FEA-Driven Design of Nonwoven Winder Drums: Stress Minimization and Rigidity Assessment for Structural Integrity

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Abstract: *Nonwoven winding machines are critical equipment where the structural integrity of the main drum directly impacts the quality and stability of the final product. This study presents the mechanical analysis and braking system design for a main winding drum (Diameter 400 mm) in a high-speed nonwoven application, driven by Finite Element Analysis (FEA) for stress minimization. The load analysis, based on the Principles of Static Equilibrium, determined the total maximum load on the drum supports, considering a maximum spool weight of 1500 kg and a nip force of 1962 N. The resultant total load applied on the supports was calculated as approximately 11.5 kN. The FEA, utilizing ST37 steel, revealed a maximum Von Mises Stress of 1.754 MPa and an extremely low maximum deflection of 0.005 mm. This confirms an optimal factor of safety (FS approx 134) and high rigidity. Furthermore, the paper addresses the safety requirement for emergency stopping from a maximum speed (omega = 50 rad/s). The minimum required braking torque was calculated as 235 Nm, while the selected COREMO PNEUMATIC CALIPER BRAKE B-2N system provides 306.8 Nm, ensuring reliable and controlled deceleration. The results validate the structural and functional design, contributing to enhanced machine performance and operational safety.*

Keywords*: FEA-DRIVEN DESIGN, STRESS MINIMIZATION, STRUCTURAL RIGIDITY, WINDING DYNAMICS*

1. Introduction

Nonwoven winding machines are central to the production chain in industries ranging from hygiene and medical textiles to automotive and geotextiles, where wide nonwoven webs must be accurately slit and rewound into stable, high-quality finished rolls (reels) [1].

The efficiency and quality of the final product depend critically on the control of the web handling process, particularly the precision applied to Tension, Nip, and Torque (TNT) parameters throughout the winding cycle [2, 3]. Failure to maintain optimum control can lead to costly defects such as telescoping, starring, wrinkling, buckling, and layer slippage, which compromise product performance and structural integrity [4, 5].

Structural and Dynamic Challenges of Winder Drums

The main drum (winding roller) serves as the primary load-bearing and driving element in most surface or two-drum winding configurations [6]. Its design is subjected to complex static and dynamic loading conditions.

The primary structural challenge lies in managing the combined loads from the increasing weight of the final spool (which can exceed 1500 kg), the controlled pressure exerted by the rider roll (nip force), and the continuous web tension [7].

High-speed operation introduces significant rotordynamic effects. As the rotational speed of the roll intersects with the natural frequencies of the winder system, resonance can occur, leading to phenomena like roll bouncing and excessive machine vibration [8, 9]. Previous research emphasizes that winder design must be guided by the principle that major excitation sources, such as manufacturing imperfections or polygonization of viscoelastic components, should not coincide with the system's resonance frequencies [10, 11]. Therefore, a comprehensive Finite Element Analysis (FEA) is necessary to evaluate the structural stress distribution and confirm that the drum's rigidity is sufficient to prevent critical deflection and guarantee stable operation [12].

The Critical Role of Braking and Inertia Control

Maintaining constant web tension and ensuring operational safety relies heavily on the deceleration mechanism. The braking system is vital not only for precise tension control during normal operation but also for emergency stopping. High-speed winders, operating at speeds up to 600 m/min, possess high rotational inertia [16]. A safe, rapid, and controlled deceleration requires a braking system (such as highly reliable pneumatic caliper brakes) capable of delivering a high torque output to absorb the total kinetic energy of the rotating masses within a very short timeframe [17]. The thermal energy generated during this process must also be managed to prevent brake performance degradation [18].

This study focuses on providing a validated engineering solution for the main drum structure and its associated deceleration mechanism, utilizing FEA as the primary verification tool. We first conduct a detailed Static Equilibrium analysis to accurately model the complex loading profile on the Diameter 400 mm main drum. Subsequently, we utilize FEA to confirm stress minimization, high factor of safety, and minimal deflection under maximum operating conditions. Finally, we design and size a specific Pnömatic Caliper Brake system to meet the critical emergency stopping requirements dictated by the system's high inertia and speed.

2. Theoretical Background and Methodology

The Schematic Representation and Free-Body Diagram of the Main Drum are given in Figure 1 and Figure 2, respectively

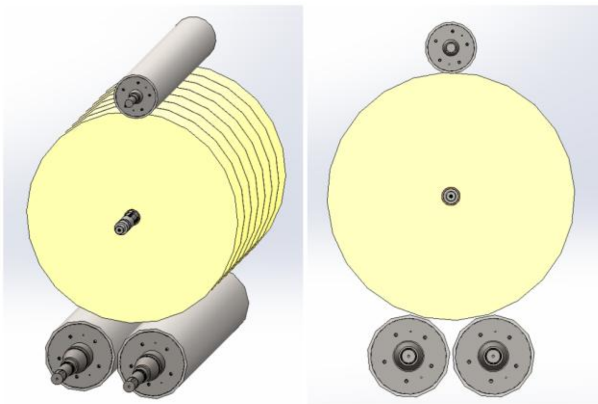


Figure 1. *Schematic Representation of the Main Drum*

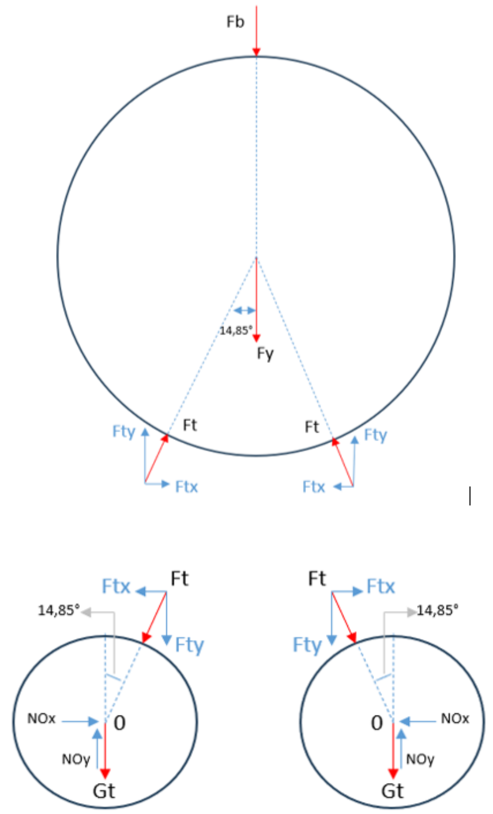


Figure 2. *Free-Body Diagram of the Main Drum*

2.1. Load Analysis based on Static Equilibrium

The main drum's static loads were calculated based on the Principles of Static Equilibrium Σ Fy = 0). The drum material is ST37 structural steel. The primary vertical loads are given in Table 1. (assuming g=9.81 m/s^2)

Table 1. The primary vertical loads

Load Component	**kg**	**N**
Spool Load Force (Fy)	1500	14715
Nip / Pressure Force (Fb)	200	1962
Drum Weight (Gt)	566	5552,46
Total Bearing Reaction Force (per Support) (Ft)	1172	11498
Vertical Component (per Support) (Fty)	1132	11107
Horizontal Component (per Support) (Ftx)	300	2942

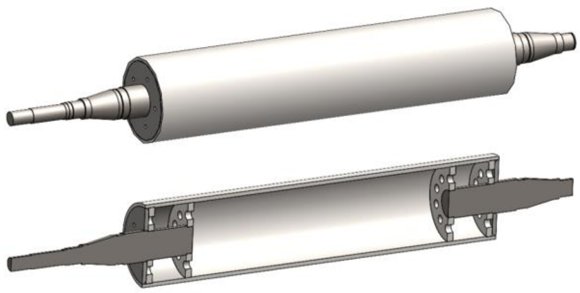
The total downward load is balanced by the two bearing reaction forces (Ft). Assuming the bearing reaction acts at an angle θ = 15o from the vertical:

Total Downward Load = 22229.46 N

The resultant force (Ft) on each bearing is:

Ft = (Fy + Fb + Gt) / 2 cos(15) = 22229.46 / 2 x 0.966 = approx 11498 N

A conservative load of 12,000 N (12 kN) was used for the FEA simulation to ensure an additional safety margin.



Main Drum Sectional View

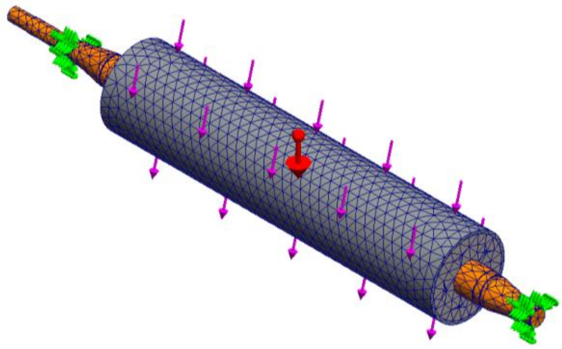


Figure 3. *Main Drum Meshing Configuration*

2.2. Finite Element Analysis (FEA)

Static structural analyses were carried out using SolidWorks Simulation (CosmosWorks). The objective of the FEA was to verify that the drum design minimized internal stresses and maintained high rigidity under the defined operational loads, thereby validating the design for structural integrity.

3. Structural Analysis Results and Discussion

3.1. Maximum Stress (Von Mises) Analysis

The FEA results confirmed the structural integrity of the drum:

Maximum Von Mises Stress (σ max): 1.754 MPa

Material Yield Strength (σ y): 235 MPa (ST37 steel)

The resultant Factor of Safety (FS) is calculated as:

FS = (σ y) / (σ max = 235 MPa / 1.754 MPa = approx 134

The exceptionally high safety factor demonstrates that the FEA-driven design has successfully minimized stress concentrations, guaranteeing high structural integrity and reliability.

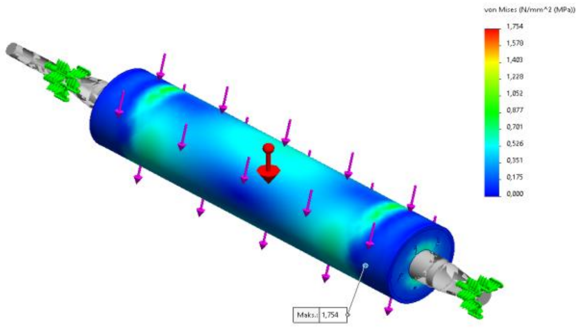


Figure 4. *Stress Distribution Analysis of the Main Drum*

3.2. Maximum Displacement (Rigidity Assessment)

Maintaining minimal displacement is crucial for winding quality.

Maximum Deflection (δ max): 0.005 mm

This remarkably low displacement value confirms the drum's high stiffness. The rigidity assessment proves that the chosen geometry and ST37 material combination ensures that the drum maintains its precise surface profile, preventing dimensional errors and quality degradation during high-speed winding.

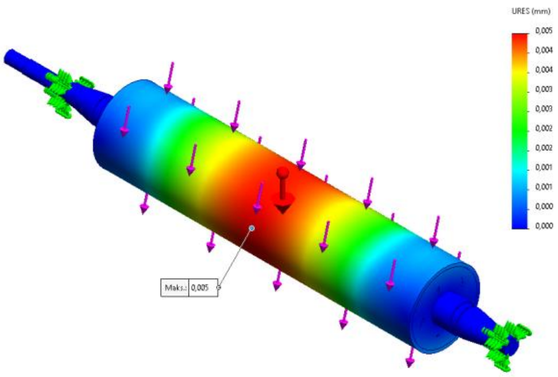


Figure 5. *Analysis of Max. Displacement in the Main Drum*

4. Braking System Design and Deceleration Control

A Pnömatic Caliper Brake system was selected to manage the high kinetic energy of the system during emergency stops and controlled deceleration.

4.1. Required Braking Torque Calculation

The braking system must ensure a safe stop within t=3 s from the maximum angular velocity (ω = 50 rad/s).

- Drum Inertia (J drum): 14.10 kg m^2

The minimum required torque (T required) is:

T required = J drum . ω / t
T required = 14.10 . 50 / 3 = approx 235Nm

4.2. Selected Brake System and Torque Capacity

The selected system is the Coremo Pneumatic Caliper Brake (Negative-Acting B-2N) with an A1303 brake disc.

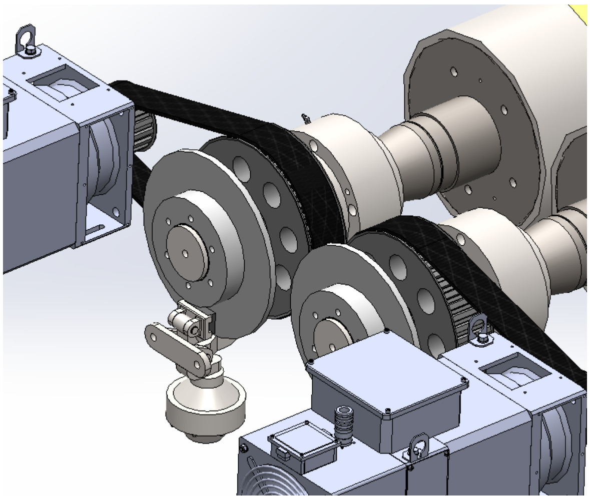


Figure 6. *Pneumatic Caliper Brake*

- Braking Force (F): 2600 N

The actual braking torque (T brake) provided is:

T brake = 2600 N (0.15 m - 0.032 m) = 306.8 Nm

4.3. Safety Margin Assessment

The provided braking torque of 306.8 Nm significantly exceeds the minimum required torque of 235 Nm. This margin ensures the system’s robust performance in safety-critical situations, accounting for operational variations and friction losses.

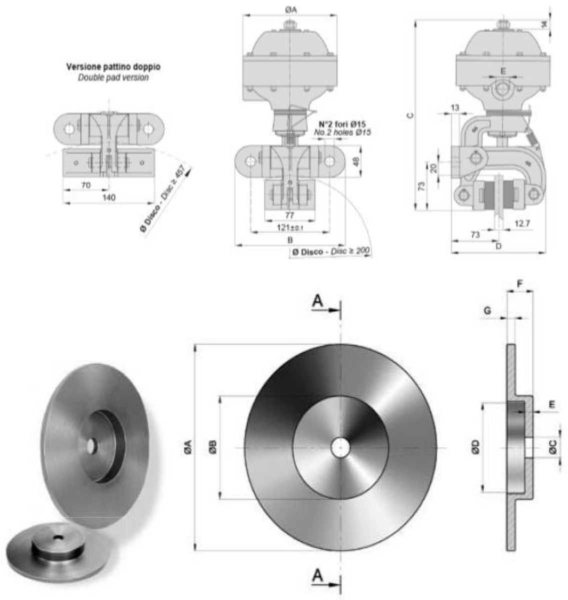


Figure 7. *The selected COREMO B-2N brake system*

5. Conclusion

This study successfully utilized FEA to validate the structural design of the main drum for a nonwoven winder, achieving stress minimization and ensuring optimal rigidity. The analysis confirmed an exceptionally low maximum stress (1.754 MPa) and a minimal deflection (0.005 mm), guaranteeing long-term reliability and winding quality. Furthermore, the designed braking system provides a torque capacity (306.8 Nm) that safely exceeds the inertia requirements (235 Nm), ensuring effective deceleration control. The results conclusively validate the FEA-driven structural and functional design of the main drum and its associated braking system.

6. References

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