DESIGN AND ANALYSIS OF PNEUMATIC EXPANSION SHAFT IN SLITTER AND REWINDER MACHINE

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Abstract - *The efficiency of slitter and rewinding machines relies heavily on the performance of their winding and unwinding shafts, with grip slip emerging as a key issue that compromises material alignment, tension control, and overall process stability. A widely used approach to reduce this problem is by increasing the number of shaft lugs to enhance grip; however, this often reduces the shaft's structural strength, creating a critical trade-off between grip efficiency and mechanical integrity.*

This study investigates enhancing the performance of a pneumatic expansion shaft made from carbon steel AISI 1035 by redesigning it with an increased number of lugs and also study the shaft performance of existing model and proposed model using Finite Element Analysis techniques. The mechanical response of the shaft under loading conditions is assessed by examining Von Mises Stress, Equivalent Strain, Displacement and Factor of safety. The analysis reveals that increased lug count enhances grip by improving frictional force distribution, but also leads to elevated stress concentrations and higher strain levels in critical shaft regions, which may accelerate fatigue failure.

***Key Words**: Slitter and rewinding machines, Grip Slip, Lug configurations, FEA Analysis*

1.INTRODUCTION

Slitters and rewinders are crucial machines used across multiple industries to process large rolls of materials such as paper, film, textiles, and nonwoven fabrics. These machines are designed to cut wide rolls into narrower widths (slitting) and then rewind them into smaller, more manageable rolls (rewinding). Whether you're in packaging, printing, textiles or converting, understanding the different types of slitters and rewinders, their key components, various applications and essential maintenance practices is vital for maximizing operational efficiency.

1.1 Introduction to Design

In this project, SolidWorks software was extensively used for 3D modelling and design. SolidWorks is a powerful CAD (Computer-Aided Design) software widely used in engineering for creating detailed 3D models, assemblies, and 2D drawings. It provided the necessary tools to design complex parts of the slitting rewinding machine with high precision and allowed for efficient visualization, simulation, and modification during the design phase. The software's intuitive interface and robust features supported the accurate representation of shafts, frames, and other mechanical components essential to the project.

1.2 Introduction to Analysis

In simple terms, analysis helps engineers predict how something will perform before actually building or using it. This can include checking: Will it break under load, Will it deform too much, how heat or pressure will affect it. Engineers use mathematical models and simulation tools (like FEA, CFD, etc.) to perform the analysis. It's an essential step in the design process to ensure safety, performance, and reliability. This analysis is used to understand and optimize the component of a pneumatic expansion shaft under load conditions to ensure uniform distribution load, which is essential for preventing grip slip improving the durability and efficiency of winding/unwinding processes. By using SolidWorks for simulation, engineers can visualize stress concentrations, identify weak points, and test design modifications virtually before physical prototyping, saving both time and cost while enhancing performance and safety.

2. LITERATURE SURVEY

Govindola Veerander Goud, Dr. K. Vijay kumar and Dr. M. Sreedhar Reddy [1] This study evaluates the structural performance of solid and hollow aluminium-BLF composite shafts through static analysis, focusing on deformation, Von Mises stress, and weight. Results show that these composites meet safety standards comparable to steel. While hollow shafts offer only a modest weight reduction (1.16%), they remain promising for applications requiring a high strength-to-weight ratio.

Thirumurugaveera kumar Sundaram and Manivel Muralidaran Velumani [2] This project focuses on developing an automated film roll cutter for roll-to-roll systems used in printing, packaging, and converting industries. Precise tension control during rewinding is critical to avoid common defects. The cutter is designed using advanced 3D modeling for visualization and optimization, with structural and thermal analyses ensuring its strength, durability, and industrial reliability.

Dr. Htay htay win and Dr. myint thein [3] Cipto Cipto, Christian Wullur, and Hariyanto Hariyanto [4] studied a shaft for a meat-cutting machine. The shaft is 12 mm in diameter and 581 mm long. It is designed to carry a 5 kg load. They used Autodesk software for finite element analysis (FEA). The analysis showed the shaft is safe. The allowable shear stress (7.38 kg/mm^2) is higher than the applied shear stress (5.62 kg/mm^2). The maximum von Mises stress is 61.89 MPa. The maximum displacement is 0.07715 mm. The safety factor is 3.34. This means the shaft is strong enough for the job.

2.1 Objectives

Grip slip in slitter and rewinding machines affects efficiency and stability. Adding more shaft lugs improves grip but weakens the shaft. To solve this:

1. Study grip slip mechanics, test lug changes for grip and strength, and find the best design.
2. Modify the design to boost system performance, reliability, and efficiency.

3. DESIGN OF PNEUMATIC EXPANSION SHAFT

3.1. Pneumatic Expansion Shaft 3d Assembly

The pneumatic expansion shaft functions based on the controlled application of compressed air to achieve mechanical expansion, which enables it to securely grip and rotate the core of a roll in slitter and rewinder machines. Internally, the shaft is equipped with a longitudinally placed inflatable bladder made from rubber or synthetic elastomers. This bladder is housed inside a cavity and connected to an external air inlet valve. Upon injecting compressed air (typically between 3 to 5 bar), the bladder inflates uniformly along the shaft's length. As it expands, it applies radial pressure to a series of mechanical lugs, strips, or leaves that are positioned in precisely machined slots on the shaft's surface. These lugs then protrude outward and make direct contact with the inner wall of the material core, generating frictional engagement.

Fig – 4.1: Pneumatic Expansion Shaft 3d Assembly

4. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a computer-based method used to simulate and analyses physical behavior of a structure, component, or system under various conditions like force, heat, vibration, or fluid flow.

FEA is a numerical method that breaks down complex structures into smaller, simpler parts (called elements) to calculate how they will respond to real-world physical effects.

4.1 Volumetric Properties

Table – 1: Volumetric Properties

Mass	17.663 kg
Volume	0.00225006 m^3
Density	7,850 kg/m^3
Weight	173.097 N

4.2 Material Properties

AISI 1035 is a water resisting carbon steel whose wear resistance and hardenability are increased by the addition of small quantity of chromium.

Table – 2: Material Properties

Name	AISI 1035 Steel (SS)
Model type	Linear Elastic Isotropic
Yield strength	2.82685e+08 N/m^2
Tensile strength	5.85e+08 N/m^2
Elastic modulus:	2.05e+11 N/m^2
Poisson's ratio	0.29
Mass density	7,850 kg/m^3
Shear modulus	8e+10 N/m^2
Thermal	1.1e-05 /Kelvin

4.3 Fixture

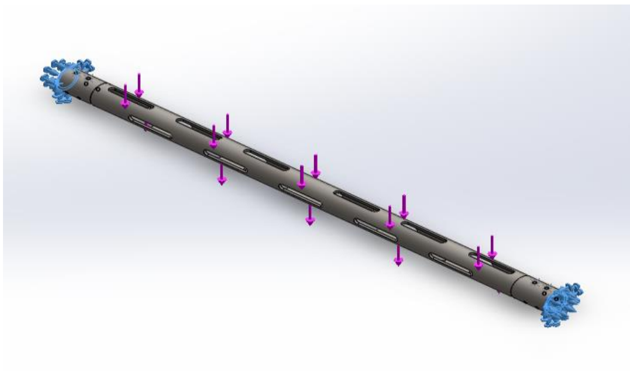

Fig – 4.1: Fixture

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To constrain the model during the analysis, fixtures were applied using reference geometry. Specifically, two faces were fixed by referencing the Top Plane to replicate real-world boundary conditions. The fixture type used was "Use reference geometry", ensuring that the selected faces remained stationary throughout the simulation. No translational displacement was applied, with the translation vector set to (0, 0, 0) in millimeter's, indicating that all degrees of freedom were fully restricted for the selected faces

4.4 Load

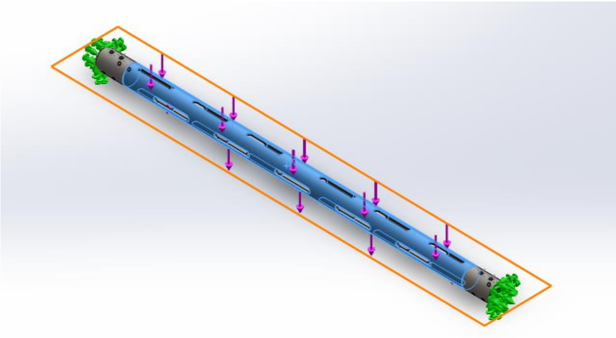

Fig – 5.6: Load

The mesh configuration, a single face was selected and referenced relative to the Top Plane. A force of -10,000 N was applied in the negative Z-direction, simulating a downward axial load. This loading condition reflects realistic working scenarios and is essential for assessing the structural response of the component under the maximum expected load.

4.5 Mesh Details

Table -4: Mesh Details

Mesh type	Solid Mesh
Mesher Used	Standard mesh
Jacobian points for High quality mesh	16 Points
Element Size	7.84074 mm
Tolerance	0.392037mm
Mesh Quality	High

4.6 Node in FEA

In Finite Element Analysis (FEA), a node is a specific point in the model's geometry where calculations are performed. Nodes serve as connection points between elements and are used to define the shape and structure of the mesh. They are crucial for applying boundary conditions (like loads or constraints) and for storing results such as displacements, temperatures, and stresses.

Table – 5: Node In Fea

Total Nodes	110251
Total Elements	56554

5. RESULT AND DISCUSSION

5.1 RESULT OF STANDARD SHAFT

5.5.1 Von Mises Stress

In this simulation, The Von Mises Stress achieve minimum stress value is 0.355N/mm2 (MPa) and maximum stress value is 141.520N/mm2 (MPa).

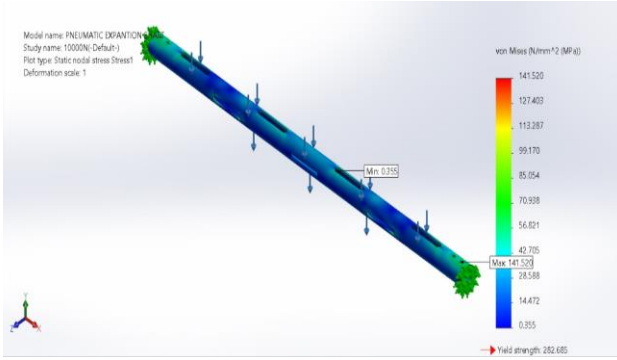

Fig - 6.5.1: Von Mises Stress

5.5.2 Equivalent Strain

In this simulation, The Equivalent Strain achieve minimum strain value 2.618e-06 and maximum strain value is 4.839e-04.

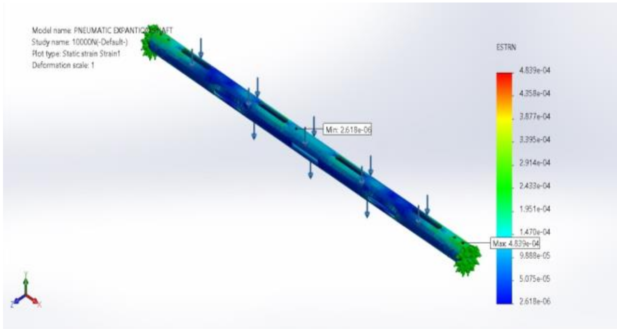

Fig - 6.5.2: Equivalent Strain

5.5.3 Displacement

During the simulation, The Resultant Displacement achieve minimum displacement value is 0.0mm and maximum displacement value is 1.0mm.

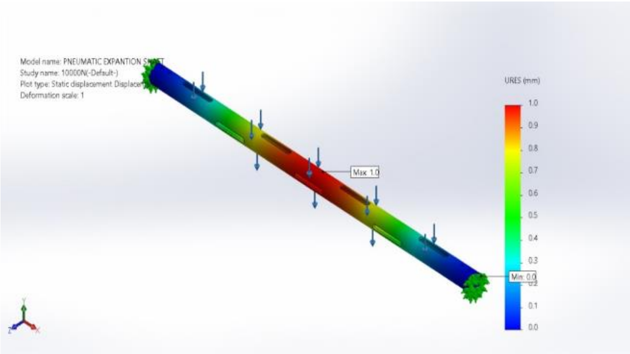

Fig -6.5.3: Displacement

5.5.4 Factor Of Safety

During the simulation, The Factor of Safety achieve minimum Factor of Safety value is 1.997e+00and maximum Factor of Safety value is 7.955e+02.

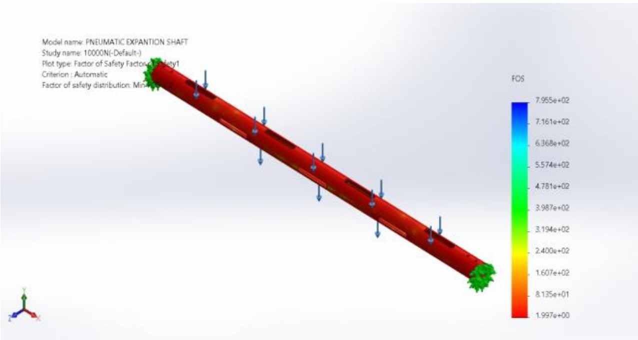

Fig - 6.5.4: Factor Of Safety

5.2 RESULT OF MODIFIED SHAFT

5.2.1 Von Mises Stress

In this simulation, The Von Mises Stress achieve minimum stress value is 0.409N/mm2 (MPa)and maximum stress value is 148.972N/mm2 (MPa).

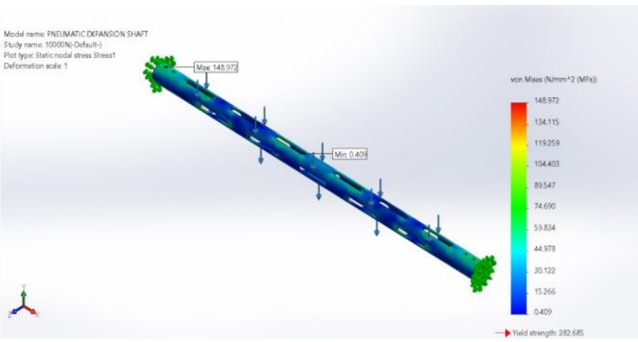

Fig – 7.1: Von Mises Stress

5.2.2 Equivalent Strain

In this simulation, The Equivalent Strain achieve minimum strain value 1.592e-06 and maximum strain value is 4.911e-04.

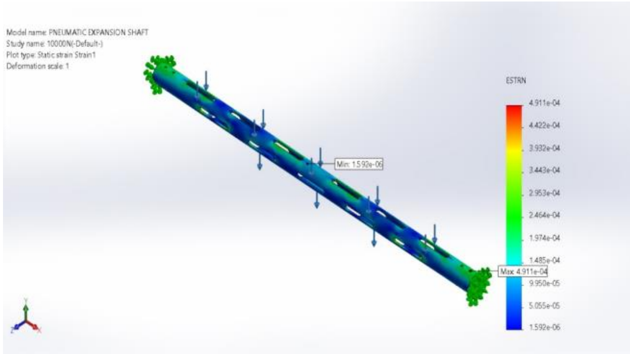

Fig - 7.2: Equivalent Strain

5.2.3 Displacement

During the simulation, The Resultant Displacement achieve minimum displacement value is 0.00mm and maximum displacement value is1.119mm.

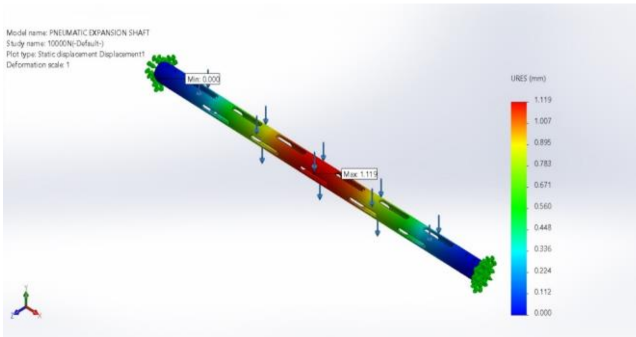

Fig - 7.3: Displacement

5.2.4 Factor Of Safety

During the simulation, The Factor of Safety achieve minimum Factor of Safety value is 1.898e+00 and maximum Factor of Safety value is 6.904e+02.

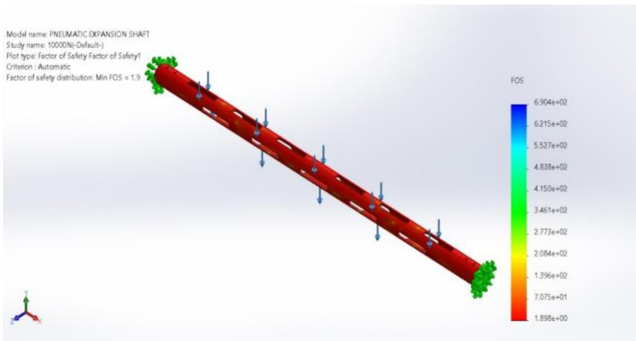

Fig - 7.4: Factor Of Safety

5.3 COMPARISON OF STATIC ANALYSIS RESULT

A comparison between the Standard Model and the Project Model based on various structural parameters. The Project Model includes more lugs, resulting in a larger total lug area. This design modification leads to a slight increase in stress, strain, and displacement compared to the Standard Model. However, the factor of safety remains within acceptable limits, indicating that the structural integrity of the Project Model is maintained despite the changes.

Table – 6: Comparison Of Static Analysis Result

DESCRIPTION	STANDARD MODEL	MODIFIED MODEL
Area of Single Lug	1352.93 mm^2	1352.93 mm^2
Number of Lugs	14	22
Area of total Lugs	18,941.44 mm^2	29,764.46 mm^2
Von-Mises Stress	141.52	148.972
Equivalent Strain	4.839×10^{-4}	4.911×10^{-4}
Displacement	0.959 mm	1.119 mm
Factor of Safety	2	1.9

6. CONCLUSION

The study focused on enhancing the performance of a pneumatic expansion shaft made from carbon steel AISI 1035 by redesigning it with an increased number of lugs. In modified design the number of lugs has been increased from 14 to 22, there by expanding the total lug contact area from 18,941.44 mm^2 to 29,764.46 mm^2. This change effectively improves the grip on the core and minimizes the possibility of slip during operation.

Static analysis was performed to compare both models under identical loading conditions. The results show a slight increase in stress (from 141.52 MPa to 148.972 MPa) and strain (from 4.839×10-4 to 4.911×10-4), with a corresponding increase in displacement (from 0.959 mm to 1.119 mm). Despite these increases, the modified model maintains a satisfactory factor of safety of 1.9, which is within acceptable design limits.

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