TEKSTİL VE KONFEKSİYON

VOL: 33, NO. 2
DOI: 10.32710/tekstilvekonfeksiyon.1084536

Experimental Investigation of Sensorless Tension Control System for Textile Processes

Recep Eren[1] 0000-0001-9389-0281
İsmail Bayraktar[1,2] 0000-0001-6344-8476
Mohamad Y. Sadoun[1] 0000-0002-7869-4212

[1]Textile Engineering Department, Engineering Faculty, Bursa Uludağ University, Görükle Campus, 16059, Nilüfer, Bursa, Türkiye.
[2]Yalova University, Yalova Vocational School, Dere Mah., Mehmet Durman Cad., No:87, Merkez, Yalova, Türkiye.

ABSTRACT

Sensorless tension control system is investigated for textile processes and machines in this paper. A prototype unit unit was designed and manufactured for this aim. Prototype unit consisted of winding and unwinding warp beams driven by a servomotor and an induction motor. Warp tension was measured by load cells for evaluating the sensorless tension control system performance. Diameters of winding and unwinding warp beams were measured by laser sensors. Wound warp length was measured by an incremental encoder fitted to the shaft of a cylinder rotated by warp yarns. Number of beam rotations of warp beams were measured by separate inductive switches. A software program was developed in LabVIEW to implemet sensorless tension control algorithms and record the performance data. Results showed that the desired tension can be kept constant within 5% deviation limits by the servomotor torque control.

ARTICLE HISTORY
Received: 08.03.2022
Accepted: 21.06.2022

KEYWORDS

Winding, unwinding, tension control, sensorless tension control, torque control

1. INTRODUCTION

Tension is an important parameter in textile processes due to the elastic nature of textile yarns and fabrics. Certain level of tension is required in fabrics and yarns during processing and usage. Tension control systems are mostly used in warp/fabric winding and unwinding units of textile machines and they provide operation with constant tension values despite the change in winding or unwinding beam diameter during processing. In such tension control systems, warp or fabric tension is measured by mostly load cells or by inductive sensors in a dancer roller system. Then the measured value is compared with the desired value and beam speed is adjusted depending on the difference between them to correct the deviation from the desired tension. This is called a feedback control system in which a measurement sensor is essential.

Figure 1 shows three system types which run with tension and/or speed control systems. In Figure 1.a, fabric or warp is drawn forward by a constant diameter roller. Hence, constant angular velocity of the roller is sufficient for constant surface speed. There is no need for speed measurement as an open loop speed control of drive motor of roller will guarantee a constant surface speed. But there is a need of tension measurement to control the tension. Warp/fabric beam angular velocity is adjusted according to the deviation of the measured tension from the desired one. Hence, this system works with an open loop speed control and feedback tension control system. Figure 1.b shows a system in which warp or fabric is fed forward at a constant surface speed. As the feed roller diameter is constant, it is sufficient to feed warp/fabric with a constant angular velocity of feed roller. But, winding diameter increases as winding continues and requires to decrease the angular velocity of the beam. This is done by a feedback tension control system. Tension is measured before in a unit before winding beam and any deviation from its desired value is detected and converted to a new angular velocity of the beam by tension controller. In this system too, there is an open loop surface speed control system and feedback

To cite this article: Eren R, Bayraktar İ, Sadoun MY. 2023. Experimental investigation of sensorless tension control system for textile processes. *Tekstil ve Konfeksiyon* 33(2), 125-134.

tension control system. In Figure 1.c, warp or fabric is transferred from one beam to another beam and diameters of both beams change during the process. In this case, both speed and tension feedback control sytems are included to control surface speed and tension constant. Angular velocity of winding beam is adjusted by feedback speed control system while unwinding beam angular velocity is adjusted under a feedback tension control system.

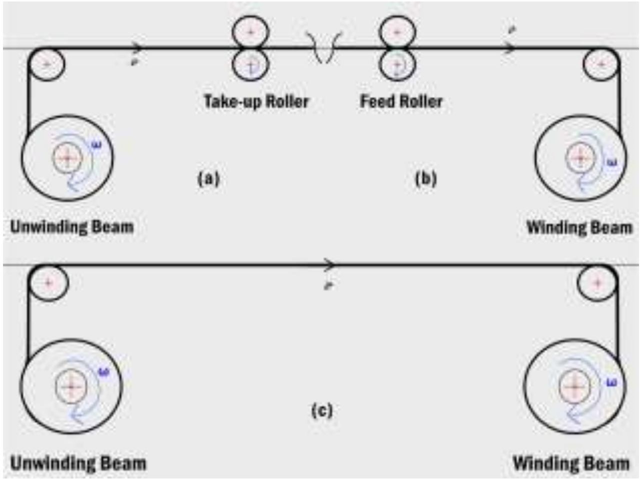

Figure 1. Three system types encountered in winding and unwinding units of textile machines

These winding and unwinding systems are also used in paper and similar industries. Sensorless tension control systems are widely used in these industries although it is very rare in textile industry. Sensorless tension control systems have advantages as tension sensor is eliminated. Apart from cost advantages, problems regarding sensor and its electronics as well as mechanical structure for sensor construction are also eliminated. When literature was reviewed, a limited publication was found regarding sensorless tension control applications specifically for textile proccesses. There are some publications investigating sensorless tension control for paper, steel, tape, ribbon and web winding industries. These are summarised below.

Abjadi et al. conducted a mathematical modelling and simulation study for speed and tension control systems using a slider mode control method in 3 motor driven elastic band winding system. They developed control algorithms using speed and tension sensors in addition to two sensorless tension observers. They concluded that tension values obtained with sensorless control system complied with measured tension values [1]. Baumgart and Pao developed a first order tension observer for a tape transport mechanism considering the tape as a model consisting of spring and damping elements. They carried out a simulation work by including this observer in the control algorithms and concluded that control system manged to keep tension between certain limits despite the variations in the inertia, friction and winding radius [2]. Baumgart and Pao conducted another research on both with sensor and sensorless tension control for a tape transport system by modelling a tape as a nonlinear dynamic system consisting of parallel connected spring and damping elements. It was shown that tension was controlled with a small error when system parameters did not change during winding using a sensorless control algorithms. But, deviations occured when system parameters changed [3]. Carrosca and Valenzuela realised a mathematical analysis for a sensorless tension control system with two roller tangential drive winding system. Tension was calculated considering winding unit, unwinding unit and their average and tension control was carried out for each case. It was shown that in all cases sensorless tension control system showed a good performaance similar to that of the control system with sensor. It was also shown that deviation in the frictional moment at 20-25% level caused only 2-2.5% deviation from the desired tension. Therefore, they recommended sensorless tension control system for industrial use [4]. Chen et al. developed a sensorless tension control system based on tension observer for elastic materials like ribbon, tape and fabric and implemented it with an experimental set up. They also experimented a feedback tension control system with sensor and an open loop tension control system. They concluded that sensorless tension control system performed better open loop control system and showed a very close performance with feedbak tension control system with sensor [5]. Dong et al. investigated performance of SVR (Support Vector Regression) method in sensorless tension control of shuttleless weaving machine by using a simulation model. Taking into account woven fabric and weaving machine parameters, they carried out a succesfull simulation work and showed SVR method success in tension control despite variations in weaving machine and fabric parameters. They pointed out that they would apply this control approach to a shuttleless weaving machine [6]. Glaoui et al. conducted a modelling and simulation study for multi motor ribbon transport and winding system. 4th motor was used for a sensorless tension control system. It was concluded that tension followed the desired tension in all zones with a PI controller [7]. Hou et al. investigated the performance of sensorless tension control in a 3 motor driven thin elastic material winding system by modelling and simulation as well as experimentally. They developed tension observers taking into account system and material properties. They used in both simulation and experimetal set up brusless servomotors and measured tension by load cells for evaluating system performance. They concluded that the tension observers predicted tension at sufficiently accurate level [8,9]. Jeftenic and Bebic developed a speed and tension control system with a minimum number of sensors. They developed a tension observer and sensorless tension control system. After developing a mathematical model, they applied sensorless tension control algorithms to a paper making machine already working in industry. They measured tension by sensors available on the machine and concluded that sensorless tension control system with the tension observer achieved a control performance with up to 5% deviation from its set value which was found sufficient by them for many practical applications [10]. Lyncha et al. explained a nonlinear tension observer to be used in a sensorless tension control system in winding of materials like tape and ribbon. They developed an experimental set up for the application of sensorless tension control system. After conducting experimental work they concluded that slider mode control and nonlinear tension observer together showed a better tension control performance than algebraic tension observers [11]. Tham et al. explained a tension regulation problem. They carried out a tension control by designing tension observers rather than measuring it. They combined tension observer with sliding mode control and concluded that this approach produced a better tension control performance and the tension followed the desired value with a minimum deviation [12]. Valenzuela et al. developed sensorless tension control systems for dry region of paper making machines. They conducted the research both theoretically and experimentally and developed mathematrical relations including system and material properties to form tension observers and predicted tension. After conducting the research, they concluded that tension could be controlled within 5% deviation limits [13,14]. Wang et al. investigated a sensorless tension control system by using PI parameters of adaptive speed controller in a winding and unwinding system. Tension observers were developed and used instead of tension measurement. Theoretical results were compared with experimental ones and a good match was reported [15]. Zhong and Pao investigated the effect of diameter change in a ribbon winding sytem on tension and studied control algorithms to regulate tension by simulation. They separated winding diameter change into 2 parts as the changes during winding layers and due to roller eccentricity. They developed feed forward control algorithms to minimise the effect of diameter change on ribbon tension [16].

A limited publication exists on the application of sensorless tension control in textile processes and up to 5% control accuracy is reported in the literature in paper making machines [10,14]. It was aimed in this research to investigate the possibility of using sensorless tension control systems for textile processes as up to 5% deviation from the set value would be acceptable for many textile processes.

2. MATERIAL AND METHOD

2.1 Material

One servomotor (4.5 kW), one induction motor (5.5 kW), two laser sensors up to 400 mm measuring interval, one incremental encoder with 100 pulses/rev resolution, two load cells with 0-1000 N measuring interval, two inductive swithches for measuring number of revolution of two warp beams were main elements of prototype sytem which are mounted on the mechanical structure of it.

2.2 Method

A prototype system consisting of winding and unwinding units was designed and manufactured for the investigation of sensorless tension control. Figure 2 shows schematic view of this prototype system. There are 2 warp beams running as winding and unwinding units depending on the direction of warp transfer. Warp beam 1 is driven by an induction motor of 5.5 kW and warp beam 2 by a servomotor of 4.5 kW. Winding (surface) speed was set to a desired value by adjusting angular velocity of induction motor. Speed control system decreases angular velocity of induction motor or warp beam 1 as its diameter increases. Warp tension is controlled by the drive of servomotor as will be explained below. Warp beam diameters were measured by 2 laser sensors which were adjusted to measure the distance between 50 to 250 mm, a total of 200 mm. An output voltage between 0 to 10 volt corresponds to 0 to 200 mm absolute distance. Warp diameters can be calculated by Equation (1) and Equation (2) as follows based on laser sensor output voltages.

$$\mathbf{D_1=d_1/2+2L\ (V_1-V_{b1})/V_b} \quad (1)$$

$$\mathbf{D_2=d_2/2+2L\ (V_2-V_{b2})/V_b} \quad (2)$$

In these equations, D_1 and D_2: are diameters of warp beam 1 and 2 in mm, d_1 and d_2 are diameters of empty warp beam 1 and 2, V_1 and V_2: output signals of laser sensor 1 and 2 (volt), V_{b1} and V_{b2}: are output signals of laser sensor 1 and 2 (volt) when warp beams are empty, V_b: output signal of laser sensors when measuring distance is maximum which is set to 10 volt and L: is maximum value of measuring distance which is set to 200 mm.

Although sensorless tension control is aimed at this research, warp tension was measured for the evaluation of the performance of sensorless tension control system. Two bearing type load cells were mounded to the right and left side bearings of roller 2 as shown in the drawing below. Each load cell has 1000 N measuring capacity. As in laser sensors, load cells produced an output voltage between 0 to 10 volt corresponding to 0 to 1000 N. Total warp tension was determined as the average of two load cell output signals by Equation (3).

$$\mathbf{T=1000.(V_{l1}+V_{l2})/(2V_m)} \quad (3)$$

Where,

T: Total tension (N), V_{l1} and V_{l2}: Output signals of two load cells (volt) and V_m: maximum output voltage corresponding to 1000 N, which is 10 volt in this system.

Warp length wound on the beam was calculated by Equation (4) based on counted encoder signals.

$$\mathbf{S=(n/R).C} \quad (4)$$

S: Warp length woun on the beam (m), n: Total encoder pulses counted from the beginning of winding operation, R: Resolution of the incremental encoder (pulses/rev) and C: Circumference of the roller 2 (m).

In addition to the above explained measurements, warp beam rotations were detected by individual inductive switches and signals (pulses) were counted and number of of rotations of both beams were determined for calculating beam diameters analytically.

Apart from the above mentioned measurements, the torque produced by servomotor and servomotor angular velocity were measured and recorded. Both parameters were measured by analog signals produced by servomotor driver between 0 to 8 volts, which correspond 0 to rated servomotor torque and velocity. Induction motor and servomotor has drivers which accept signals between -10 and 10 volt for controlling motor speed or motor torque depending on if motors are operated in speed or torque control mode. '-' sign indicates opposite direction for speed or torque. In speed control mode, 0 to 10 volt control signal means 0 to rated or maximum running speed of motors while it corresponds to 0 to the rated torque in torque control mode. All the signals in the prototype unit were interfaced to a PC via 2 USB DAQ (Data acquisition) cards. Figure 3 shows schematic view of analog and digital signals coming from the system and going to computer through DAQ cards as well as 2 analog signals going to servomotor and AC motor driver control units also through one of DAQ cards. USB 6001 DAQ card has ADC (analog to digital converter) and DAC (digital to analog converter) both with 14 bits resolutions. Counters in both cards have 32 bits capacity which can count up from zero to 2^{32}-1. The following are the explanatipn of signal.

Ao1: Analog signal to induction motor driver for speed or torque control.

Ao2: Analog signal to servomotor driver for speed or torque control.

AI0: Laser sensor 1 analog signal to NI 6001 DAQ CARD 0th analog input channel.

AI1: Loadcell 1 analog signal to NI 6001 DAQ CARD 1st analog input channel.

AI2: Laser sensor 2 analog signal to NI 6001 DAQ CARD 2nd analog input channel.

AI3: Induction motor analog torque signal to NI 6001 DAQ CARD 3rd analog input channel.

AI4: Induction motor power analog signal to NI 6001 DAQ CARD 4th analog input channel.

AI5: Servomotor torque analog signal to NI 6001 DAQ CARD 5th analog input channel.

AI6: Servomotor speed analog signal to NI 6001 DAQ CARD 6th analog input channel.

AI7: Loadcell 2 analog signal to NI 6001 DAQ CARD 7th analog input channel.

CNI: Encoder dijital (pulse) signal to counter input of NI 6001 DAQ CARD.

CN 1: Digital signal of induction motor inductive switch to ADVANTECH 4750 counter input 1.

CN 2: Digital signal of servomotor inductive switch to ADVANTECH 4750 counter input 2.

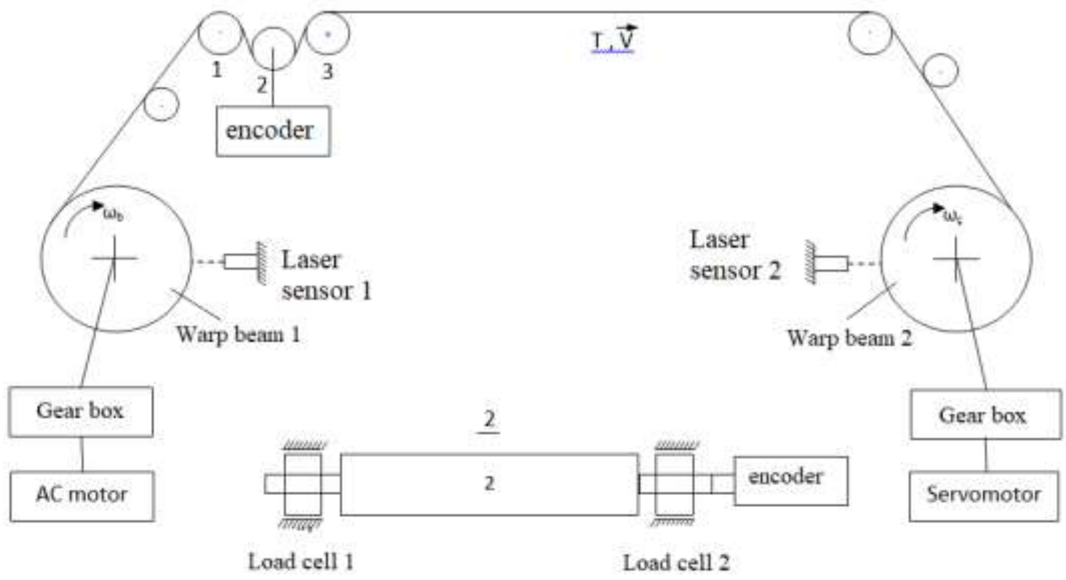

Figure 2. Schematic view of prototype unit

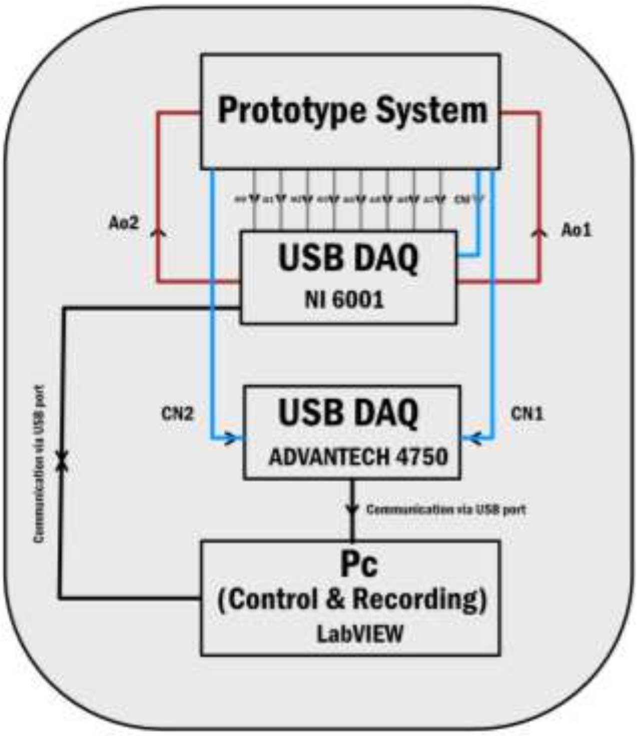

Figure 3. Communication signals between the prototype system and computer

A software was developed using LabVIEW software Community Edition to control the prototype system operation and read and record the performans data. As one second interval was found sufficient to follow accurately the tension change, the reconding all the data was carried out from the full to empty beam with one second intervals.

Sensorless tension control algorithms were developed based on servomotor operation in torque control mode. Servomotor torque is dependent directly on current drawn by the motor and can be written by Equation (5) as follows.

$$\mathbf{M=k.i} \qquad (5)$$

Where,

M_m: Tork produced by a servomotor (Nm).

k: Torque constant (Nm/A)

i: Servomotor curent (A).

Because of this linear relationship, torque control is implemented by servomotor control unit with a current feedback control system. Current feedback control system in the servomotor driver has its own optimisation algorithms and does not accept any intervention from outside apart from inputting the desired torque signal. Hence, the torque control signal should be calculated during winding process and updated with changing diameter of warp beam and inputted to the driver as the torque control signal. Torque control signal can be calculated by Equation (6) as follows.

$$\mathbf{ts=((T.D_2)/(2.sr)).10/M_r} \qquad (6)$$

Where,

ts: Torque signal (volt)

T: Desired total tension (N)

D_2: Servomotor warp beam diameter (m)

sr: Gear ratio between servomotor and warp beam (it is 3 in the prototype)

M_r: Servomotor rated torque (Nm). Rated torque for 4.5 kW servomotor having 1500 rpm rated speed is 28.6 Nm.

For constant tension operation, torque signal needs to be updated with respect to warp beam diameter as the gear ratio and the rated torque values are constant. D_2 is measured by laser sensor 2 or can be calculated mathematically during winding process and torque signal is updated for a new diameter with 12 ms intervals by the control software.

Speed control signal (0 to 10 volt) for induction motor is calculated by Equation (7).

$$\mathbf{ss=2.V_s/D_1.ar.10/n_r} \qquad (7)$$

Here,

ss: Speed control signal for induction motor driver (0 to 10 volt).

V_s: Winding (or surface) speed (m/min).

D_1: Diameter of induction motor warp beam (m).

ar: Gear ratio between induction motor and warp beam 1.

n_r: Nominal speed of induction motor (1455 rpm).

As 'ar' and 'n_r' are constant, speed control signal of induction motor decreases with increasing warp beam diameter (D_1) and vice versa for constant surface or winding speed operation. Accuracy of winding speed control directly depends on the accuracy of diameter determination accuracy. Laser sensors used for diameter measurement in the prototype has 0.1 mm resolution which is sufficient for accurately controlling the winding speed. But, using laser sensor in diameter measurement for speed control is an expensive method. Therefore, alternative methods calculating warp beam diameter are presented below.

If the thickness of winding layers is known, then diameter can be calculated as follow (Equation (8)) considering Figure 4.

$$\mathbf{D_1=d_1+2.n.k/1000} \qquad (8)$$

Where,

n: Number of layers or warp beam rotations.

k: Warp layer thickness in mm.

D_1 and d_1 are winding and empty beam diameters of warp beam 1 in meter.

Total warp or fabric length wound on the beam can be calculated by adding circumference of each layer as given by Equation (9).

$$S=\pi.d_1+\pi.(d_1+2k)+ \pi.(d_1+4k)+\pi.(d_1+6k)+\ldots\ldots\ldots+ \pi.(d_1+(2(n-1)k) \quad (9)$$

After following mathematical simplifications, winding layer thickness (k) is found by Equation (10).

$$S=\pi.d_1.n+2\pi.k(1+2+3+4+ \ldots\ldots..+(n-1))$$

$$S=\pi.d_1.n+2\pi.k(n.(n-1)/2)$$

$$k=(S-\pi.d_1.n)/(\pi.n.(n-1)) \quad (10)$$

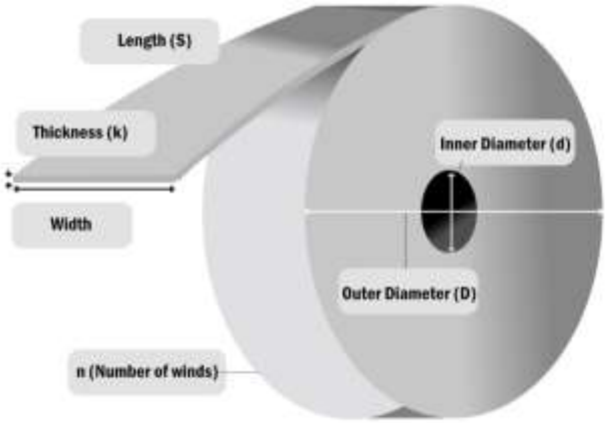

Figure 4. Winding on a roller or beam

As d_1 is constant, thickness of each winding layer can be calculated from Equation (10) if the length of wound warp or fabric length and number of warp beam revolutions (i.e., number of winding layers on the beam) are known. As was explained above, S can be determined from Equation (4) based on counted encoder signals of roller 2. Number of warp beam 1 revolution or number of winding layers on the beam is measured by inductive sensors and counted in the 32 bits counters of USB DAQ card. As both number of encoder signals and number of warp beam rotations are read with 12 ms intervals, warp beam diameter can also be calculated during winding using Equation (8) and Equation (10) with the same interval. All the data are recorded with 1 second intervals and therefore warp beam diameter calculated from Equation (8) and Equation (10) can be compared with the one measured by the laser sensor 1. Results will be presented in the following part.

Warp beam diameter can also be calculated by Equation (11) after determining winding (surface) speed and angular velocity of warp beam from encoder and inductive sensor signals respectively. Winding velocity and angular velocity of warp beam 1 are determined as the difference between two succesive values of S and n.

$$d_{1i}=(S_i-S_{i-1})/(\pi.(n_i-n_{i-1})) \quad (11)$$

Diameter determination of this method will also be compared with laser sensor measurement results in the following part.

A view of the designed and manufactured prototype winding system is seen in Figure 5.

Figure 5. Wiew of prototype winding system

3. RESULTS and DISCUSSION

Experimental results will be presented in two steps. First step is the comparison of warp beam diameter determination methods. Direct warp beam diameter measurement by laser sensor, diameter calculation using Equation (8) and Equation (10) and diameter calculation by Equation (11) are three methods to compare the results. As explained above daimeter calculation by Equation (8) and Equation (10) as well as Equation (11) require the measurement of warp beam number of rotation and warp length wound on the beam. Following 3 figures show warp beam diameter change with respect to number of warp beam rotations for different winding speeds. In Figure 6, winding is carried out with 100 m/min and total warp tension is kept constant at 250 N with 5% deviation limits. All three diameter change follow a linear curve with respect to number of beam rotation. Beam diameter measurement by laser sensor (M3) takes lowest values and M1 (calculated by Equation (11)) and M2 (calculated by Equation (8) and Equation (10)) follow it with higher diameter values. But, three curves are very close to each other. Deviations are at maximum 5 mm levels between M2 and M3 curves and lower between M1 and M3.

Figure 7 shows warp beam diameter changes with respect to number of beam revolution at 25 m/min winding speed. Total warp tension changed from 220 N to 90 N from empty to full beam during winding operation. In this case too, warp beam diameters detemined by 3 methods demonstrate almost a linear change. But towards the full beam diameter, a slight deviation from linearity is observed due to increasing warp tension. But this happens in all 3 curves. Up to 10 mm deviations are observed between M2 and M3 curves. M1 curve calculated using Equation (11) has values closer to the laser sensor measured warp diameter curve M3. Deviation between them is less than 5 mm.

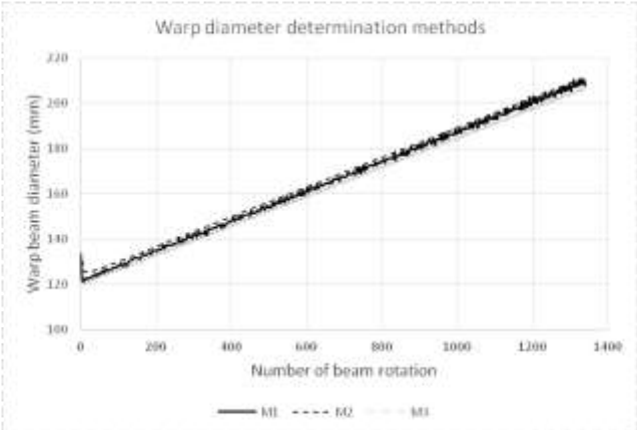

Figure 6. Warp beam diameter change with respect to number of beam rotations-100 m/min

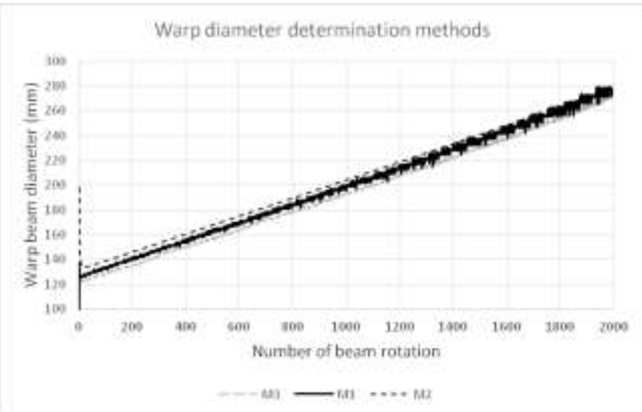

Figure 7. Warp beam diameter change with respect to number of beam rotations-25 m/min

Figure 8 shows warp beam diameter changes with respect to number of beam rotation at 50 m/min winding speed. Total warp tension changed from 90 N to 190 N during winding from empty to full warp beam. A similar linear change of warp diameter with respect to number of beam rotation is observed in all of 3 curves. Here again, lowest diameter values are obtained with laser measured diameter curve (M3) and highest values are recorded in M2 curve which is obtaned by usin Equation (8) and Equation (10). M1 curve obtained by Equation (11) has values in between. Deviation between the calculated and measured diameters is higher at higher diameters. Deviation from the measured (M3) and calculated M1 and M2 curves becomes around 10 and 5 mm respectively.

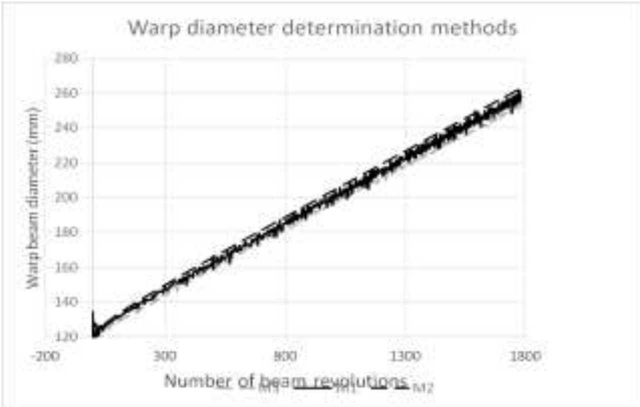

Figure 8. Warp beam diameter change with respect to number of beam rotations-50 m/min

Considering that empty beam diameter is 120 mm, warp beam diameter was measured by less than 5% deviations from laser sensor measurement. Percent deviation decreases with increasing warp beam diameters. If empty beam diameter was 200 mm and over, deviation would become even less than 2%. These results show that speed control can be carried out accurate enough for textile processes without using an expensive laser sensor for diameter measurement. On the other hand, sensorless tension control system requires determination of beam diameter to update the desired torque signal sent to motor driver control unit. In this case too, warp beam diameter determination especially with Equation (11) would enable sensorless tension control to control the tension with less than 2-3% deviation.

Sensorless control algorithms based on tork control was implemeted firstly without taking into account mechanical losses in the motion transmission system. The desired torque signal (‘ts’) was calculated from Equation (6) and changed (updated) with respect to warp beam diameter change at 12 ms intervals. The warp was drawn forward and wound on the warp beam 1 by induction motor at a constant surface speed. First sensorless tension control algorithm was implemented at 25 m/min winding speed and 100 N desired warp tension.

Figure 9 shows warp tension change with respect to number of warp tension readings. ‘0’ reading corresponds to full beam diameter (0.27 m) and ‘2000’ to empty beam diameter (0.12 m). Although the desired warp tension is 100 N and torque signal is updated with respect to warp beam diameter, the actual or measured total warp tension changed from 180 N (at full beam) to 220 N (at empty beam). This ia a very significant deviation. In addition to deviation to 180 N as 80 N at full beam, total warp tension also changed with respect to warp beam diameter from 180 to 220 N which corresponded to 40 N deviation. Both deviations (80% and 40%) in warp tension are very significant and unacceptable from practical point of view considering 100 N desired total warp tension. These deviations are caused by mechanical losses in the motion transmission system.

To observe the total warp tension change at higher total warp tension levels, the system was run with 250 N desired total warp tension at 25 m/min winding speed. Figure 10 shows the result. In this case too, total warp tension changed from 385 N (full beam, 0.30 m) to 415 N (partly empty beam, 0.18 m) despite 250 N desired total tension. Trend in warp tension curve indicates that there would be more increase in warp tension if the system run up to full empty beam (0.12 m). Running was stopped at 0.18 m diameter because of an electronic fault. As in 100 N total warp tension, warp tension level increased at a very significant amount (135 N) at full beam diameter when the desired tension was 250 N. Also warp tension increased from 385 to 415 N (30 N) at a smaller diameter change than the above figure. Speed was kept at 25 m/min in both 100 N and 250 N desired total tension running. A larger deviation from the desired total tension (250 N) can be related to higher load affecting to the bearings.

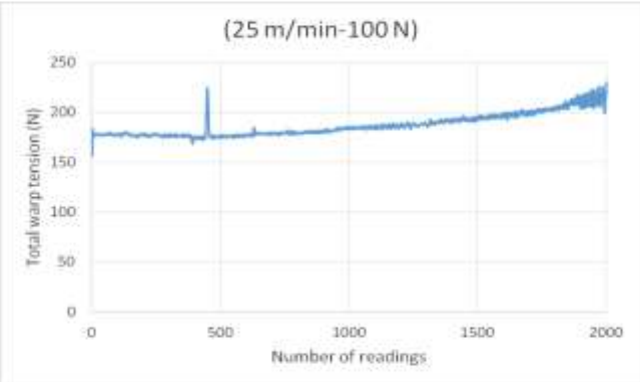

Figure 9. Total warp tension change with respec to number of readings from full to empty beam-100 N desired total tension

The above figures show that mechanical losses are dependent on warp tension level and they increased level of the tension as well as changing it with respect to warp beam diameter. The change in warp tension with decreasing warp beam diameter might be partly related to speed as warp beam speed increases with decreasing diameter. Torque balance for servomotor driven warp beam is shown in Figure 11. Moment (or torque) of warp tension (T_m.r) drives the beam and torque generated by servomotor (T.r) and torque representing mechanical losses oppose the motion of warp beam. Servomotor torque is calculated as the desired motor torque representing the moment of desired (constant) total warp tension. It decreases with decreasing beam diameter. Even though torque representing mechanical losses remains the same irrespective of speed and tension, actual tension will increase with decreasing beam diameter as torque corresponding to mechanical losses will form a larger portion of total opposing torque.

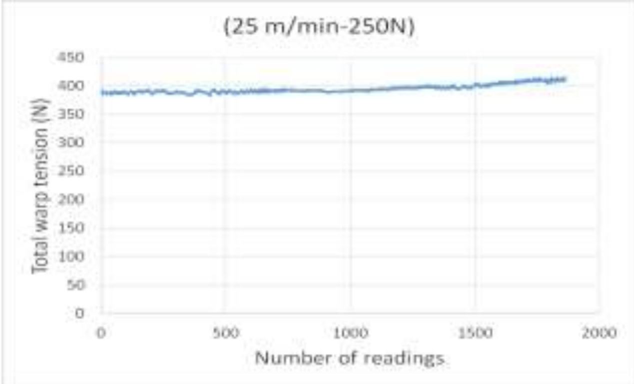

Figure 10. Total warp tension change with respect to number of readings from full to empty beam-250 N desired total tension

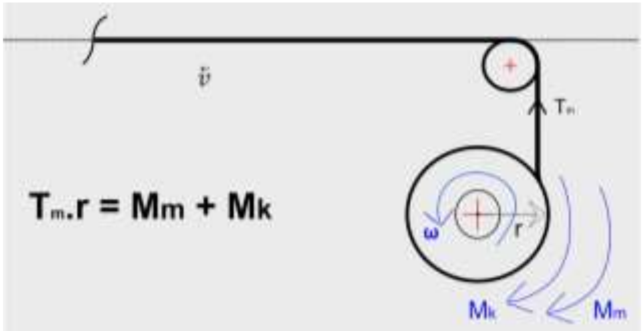

Figure 11. Servomotor warp beam moment (torque) balance during unwinding from servomotor driven warp beam

To eliminate the effect of mechanical losses, a torque signal representing mechanical losses was derived empirically based on the tension curve in Figure 10 as follows (Equation (12)). The torque signal calculated from Equation (12) was substracted from the tork signal calculated from Equation (6). This torque signal difference was applied to servomotor driver control unit as the desired torque control signal. Winding operation was carried out from full to empty beam with 250 N desired total warp tension at 25 m/min winding speed. Warp tension change with respect to number of reading from full (0.26 m diameter) to empty (0.135 m diameter) warp beam is seen in Figure 12. Around 10 N deviation was observed from full to almost empty beam. This shows that taking into account the mechanical losses enables tension control with 5% deviation limits. If the losses in mechanical motion transmission system is determined accurately, then warp tension can be controlled within acceptable deviation from the desired tension value.

ts_k=0.0583.(12+45.d) (12)

A further winding operation was carried out at 100 m/min winding speed and 250 N desired total warp tension using the same torque signal representing mechanical losses (Equation (12)). Warp tension change is seen in Figure 13. There is a slight increase in the warp tension level over 250 N at full beam diameter and a slight increase in warp tension up to empty warp beam. But deviation from the desired total warp tension is around 15 N. In this case too, warp tension can be controlled with 5-6% deviation limits. Increase in total warp tension with decreasing beam diameter is thought to be due to the speed dependent mechanica losses.

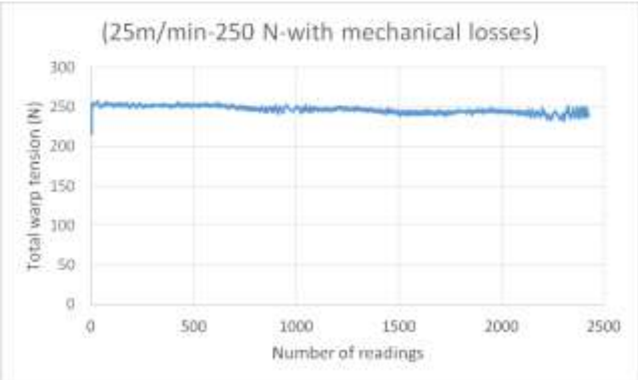

Figure 12. Total warp tension change with respect to number of readings from full to empty beam with mechanical losses included in the control signal-250 N desired total tension.

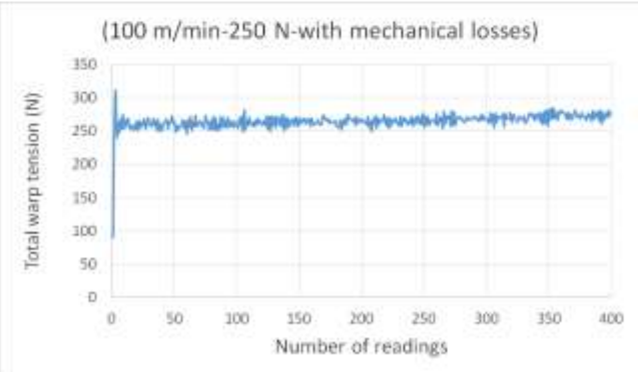

Figure 13. Total warp tension change with respect to number of readings from full to empty beam with mechanical losses included in the control signal-100 m/min winding speed

4. CONCLUSION

A sensorless tension control system for textile processes was investigated in this research. Control approach was based on torque control of a servomotor. A prototype system consisting of an induction motor and servomotor driven winding and unwinding units were designed and manufactured. Tension, winding length, warp beam diameters, motor angular speeds and torques produced by both motors were measured and continuously read and recorded by a PC. Speed and sensorless tension control algorithms were implemented by a real time software developed for this purpose. The following conclusions can be drawn from this research.

- A sensorless tension control caused a significant deviation from the desired tension value when mechanical losses were not taken into account. A higher deviation was observed at higher tensions. Around 135 N deviation occured with 250 N desired tension while it became 80 N with 100 N desired total warp tension.

- During unwinding from a warp beam (or fabric roller), tension drives the beam and servomotor torque and load torque representing mechanical losses oppose the motion and cause breaking effect. The higher the load torque representing mechanical losses the higher the tension deviation from its desired value.

- Higher deviation from the desired tension at higher tension levels indicate that mechanical losses are dependent on tension value.

- Research results show that mechanical losses in the motion transmission sytem should be very well determined covering whole running speed and tension interval. If the well determined mechanical losses are included in the sensorless control algorithms, warp or fabric tension can be controlled in textile processes accurately enough satisfying practical expectations.

- Warp beam diameter needs to be determined during the implementation of sensorless tension control algorithms. It was shown that warp beam diameter could be determined by using cheaper sensors like encoder and inductive switches with 2-3% deviation from laser sensor measurement.

- Further research is in progress regarding improving sensorless tension control accuracy and developing new control techniques.

Acknowledgement

Research pesented in this paper was produced from the results of a project supported by TUBITAK (Project no: 217M738). The author(s) express their sincere thanks to TUBITAK for the support.

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