal Lonjoran Batang Rokok :

$$N = m \times g$$
$$N = 0{,}0007\ kg \times 9{,}81$$
$$N = 0{,}00678\ \text{N} \quad (2)$$

Gaya Proses Penyaluran :

$$F = N \times \mu$$
$$F = 0{,}00678\ \text{N} \times 0{,}4$$
$$F = 0{,}00275\ N \quad (3)$$

Waktu Proses Pemotongan

$$t = \frac{L}{v}$$
$$t = \frac{0{,}057\ \text{m}}{3{,}844\ m/s}$$
$$t = 0{,}01484 \quad \text{detik} \quad (4)$$

The length of the cigarette bar is 57 mm, the time it takes for the cigarette stick to reach the cutting point is about 0.01484 seconds. These results show that the cutting process must be carried out precisely every 14.84 milliseconds to be in sync with the distribution speed, so that a consistent and tolerable length of the cigarette is obtained.

1. FEA Analysis Results on Shaft

Finite Element Analysis (FEA) is a method for analyzing structures in solidwork software [6]. The load on the transmission shaft is located on both bearings as a concentrator. The shaft material uses C45 material with a yield strength of 530N/mm2 according to the yield strength in the C45 SolidWorks software.

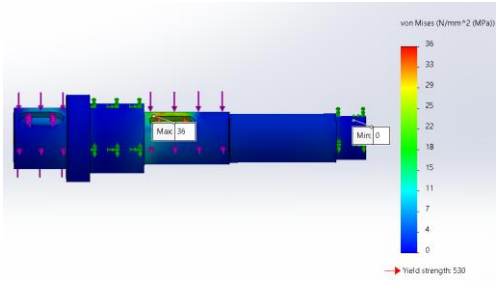


Figure 13 Analysis of the First Shaft of the Transmission System

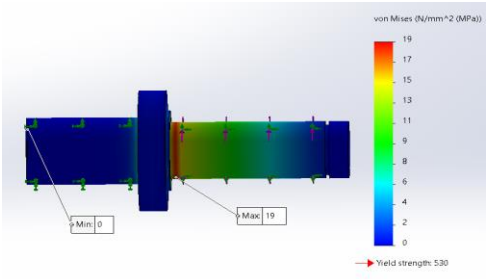


Figure 14 Analysis of the Second Axis of the Transmission System

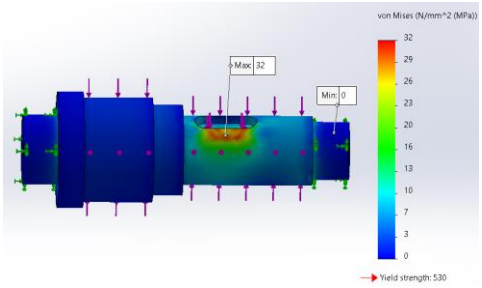


Figure 15 Analysis of the Third Axis of the Transmission System

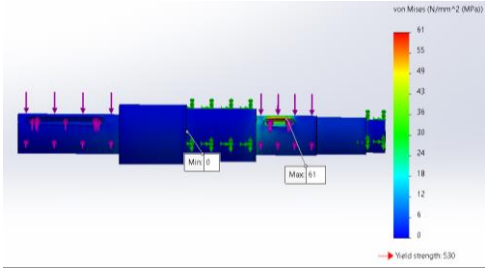


Figure 16 Analysis of the Fourth Axis of the Transmission System

The results of the stress analysis on the shaft of the transmission system show that the voltage value is below the material strength limit. This signifies that the shaft design is safe and able to withstand the accepted workload.

2. FEA Analysis Results on Gears

Analysis of the gears is determined to find out the force that occurs in the gears. The material on the gears uses S45C with a yield strength of 530 N/mm^2.

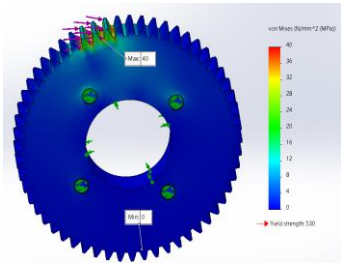


Figure 17 Analysis of the first gear of the transmission system

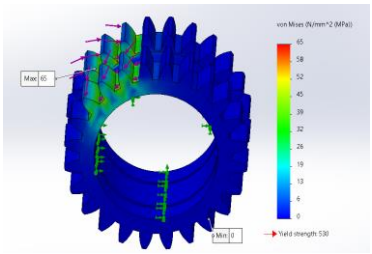


Figure 18 Analysis of the Second Gear of the Transmission System

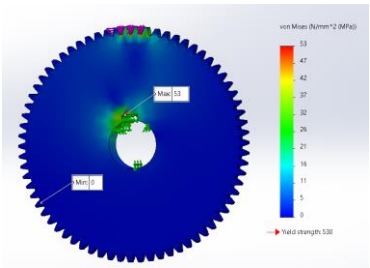


Figure 19 Analysis of the Third Gear of the Transmission System

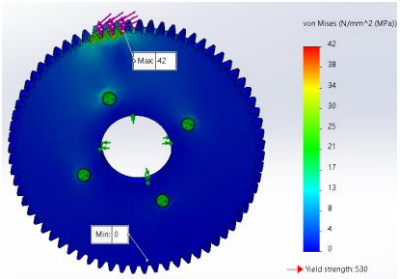


Figure 20 Analysis of the Fourth Gear of the Transmission System

The results of the stress analysis on the gears of the transmission system show that the voltage value is below the material strength limit.

This signifies that the shaft design is safe and able to withstand the accepted workload.

3. Analisis FEA *Bracket* dan *Body* Sistem Transmisi

The bracket is designed to withstand the working forces that arise in the system. The bracket will receive the tangential force generated by the interaction between the two wheels, as well as bear the load due to the weight of the shaft it supports.

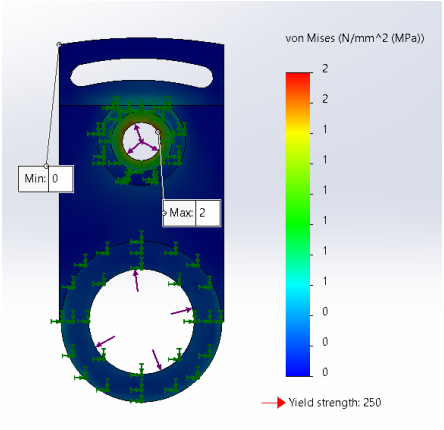
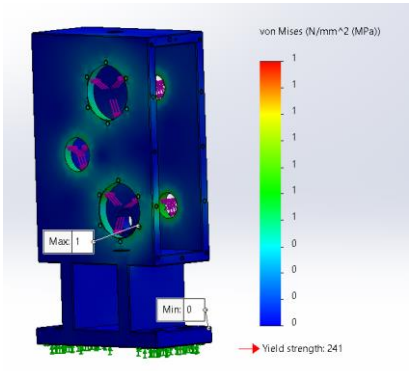


Figure 21 Transmission System Bracket Analysis

The body of the transmission system is designed to withstand the working forces that arise within the system. The body of the transmission system will receive the normal force generated by the interaction between two wheels, the force due to the belt, as well as bear the load due to the weight of the shaft it supports.



Gambar 22 Analisis *Body* Sistem Transmisi

4. Prototype Testing

The analysis is carried out by calculating the number of revolutions on each shaft when the first shaft (input) is given a certain number of revolutions, with reference to the gear configuration and pulley timing used in the physical prototype.

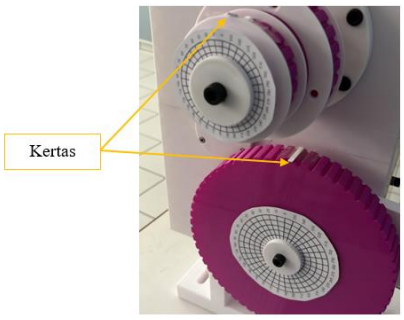


Figure 23 Paper Pasted

The prototype precision test begins by ensuring that the initial position of the paper is at zero degrees perpendicular to the reference. The input shaft is rotated one full rotation (360°), the position of the paper on the output shaft shows a rotation angle of more than 290°. This shows compatibility with the results of theoretical calculations based on a transmission ratio of 0.815, which predicts an output angle of 293.4°.

Based on the results of the prototype precision test carried out five times, it was obtained that all measurement results showed conformity with the theoretical value of 293.4°. This proves that the transmission system in the prototype has a good level of accuracy and is able to maintain the stability of mechanical performance consistently in each test.

CONCLUSION

The conclusion of the Transmission System Prototype as Speed Optimization on the Power Drive Mechanism of the Maker S4000 Engine at PT DM is:

1. The design of the gear transmission system as a speed optimization on the S4000 maker engine is able to distribute rotations synchronously, resulting in a consistent measurement of cigarette length. Based on the results of the planning calculations, this system is designed to transmit rotation with a final speed of 272 rpm on the tape drum and 1152 rpm on the printer, according to the needs of the production process.
2. Design analysis using the FEA method shows that all major components of the transmission system are within safe limits. The maximum stress on the gears is 53 MPa compared to the yield limit of

S45C material of 530 MPa. The bracket is subjected to a voltage of 2 MPa against the ST37 yield limit of 250 MPa, and the body is only 1 MPa of the Cast Alloy Steel material limit of 241 MPa. The maximum torque calculation of 2.9 Nm is also still within the capacity of the shaft material, so the system is declared safe for workloads.

3. The creation of a prototype transmission system has been realized by 3D printing. This prototype serves as an initial validation of the design form and function, as well as a simulation medium in the process of evaluating system performance before actual implementation. Validation of the prototype precision is carried out through tests on the prototype by rotating the input shaft rotated once, the turning angle on the output shaft reaches more than 290 degrees, which indicates conformity with the transmission gear ratio calculation.

BIBLIOGRAPHY

[1] Pangabean A.D. (11 Desember 2024). 5 Provisi Dengan Konsumen Rokok Terbanyak Versi BPS Tahun 2024**.** Radio Republik Indonesia.

[2] Jänsch, J. & Birkhofer, H. (2006). *The development of the guideline VDI 2221-the change of direction. In DS 36: Proceedings DESIGN 2006, the 9th International Design Conference*, Dubrovnik, Croatia

[3] Sudibyo, B. (2009) Bantalan Gelinding. Surakarta: ATMI Press

[4] Zagloel, Yuri M, and Rahmat Nurcahyo. *TQM - Manajemen Kualitas Total Dalam Perspektif Teknik Industri 12.01.2023*. 29 Apr. 2023.

[5] Jos, C., & Mathew, G. (2008). *FMEA Analysis for Reducing Breakdowns of a Sub System in the Life Care Product Manufacturing Industry*. *Certified International Journal of Engineering Science and Innovative Technology (IJESIT)*, *9001*(2), 2319–5967.

[6] Awwaluddin M (2020). *Analisa Kekuatan Rangka Sepeda Listrik Menggunakan Software SolidWorks*. Vol. 3, no. 1, 25 Oct. 2020.