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Portable Semi-Automated Thread Seal Tape Wrapping Machine

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ABSTRACT

PTFE thread seal tape is commonly employed to seal threaded joints in industrial and plumbing applications to protect against leakage and ensure durable connections. Hand application, while simple, is susceptible to variability due to variations in operator competence, orientation of the tape, and tension. Such variability in high-volume or mission-critical applications can lead to leakage, increased rework, and material wastage. Even if there are wrapping machines that are automated, they are typically costly, large, and not suitable for on-site or small-scale use. This work presents the conceptualization of a low-cost, portable, and semi-automatic thread seal wrapping machine consisting of mechanical, electrical, and embedded system components to enhance sealing consistency, reduce labor dependency, and enhance operations efficiency.

The conceptualized system underwent several design iterations including mechanical analysis, CAD modelling, stress simulation, and prototype testing. The finished product integrates a jaw-based clamping system, an Arduino-controlled motor system, and a multi-stroke tape applying module. Real-world use in real pipe sealing applications demonstrated consistent performance on various pipe diameters, reduced wastage of tape, and reduced operator fatigue. The product is aimed towards small and medium businesses, field technicians, and repair shops that need portable and reliable automation. Future enhancements will involve modular flexibility, IoT-monitoring features, and battery-powered mobility.

Key: PTFE tape, semi-automated sealing, Arduino automation, portable wrapping device, plumbing efficiency, thread joint integrity, ergonomic machine design

Introduction

Thread seal tape, or PTFE tape, has been a mainstay in plumbing and mechanical threading systems due to its lubricative and sealing properties. Manual wrapping, the conventional method, poses several challenges: tape misalignment, insufficient or excessive wrapping, operator fatigue, and variable pressure application. Inconsistencies in sealing quality can lead to operational failures and increased maintenance requirements. Automated thread-sealing machines provide superior consistency but are often stationery and cost-prohibitive for field technicians or small enterprises.

This research is driven by the need to bridge the gap between manual and industrial-grade automated wrapping processes. The objective is to develop a lightweight, cost-effective, and semi-automated thread seal wrapping machine that addresses the shortcomings of manual application while being viable for low-volume, on-site, and mobile operations.

PTFE tape or thread seal tape has been omnipresent in plumbing and mechanical threading systems due to its lubricative and sealing properties. Manually wrapping, the old-fashioned method, has a number of disadvantages: improper wrapping, tape misalignment, operator fatigue, and unequal pressure application. Differences in the quality of the seal may result in operational breakdown and increased maintenance expenditures. Thread-sealing machines with automated thread-sealing machines have improved consistency but are typically fixed and too costly for field engineers or small companies to purchase.

The inspiration behind this study is a move to bridge the gap between industrially manufactured automated wrapping methods and hand-threading practices. The goal is to develop a lightweight, budget-friendly, and half-automated thread seal wrapping machine that addresses the shortcoming of hand application while remaining environmentally sustainable for low-volume, on-site, or mobile applications.

Objectives

1. To design a small, portable device that will semi-automatically wrap PTFE thread seal tape over pipe threads more accurately and uniformly.
2. To implement an ergonomically and user-friendly mechanism of design that reduces manual labor and human error associated with traditional thread-sealing methods.

3. To utilize an Arduino-based control system for coordinating mechanical operations such as clamping, taping feeding, and cutting with the least amount of user intervention.
4. To evaluate the machine's effectiveness in reducing tape wastage, improving sealing accuracy, and making operations more efficient under field conditions.
5. To carry out and validate the performance of the machine under simulation and real-field testing under different pipe diameters and application contexts.
6. To provide an economically viable alternative for large-scale automatic sealing machines, particularly for small businesses and maintenance teams
7. To explore the scaleability of the design for further development, such as wireless control and battery life in future versions

Description of Problem

Application of PTFE tape by hand tends to result in non-uniform tension and alignment, leading to leaks and rework. It generates significant amounts of material scrap due to excess application or incorrect wrapping. It is also labour-intensive and time-consuming, which makes high-volume or field applications infeasible. All these challenges outline the need for an improved and efficient solution.

Working Principle

This project is for the design of a semi-automated device that assists in the application of PTFE thread seal tape on threaded pipe fittings. The operation principle is a combination of mechanical motion and electronic control in an effort to acquire a uniform, effective, and accurate wrapping process.

The machine utilizes a pipe-clamping system with two jaws: Two immovable and one movable. The movable jaw is controlled by a servo motor to grip the pipe firmly in position. Subsequent to gripping, the plate is rotated by a DC motor whilst PTFE tape borne on a tension-adjustable spool is wound onto the threads aided by a guide roller. Sufficient tension is required for the tape to adhere uniformly without tearing or overlapping.

The whole process is governed by an Arduino Uno microcontroller. The Arduino makes the servo motor close the pipe clamp when the start button is pressed, and then the DC motor shifts the plate. Once the number of rotations set is reached, a backup rack and pinion activate a blade to cut the tape, closing the sealing process.

This system eliminates human mistake, saves time, and enhances the efficiency and quality of the tape-wrapping mechanism. This system is lightweight and transportable in design and may be perfect for on-site plumbing work and maintenance operations.

Methodology

Design Overview

The final production design of the Portable Semi-Automated Thread Seal Tape Wrapping Machine is the result of extensive research, multiple prototype iterations, and lessons gained from previous failures. The final system is designed to provide precision, efficiency, portability, and ease of use and address the main drawbacks of manual and fully automated sealing. The equipment features two-fixed jaw and one-movable jaw clamping, which adapts dynamically based on the socket size. An adaptive clamping system ensures that the pipe or fitting is accurately and safely positioned, allowing for even and consistent application of tape. The equipment further incorporates an optimized tape-wrapping system as well as automatic cutting system in order to enhance overall utility and sealing performance.

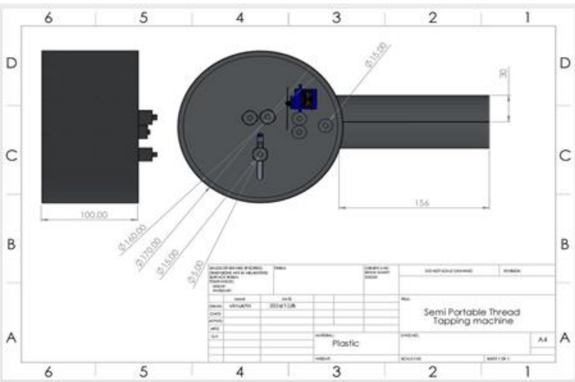

Figure 2: Final Design Drawing

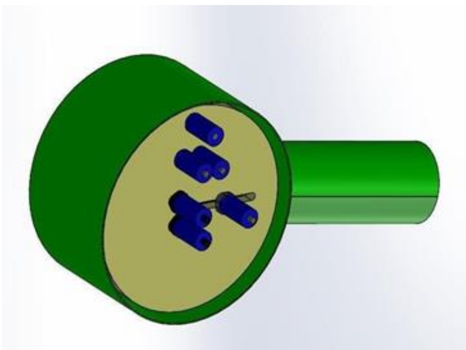

Figure 1: 3D model of the machine

System Initialization and Servo Setup

Once the machine is turned ON, the setup() function is run by the Arduino board. It serves as an essential function to initialize all components prior to any mechanical activity. The three servo motors are each attached to their corresponding digital pins the jaw servo to pin 9, the cutting servo to pin 10, and the hold servo to pin 4. These servos control three essential parts of the machine: the jaw mechanism for clamping down on the pipe, the blade mechanism for cutting the thread tape, and the hold mechanism for keeping the tape in place while it is cut. The relay pin on 3 is configured as an OUTPUT and is utilized to switch the DC motor ON or OFF. For default status and safety, the relay pin is initially set to HIGH, switching the DC motor OFF. The push button on pin 2 is set up with the INPUT_PULLUP mode, so it would read HIGH when not pressed and LOW when pressed. With the servos mounted and the digital pins defined, the servos are told to move to their home positions the jaw servo to 0° (open), the cutting servo to 180° (retracted), and the hold servo to 180° (retracted). A 1000-millisecond delay is employed to provide plenty of time for all servos to get into position and for the system to be mechanically stable before entering the work cycle.

Button Press Detection and Jaw Engagement

The entire operation of the machine is initiated by the user pressing a push button as a sole control interface. The loop () function continuously checks the status of the button. If the button is pressed, the Arduino senses a LOW reading due to the pull-up configuration. Mechanical bounce-induced false triggering is prevented by utilizing a debounce delay of 50 milliseconds. The system then waits in a loop until the button is pressed, then another wait. Once the correct press is determined, the sequence continues. First, the jaw mechanism is turned on. The jaw servo moves from a released state (0°) to a close grip state (35°). This mechanical movement causes the jaw to engage, holding the pipe or threaded fitting firmly in place. The jaw Delay, 3000 milliseconds, provides ample time for the physical components (gears, linkages, or pressure arms) to engage and fully stabilize. The operator is not supposed to do anything at this point. This operation is intended to keep the workpiece stationary before rotation, preventing wobbling or slippage during wrapping.

Primary Wrapping with DC Motor Rotation

Once the pipe is clamped firmly in place, the DC motor is activated to start the thread seal wrapping process. The motor is driven by a relay module, which is like a relay that is switched by the Arduino. A LOW level setting of the relay Pin activates the relay and consequently the motor. The motor drives the rotation mechanism, which turns the pipe around its axis. Meanwhile, a roll of PTFE tape is placed in alignment so that the rotating pipe picks and wraps the tape around its threaded surface. The motor has been programmed to run for 50,000 milliseconds (50 seconds). This is calculated by an estimate of the motor's speed of typically 6 RPM giving about 5 full rotations of the pipe. This allows for multiple overlapping layers of tape for the adequate coverage of sealing. The rotation of the wrap is controlled automatically to maintain constant tape tension and alignment with manual provisions. Upon expiration of the 50-second time, Arduino resets the relay Pin to HIGH to disconnect power to the motor and stop the rotation immediately. To allow all the mechanical components to be completely stopped and to ensure complete loss of residual motion, a short pause of 1 second (1000 ms) upon shutdown of the motor is employed before commencing cutting.

Tape Hold Activation Before Cutting

Having wrapped the pipe with tape and the motor stopped, the machine engages to cut the tape smoothly. To avoid the tape recoiling, sliding, or moving, hold servo is activated. The servo moves from 180° (retracted) to 45° (engaged), applying pressure on the tape at the last wrap. This movement keeps the tape pressed against a surface or tape guide, without moving as the blade cuts through it. This hold feature is required otherwise, the cutting motion would tear the tape or make a ragged or incomplete cut. After the hold servo is engaged, the system includes a 500-millisecond cutting start delay, during which all components have time to settle. This pause ensures that there is no movement or tension imbalance when the cutting blade is activated. It also protects the mechanical parts from damage due to unintended movement during the cutting process. The machine is now in the perfect position and firm for a clean and accurate cut.

Automated Multi-Stroke Cutting Sequence

Once the tape is held in place by the hold mechanism, the cutting servo is triggered to perform its function. The cutting servo begins at 180° (the fully retracted position of the blade) and proceeds to 50°, advancing the cutting blade into contact with the tape. After a short delay of 400 milliseconds, during which the blade cuts the tape, the servo is returned to 180°, withdrawing the blade. This cutting operation is not performed just once but the system repeats the operation three times with the assistance of a for loop. The three-time repetition ensures a 100% successful cut through the tape even if the initial cut is not clean due to variations in tape thickness, angle, or cutter sharpness. Each forward and backward stroke of the blade is followed by a 400 ms delay to avoid overstraining the servo motor and allow time for the mechanism and tape to recover. This multi-stroke cutting system guarantees durability and reliability over different operating conditions. At the end of the third cut, the tape is cleanly severed from the roll, and the system sets to reset the hold mechanism

Releasing Hold and Final Tape Tightening Rotation

After the tape has been successfully cut, the hold servo is returned to the initial position of 180°, retracts the pressure or hold arm and clears the work surface. This retraction is necessary so as not to exert physical hindrance on the final step of rotation. The DC motor is powered ON once more but for a lower duration of 10,000 milliseconds (10 seconds). This final rotation keeps the loose tail end of the tape firmly pressed and rolled over the thread so that it doesn't flake off. This final rotation provides a clean finish to the wrap and contributes to the reliability of the seal. The motor is once again regulated by the relay by setting relayPin LOW, the motor is switched on, and after a certain desired time delay, it is switched off by setting the pin HIGH. The wrapping and cutting process is now completed, and the pipe is ready for use.

Jaw Release and Return to Idle State

The final action of the automated process is breaking the pipe off from the jaw clamp. After a 1-second post-motor delay, the jaw servo is commanded back to 0°, opening or releasing the clamping action. This frees the pipe away from the machine for the operator to remove and replace with a fresh one if needed. The system then goes back to its initial idle state with the servos fully retracted and the motor off, in readiness for the next button press. This repetitive cycle of button press to grip, wrap, cut, and eventual release is the reason why the machine is semi-automated, with very little human intervention, to achieve consistent, effective, and high-quality wrapping operations.

Code for the program

```
#include <Servo.h>

// Define servo objects Servo jawServo; Servo cuttingServo;

Servo holdServo; // New servo

// Define pin assignments const int jawServoPin = 9; const int cuttingServoPin = 10;

const int holdServoPin = 4; // New servo pin

const int relayPin = 3; // Relay controlling the DC motor const int buttonPin = 2; // Push button pin

// Define servo positions

const int jawInitialPosition = 0;    // Initial position for the jaw servo const int jawTightPosition = 35;    // Position to move the jaw to tighten

const int cuttingInitialPosition = 180; // Initial position for the cutting servo const int cuttingActivePosition = 50; // Position to perform the cutting action
const int holdInitialPosition = 180;    // Initial position for the hold servo const int holdPosition = 45;    // Hold position for the hold servo


// Define timing constants

const unsigned long jawDelay = 3000; // 3 seconds delay after moving the jaw const unsigned long motorRunTime = 50000; // 50 seconds for 5 rotations at 6 RPM

const unsigned long postMotorDelay = 1000; // 1 second delay after stopping the motor const unsigned long cuttingStartDelay = 500; // ***Delay before cutting starts*** (2 seconds)

const unsigned long cuttingDelay = 400;  // 400 ms delay after each cut

const unsigned long secondMotorRunTime = 10000; // 10 seconds motor run time


void setup() {

// Attach servos to their respective pins jawServo.attach(jawServoPin);

cuttingServo.attach(cuttingServoPin); holdServo.attach(holdServoPin); // Attach new servo


// Initialize relay and button pin pinMode(relayPin, OUTPUT);

pinMode(buttonPin, INPUT_PULLUP); // Enable internal pull-up resistor for button digitalWrite(relayPin, HIGH); // Ensure the DC motor is off initially


// Initialize servo positions jawServo.write(jawInitialPosition); cuttingServo.write(cuttingInitialPosition); holdServo.write(holdInitialPosition); // Initialize hold servo delay(1000); // Allow time for servos to reach initial positions
```

```
}

void loop() {
// Wait for button press
if (digitalRead(buttonPin) == LOW) { delay(50); // Debounce delay
while (digitalRead(buttonPin) == LOW); // Wait for button release delay(50); // Additional debounce delay

// Step 1: Move the jaw to the tight position jawServo.write(jawTightPosition); delay(jawDelay);

// Step 2: Start the DC motor for 50 seconds digitalWrite(relayPin, LOW); delay(motorRunTime);

// Step 3: Stop the DC motor digitalWrite(relayPin, HIGH); delay(postMotorDelay);

// Step 4: Move hold servo to hold position before cutting holdServo.write(holdPosition);

// Step 5: ***Delay before cutting starts*** delay(cuttingStartDelay);

// Step 6: Perform the cutting mechanism 3 times for (int i = 0; i < 3; i++) { cuttingServo.write(cuttingActivePosition); delay(cuttingDelay); cuttingServo.write(cuttingInitialPosition); delay(cuttingDelay);
}
// Step 7: Return hold servo to initial position after cutting stops holdServo.write(holdInitialPosition);

// Step 8: Run the DC motor again for 10 seconds
digitalWrite(relayPin, LOW); delay(secondMotorRunTime); digitalWrite(relayPin, HIGH);

// Step 9: Move the jaw back to the initial position delay(postMotorDelay); jawServo.write(jawInitialPosition);
}
}
```

Results

Simulation of final design

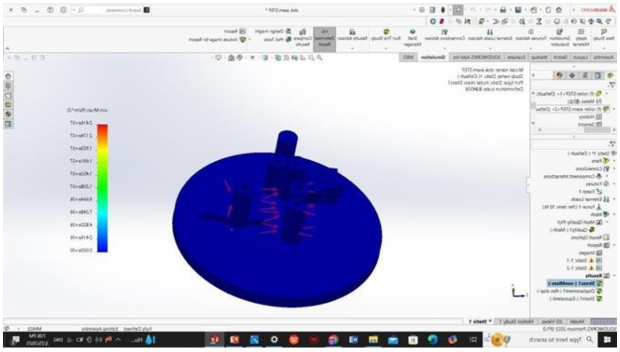

Figure 3: Stress of apply force in jaws

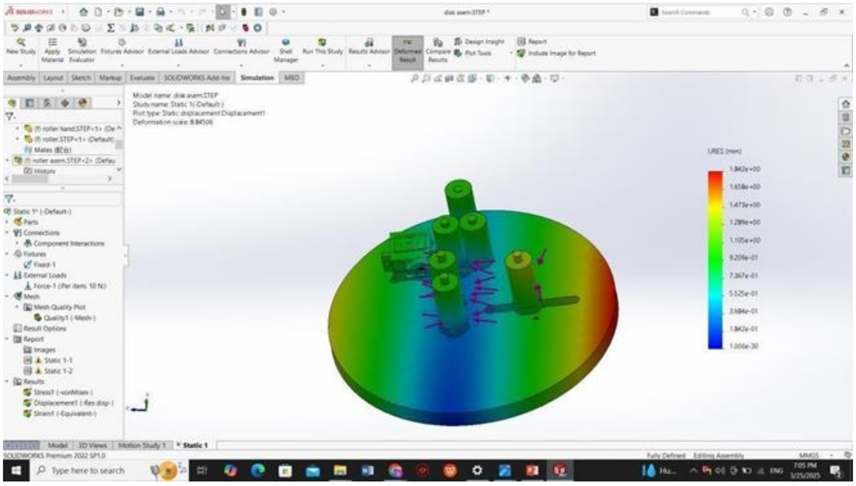

Figure 4: Displacement of plate according to force in jaws

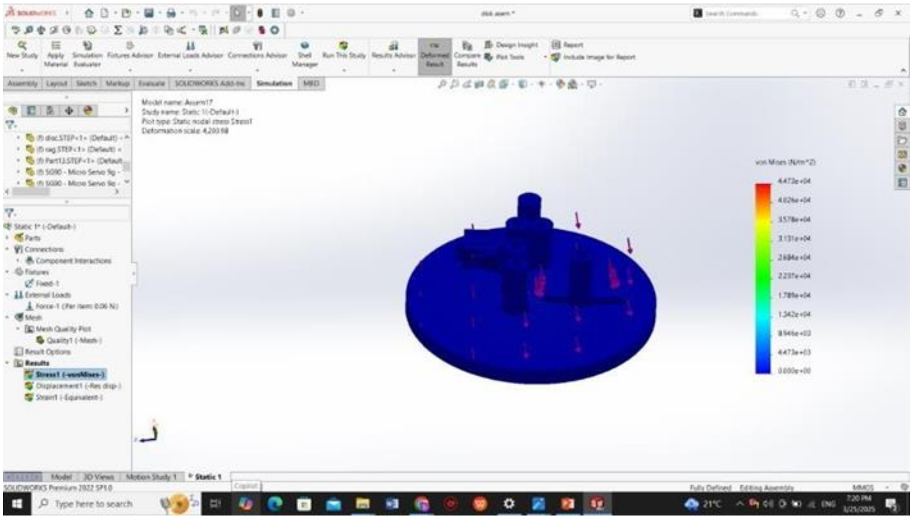

Figure 1: Stress when apply force on to a plate

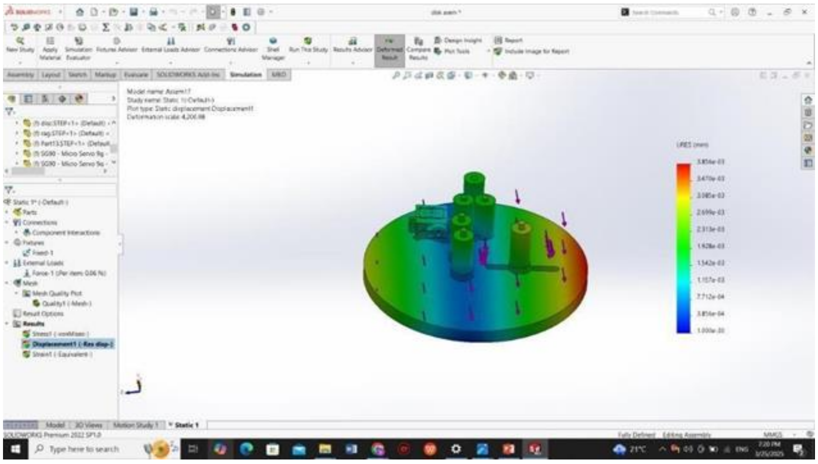

Figure 6: Displacement when apply force on to a plate

Fabrication of the Portable Semi-Automated Thread Seal Wrapping Machine

The fabrication of the portable semi-automated thread seal wrapping machine was carried out in three main phases: mechanical structure development, electronic system integration, and software programming. The design focused on portability, user safety, efficient operation, and cost-effectiveness.

Figure 2: Prototype of Portable Semi-Automated Thread Seal Wrapping Machine

Mechanical Structure Fabrication

The frame was constructed using lightweight materials (PLA+), ensuring both structural integrity and ease of transport. The key mechanical subsystems are as follows.

Pipe Clamping Mechanism:

The clamping system comprises a fixed jaw and a movable jaw. The movable jaw is actuated by an SG90 servo motor, which provides adequate torque to securely hold the pipe in position. Rubber pads were added to both jaws to prevent pipe damage and slippage.

Rotational Assembly

A 12V DC gear motor is used to rotate the pipe. The pipe is coupled to the motor shaft using a flexible coupling, with additional bearings supporting the rotation for stability and smooth operation.

Tape Dispenser with Braking System

A custom spool holder is mounted to hold and feed the PTFE tape onto the pipe thread. A servo motor-operated braking mechanism is integrated into the holder to maintain constant tension in the tape during operation. This braking system engages just before the cutting phase to prevent slack and ensure clean, accurate wrapping.

Tape Cutting Mechanism with Rack and Pinion

The cutting unit employs a rack and pinion mechanism for linear blade motion. A servo motor drives the pinion gear, which translates rotational movement into linear displacement of the rack, pushing the blade across the tape. This ensures smooth and precise cutting after each wrapping cycle.

Electronic System Integration

The control system is built around an Arduino Uno microcontroller. The electronic components include

SG90 Servo Motors:

One for pipe clamping, one for braking tension control, and one for actuating the rack-and-pinion cutting blade.

12V DC Gear Motor

Responsible for pipe rotation, driven through an L298N motor driver for speed and direction control.

Power Supply System

A 12V DC power source supplies the main circuit. Voltage regulators provide 5V outputs for logic-level components.

Control Interface

A start/stop push button and LED indicators are used for user interaction and system status monitoring.

Software Programming

The Arduino Uno was programmed using the Arduino IDE. The logic flow included:

1. System idle until start button is pressed.

2. Activate clamping servo to grip the pipe.
3. Start pipe rotation motor.
4. Engage tape brake servo motor before the cut.
5. After preset rotations, stop the motor.
6. Activate rack and pinion cutting servo to cut tape.
7. Reset system and release the pipe.

Conclusion

This research was able to successfully propose the design, development, and testing of a portable semi-automated thread seal wrapping machine for both plumbing and industrial applications. The machine was created to overcome the disadvantages of traditional manual wrapping such as inconsistency, inefficiency, and wastage of materials without the accompanying high costs and complexity of fully automated industrial machines.

The prototyped machine integrates an accurate clamping system, servo motor tension brake, and rack-and-pinion cutting machine, all operated with an Arduino-based control system. In testing, the machine was found to have even and consistent tape application, reduced human error, and improved working efficiency. It is easy to use, portable, and suitable for field engineers and small-scale businesses with mobility and reliability needs.

The project also validates the feasibility of low-cost automation for sealing operations, hence providing possible advantages to small and medium enterprises (SMEs) wanting to improve productivity at low cost. Implementation of ergonomic and modularity design principles also enhances its applicability in real-world applications.

Any future improvements may include the inclusion of feed-back sensors for automatic tensioning control, a digital input for parameters, and structural optimization by simulation and material selection to further reduce weight and cost.

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