This paper defines a PID type yarn tension control run by a PLC system that is used to control the yarn tension below the twisting head of the novel air jet texturing and twisting (AJT²) machine. In the standard sequence of the AJT², if the yarn is transported to the twisting and winding head with a low tension value, the yarn is bound to wrap around the shoulder below the twisting head and break immediately afterwards. Additionally, when the yarn tension is high, the yarn is also inevitable broken. Using the tension control, it is planned to stabilize the tension by controlling the transport cylinder motor with the help of the tension sensor and the S7300 type PLC.

**Keywords:** Yarn, Air-Jet Texturing and Twisting (AJT²), PID, PLC, Yarn Tension.

**1. INTRODUCTION**

In this study, after improvement and manufacturing of a prototype Air-Jet Texturing and Twisting Machine (AJT²) by the financial support of TUBİTAK (Research Grant No: 105M134 patented as TPE Document Code: 69065, Registration No: 2007/02344), we aimed at controlling the tension values between reference tension levels.

In the AJT² machine, wrapping, twisting and the transport cylinder motor should be working synchronized within a certain tension level within the area that is below the wrapping and twisting head, preventing the break of the yarn due to the lower and higher tension levels which causes the yarn to wrap around the twisting head and which causes the yarn to high strain respectively.

**2. SYSTEM DESCRIPTION**

The AJT² machine composed of three main processes. These processes are:
- **Drawing,**
- **Air-Jet Texturing and**
- **Twisting processes**

in the sequence of the yarn processing.

**Drawing Process**

The drawing process is implemented by two units of ceramic plated cylinder-rubber cylinder pair (FC-feed cylinders) and two units of heated cylinder-separator roller pair (DC-drawing cylinders). The yarn transferred from creel is wrapped around the DC and heated until the glass transition temperature of the polymer. The yarn has to be fed by the DC at lower speed than the FC in order to create a draw between the DC and FC. After the drawing operation, the yarn is then ready as finished yarn to be fed into the yarn channel of the air-jet nozzle by the FC.

**Texturing Process**

The air-jet texturing process forms a yarn with tightly convoluted, entangled and looped filaments resembling yarns spun from staple fibres such as cotton and wool. In this process of air-jet texturing, multi filament yarn is fed into a narrow channel where it meets with a flow of compressed air and taken away from that channel at a lower speed than the feeding speed (called overfeed) and makes a right turn just after the narrow channel. At the exit of the narrow channel a supersonic, highly turbulent air jet is formed by the compressed air flow that pushes the freely available filaments in any direction in such a way that they entangle, convolute and loop with each other (Figure 1). Such converted yarn is much softer, bulkier and gives warmer feeling to wearer and possesses natural look and appearance than the supply yarn which may be composed of one or many filament yarns be thermoplastic, organic or metallic.
Twisting Process

Twisting is a very essential process in the production of staple fiber yarns, twines, cords and ropes. Twist is inserted to the staple yarn to hold the constituent fibres together, thus giving enough strength to the yarn, and also producing a continuous length of yarn. The twist in the yarn has a two-fold effect; firstly the twist increases cohesion between the fibers by increasing the lateral pressure in the yarn, thus giving enough strength to the yarn. Secondly, twist increases the helical angle of fibres and prevents the ability to apply the maximum fibre strength to the yarn. Due to the above effects, as the twist increases, the yarn strength increases up to a certain level, beyond which the increase in twist actually decreases the strength of staple yarn. In the air-jet texturing and twisting machine, in order to obtain twisted yarn, DirectTwist twisting method is used (Figure 2).

Problem Statement

In the textile machines, one of the main problem is the modeling of the yarn tension. It is needed to control the tension of the yarn to avoid the risk of a yarn break which causes the manufacturing to cease. Before control algorithm, the mathematical model which represents the air-jet texturing and twisting machine has to be identified. After some experiments, four main reasons are identified to affect the tension of the system:

- Yarn count (dtex) which represent the yarn thickness,
- The material and hence the type of the yarn (Polyester, Polypropylene, etc.),
- The number of yarns to be processed,
- The process speed (m/min).

In this study, three FDY yarns each with a yarn count of 167 dtex are used. The system speed is accepted to be 80 m/min. According to these parameters, the reference tension value is estimated to be 18 cN.

3. PROCESS MODEL

Yarn transfer with the twisting process can be simply considered as a SISO system. The tension is obtained as a result of yarn transfer between the wrapping motor and the transport cylinder in the air-jet texturing machine (Figure 3).

Dynamical Model of System

The yarn between the transport cylinder and the winding motor can be modeled as a spring and damping pair as shown in Figure 4. Tension depends on the synchronization between the transport cylinder and the wrapping unit motors. If the tension value between the transport cylinder
and the winding motor reaches above 50 cN or below 10 cN, it is considered as a dangerous value.

\[
(J_{M} + J) \cdot \ddot{\theta} = (-b \cdot R + B_{M}) \cdot \dot{\theta} + (-k \cdot R) \cdot \dot{\theta} + (K_{M} \cdot U)
\]  

where:

- \(J\): Moment of inertia of the transport cylinder,
- \(J_{M}\): Moment of inertia of the transport cylinder motor,
- \(R\): Radius of the transport cylinder,
- \(B_{M}\): Damping coefficient of the transport cylinder motor,
- \(K_{M}\): Motor constant,
- \(k\): Stiffness of the yarn,
- \(b\): Damping coefficient of the yarn.

### 4. PID CONTROLLER USING PLC

A programmable logic controller (PLC) or programmable controller is a digital computer used for automation of several electromechanical processes. PLCs are used in many industries and machines, such as packaging and semiconductor machines. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory. A PLC is an example of a real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result. A digital control application diagram can be seen in Figure 6. PLC systems can include all of the sequences mentioned in the figure with their extension modules or embedded I/O features.

In this tension control system, a S7-300 type Siemens CPU-314 PLC is used with two 32-channel (16 DI-16 DO) digital I/O and two 8-channel analog input and one 8-channel analog output modules.

#### Yarn Tension Measurement Sensor

The yarn tension sensor used in the system should have a linear analog output with a fast update rate and resolution. Due to this reasons, a TEMCO ZKS50 tension control unit (Figure 7) is used in the tension control system. It has analog output of 0-10V which has a linear output depending on the tension value (Figure 8).
Selected PID Algorithm

A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly and rapidly, to keep the error minimal. The PID controller calculation (algorithm) involves three separate parameters; the proportional, the integral and the derivative values. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the setpoint and the degree of system oscillation.

There are several PID algorithms that can be used to control a system. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. In this system a standard PID system is preferred and embedded in a STEP7 function block.

\[
u(t) = K_P e(t) + T_1 \int_0^t e(\tau)d\tau + T_D \frac{de}{dt}(t)
\]

where;
- \( u(t) \) : Output value
- \( K_P \) : Proportional effect depending on the error
- \( T_1 \) : Integral effect depending on the error
- \( T_D \) : Derivative effect depending on the error

5. PID PARAMETER ADJUSTMENT

Tension control is one of the most important process parameters in textile machines. Therefore the selection of reliable control algorithm for tension control is crucial.

If the system is run without a PID control mechanism and with a transport cylinder motor voltage value of 4V (Figure 10), the tension value is unsteady and changes around 5-25 cN (Figure 11).

Since there is a system model, it is easy to calculate the PID parameters using Ziegler Nichols methods. The calculated PID parameters from the model are: \( K_P = 1.3 \), \( T_1 = 0.5574 \) and \( T_D = 0.139 \).

![Figure 9. The Air-Jet texturing and twisting machine with controller](image)

By using these calculated parameters and after some adjustments we find the ideal PID parameters for this system as: \( K_P = 1.5 \), \( T_1 = 0.5395 \) and \( T_D = 0.349 \). The speed output and the tension values can be seen in Figure 12 and Figure 13 respectively.

It should be noted that in this PID controlled system, the system has a dead time of 10 seconds in which texturing is started and rubber cylinders presses on the transport cylinders. After 10 seconds, PID control mechanism takes control of the transport cylinder speed and stabilizes the tension change (Figure 12 and 13).

![Figure 10. Transport cylinder speed graph having a stable input of 4 volts](image)

![Figure 11. Tension change without the control mechanism](image)
As seen from the figures, the control mechanism stabilizes the tension value at a reference value of 18 cN.

In the experiments, optimal process speed, yarn count and reference tension values of the AJT² are used. It is suggested to use other process speed, reference tension and yarn thickness values to obtain new models and new PID parameters for each system. It’s also strongly suggested to use alternative control methods such as fuzzy and optimal control.

**Figure 12.** Transport cylinder speed controlled with a pid control mechanism

**Figure 13.** Tension change with the pid control mechanism

### 7. ACKNOWLEDGEMENT

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### 8. REFERENCES

[9] www.temco.de/uploads/media/ZKS50.pdf last access date: 10.05.09