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DESIGN AND REALISATION OF A YARN TENSION SENSOR USING STRAIN GAUGE TYPE LOAD CELLS

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Özge ÇELİK *

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Abstract: Yarn tension sensors are used extensively in industrial applications as well as in laboratories for research purpose. In many textile processes like warping, winding, unwinding and knitting, yarn is subjected to cyclic forcing due to motion of mechanisms and nature of the process. This causes a cyclic change in yarn tension and frequency of tension signal depends on process speed. Therefore, it is required that yarn tension sensor detects even small tension changes caused by the process and rejects higher frequency variations called noise. This paper examines the general techniques used in constructing yarn tension sensors and then explains the design and realisation of a yarn tension sensor using strain gauge type load cell. After constructing the sensor, tension measurements are carried out at different yarn speeds up to 800 m/min and tension signals are analysed. After comparing the measured tension signals with the tension signals recorded by a commercial tensiometer, some suggestions are given for improving the measurement precision of the developed yarn tension sensor at high speeds.

Keywords: Tension, Tension Sensor, Tension Measurement, Load Cell, Strain Gauge

Direnç Tipi Yük Hücresi Kullanılarak Bir İplik Gerginlik Sensörü Tasarımı ve Üretimi

Öz: İplik gerginlik sensörleri laboratuvarlarda araştırma amaçlı olduğu gibi endüstriyel uygulamalarda da oldukça yaygın olarak kullanılmaktadır. Örme, bobinden sağım, bobine sarım ve çözgü hazırlama gibi birçok tekstil prosesinde iplikler prosesin doğası ve mekanizmaların hareketinden dolayı tekrarlı zorlamalara maruz kalırlar. Bu durum iplik gerginliğinde tekrarlı değişimlere sebep olur ve gerginlik sinyali frekansı proses hızına bağlı olarak değişir. Bundan dolayı gerginlik sensörünün iplik gerginliğinde meydana gelen en küçük bir değişimi dahi algılaması ve gürültü olarak isimlendirilen daha yüksek frekanslı değişimleri sinyalden uzaklaştırması gerekmektedir. Bu makale iplik gerginlik sensörlerinde kullanılan genel teknikleri incelemekte ve daha sonra direnç esaslı yük hücreleri kullanılarak gerginlik sensör tasarım ve geliştirilmesini açıklamaktadır. Sensör geliştirilip üretildikten sonra 800 m/dak'ya kadar iplik hızlarında gerginlik ölçümleri gerçekleştirilmekte ve ölçülen gerginlik sinyalleri analiz edilmektedir. Çalışma kapsamında geliştirilen sensör ile bir ticari iplik gerginlik sensörü ile eş zamanlı yapılan gerginlik ölçümleri karşılaştırılmakta ve geliştirilen gerginlik sensörünün yüksek hızlarda daha hassas bir gerginlik ölçümü yapabilmesi için yapılması gereken iyileştirmeler öneri olarak verilmektedir.

Anahtar Kelimeler: Gerginlik, Gerginlik Sensörü, Gerginlik Ölçme, Yük Hücresi, Gerinim Ölçer

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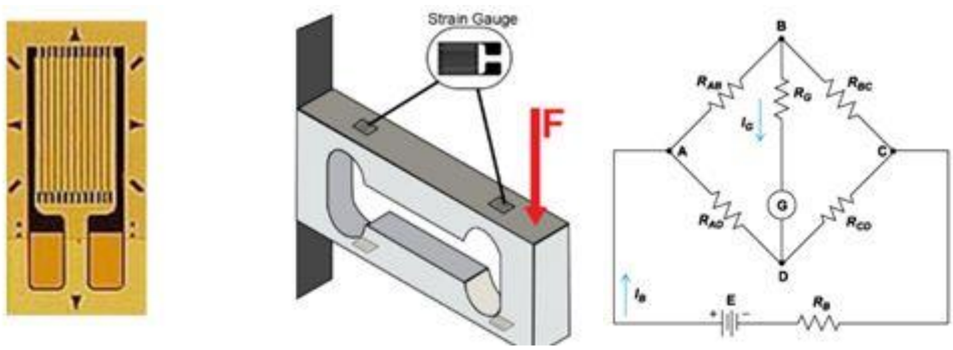
1. INTRODUCTION

Yarn tension is an important process parameter and it affects both process efficiency and product quality for many textile processes. Therefore, it is important to keep yarn tension in warping, weaving, knitting, winding etc. at the adjusted level from the beginning up to the end of the process for optimum process performance. This requires measurement of yarn tension. In practice, yarn tension is measured for two aims. First aim is to use the measured tension signal for automatic control purpose. In weaving, warping and winding processes, warp tension measurement is used as a part of a tension feedback control system. Many times, average yarn tension is sufficient for automatic control purpose. Second aim is to measure yarn tension variation, the maximum and minimum tension values etc. to analyze the effect of process parameters and machine mechanisms on it. In this case, tension sensor design should be done according to dynamic requirements and natural frequency of the tension sensor should be as high as possible to carry out a precise measurement at high speeds.

There are different physical principles and methods developed based on these principles used to measure yarn tension. These can be classified as contact and non-contact yarn tension measurement methods. Non-contact methods are in limited use in textile industry. Contact method of yarn tension measurement based on different physical principles dominates the textile industry and research field. Most widely used principle is to employ load cell with resistances called "strain gauge". As seen from Figure 1.a, yarn tension exerts a force to an elastic metal plate on which strain gauges are fixed. The metal plate is bent due to yarn tension affecting it in vertical direction and causes a resistance change in the strain gauges. This resistance change is converted to a voltage by Wheatstone bridge circuit (Figure 1.b). This output voltage is obtained in mV level (voltage measured between points 'B' and 'D'). It is then amplified and used as tension signal after calibration.



a. b.

Figure 1:

Yarn tension measurement principle using load cell with strain gauges

a. *A bending beam load cell with strain gauges **b**. Wheatstone bridge circuit (http://www.kyowa-ei.com/eng/download/technical/strain_gages/pdf_index_001_eng.pdf, 2019)*

Second approach to measure yarn tension is to employ capacitance change (Figure 2). In fact, the principle of yarn tension measurement by capacitive method is similar to that shown in Figure 1. Yarn tension acts in one end of an elastic metal element (whose other end is fixed to the frame) and bends it. Therefore, its free end displaces. A capacitance is formed by fixing its first plate to the free end of the metal plate and second plate to the sensor frame. Two capacitances are formed between the upper and middle plates and between the lower and middle plates. If middle plate moves upwards because of the yarn tension to be measured, the capacitance between upper and middle plates decreases due to decreasing air gap between them. But, the second capacitance between the lower and middle plates increases as the air gap between them increases. This capacitance change is converted to electrical signal and used as yarn tension signal after amplification and calibration process. Using two capacitance increases the sensor sensitivity.

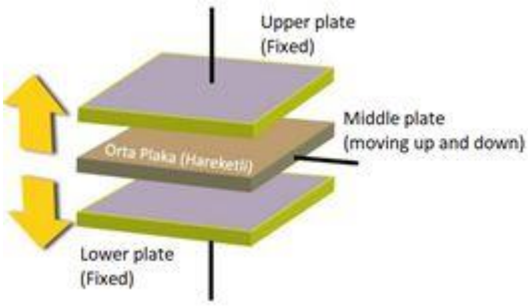


Figure 2:
Yarn tension measurement principle using capacitive method (http://kisi.deu.edu.tr//asli.ergun/4-Basinc%20Transduserleri.pdf, 2019)

Third approach is to measure yarn tension by using Hall effect sensor. In Hall effect sensing principle, a voltage is generated transversely to the current flow direction in a conductor if a magnetic field is applied perpendicular to the conductor (Figure 3). If a magnetic material is fixed to the bending end of an elastic metal element and current carrying conductor is fixed in the sensor frame, then the voltage generated changes with magnetic material approaching the conductor due to yarn tension. Change in voltage is amplified and used as yarn tension signal after calibration. It should be noted here that output voltage is produced in proportion to magnetic flux, but it changes non-linearly with the distance. This should be considered in sensor design. Distance is measured and then tension is determined from output of distance measurement sensor in capacitive and Hall effect methods. Optic sensors can also be considered for the same purpose.

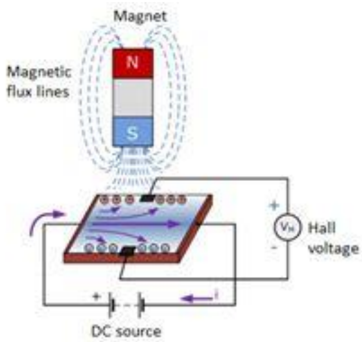


Figure 3:
Yarn tension measurement principle using Hall effect method (https://www.electronics-tutorials.ws/electromagnetism/hall-effect.html, 2019)

The above-mentioned methods require a contact of the yarn with pulleys, ceramic bar or a metal surface to measure yarn tension. This is not an ideal way to measure yarn tension as frictional forces affect the tension measurement. Measuring yarn tension by contactless means has always been a strong wish. Unfortunately, no contactless method became commercial for yarn tension measurement although some attempts were made to develop. Commercial contactless belt and wire tension measurement instruments are available for industrial use (https://www.hans-schmidt.com/en/produkt-details/belt-tension-meter-rtm-400/, 2019, https://news.thomasnet.com/fullstory/tension-measurement-device-targets-pre-stressed-wire-cable-574147, 2019, http://www.unitta.co.jp/data/support/pdf/u507_manual_e.pdf, 2019)

Academic research conducted on contactless yarn tension measurement for textile processes is explained in reference 4 and 5 (Vanijvongse, 2003 and Sanae, 2009). Also, another research is explained in reference 6 for contactless measurement of fixed and moving wires (Banitalebi et al., 2012).

In all these methods of contactless tension measurement, yarn, wire or belt is vibrated by a stimulus firstly and then frequency of vibration is measured by different methods using optics (laser), ultrasonic or magnetic sensors. Magnetic sensors are used for the tension of steel wires. Optic and ultrasonic sensors are employed in the case of belt and filament tension measurement. Tension calculation needs length and mass of vibrating wire, yarn or belt. After determining vibrating frequency, tension is calculated according to the following formula.

$$f(Hz) = \frac{n}{2L}\sqrt{\frac{T}{m/L}} \qquad (1)$$

$$T = m.L.(\frac{2f}{n})^2 \qquad (2)$$

Where;

T: Belt, yarn or wire tension (N)

f: Measured vibration frequency (Hz)

m: Mass of vibrating wire, belt or fiber (kg)

L: Length of vibrating wire, belt or fiber (m)

n: It is taken as “1” for fundamental resonant frequency.

When scientific and patent literature were reviewed, some more yarn tension measuring methods working on the above-mentioned contact and non-contact principles were found. They are shortly explained below.

Hartel et al. (1994) developed a tension sensor for especially winding and texturizing machines to measure yarn tension moving at high speeds. The sensor operates on magnetic principle and Hall effect or optical sensors are used as tension detecting method. Yarn moves with an angular contact to a yarn guide and applies a force to it. This force is balanced by a magnetic force. Position of the yarn guide is measured by a Hall effect or optical sensor. When there is an increase or a decrease occurring in yarn tension, yarn guide changes its position. Even a very small change in yarn guide position is detected by position sensor and current applied to electromagnet winding is adjusted to balance the force of yarn tension its initial position. As a very small position change is detected and magnetic force is adjusted, yarn guide position almost remains unchanged during tension measurement but current flowing through the winding of electromagnet changes in proportion to yarn tension. By measuring the electromagnet current yarn tension is determined.

Wessolowski et al. (1987) explains a yarn tension sensor design where optical detection principle is used. Yarn tension sensor has binocular type bending beam. At free end of it, a profiled light reflector unit is fixed. It moves together with the beam due to yarn tension. Inside a grooved part of the beam, a light emitter LED and an optical sensor is fixed and they do not move together with the binocular shaped beam. Depending on amount of yarn tension, beam's free end deflects at different amount and amount of light reaching the optical sensor changes. This change is converted to output voltage calibrated with respect to yarn tension. It is mentioned that the sensor can measure dynamic yarn tension up to few hundred Hz frequency.

Barat and Salles (1996) explains a contactless yarn tension and yarn speed sensor using capacitive principle. Three groups of capacitors are used in the sensor design and yarn moves at the adjusted speed between plates of the capacitors. There is a distance of "D" between the 1st and 3rd group capacitors. Any random signal is detected by the 3rd group capacitance Δt time lag after it is detected by the 1st capacitance. As "D" is a fixed distance and "Δt" is determined from the1st and 3rd group capacitance signals, yarn speed is calculated as $D/\Delta t$. Tension measurement is carried out by 2nd group capacitors signal. Second group capacitors consist of two capacitances and values of capacitances change in opposite way with the yarn position going up and down. As yarn oscillation and vibration between capacitance plates is dependent on yarn tension, it changes capacitance output signal and yarn tension is determined after conducting spectral analysis and finding fundamental modes and harmonics.

Bandara (2005) developed a contactless tension measurement sensor using optical principle. As shown in Figure 4, he uses two LEDs (30) as light emitter and light is reflected from yarn (O) on a lens (22) and directed to optical sensor (20). A CCD line camera or photodiode can be used as optical sensor. Yarn position is recorded and vibration frequency is calculated from the recorded data. Finally yarn tension is calculated from equation (2).

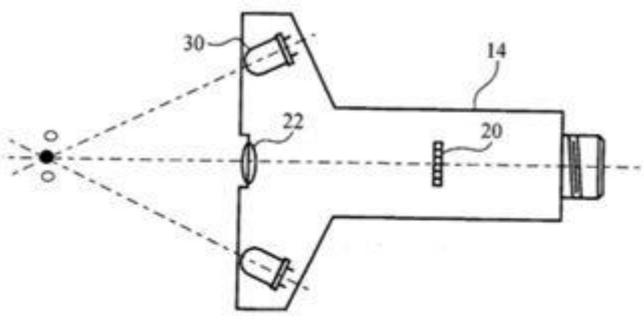


Figure 4:
Contactless yarn tension measurement sensor (Bandara, 2005)

Shankam et al. (2009) developed a wireless yarn tension sensor for measurement and control of yarn tension in direct cabling process. As shown in Figure 5, yarn passes through two ceramic eyelets and around a ceramic bar on which two semiconductor strain gauges are fixed. Semiconductor strain gauges are manufactured at very small size (at mm level) and has a very high sensitivity compared to conventional strain gauges. After design and manufacturing of the sensor, tests were performed at speeds up to 100 m/min and noise free measurement and wireless data transmission are reported about the performance of the sensor.

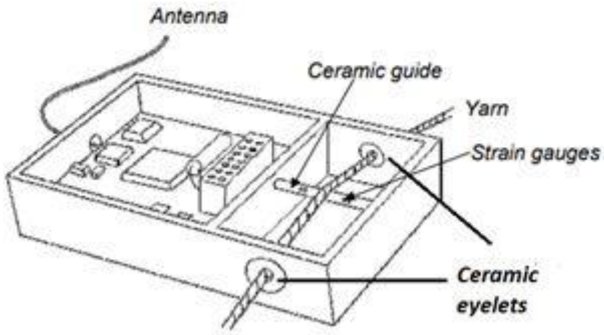


Figure 5:
Yarn tension sensor developed for direct cabling machine by using MEMSTh (micro electromechanical system, semiconductor straimn gauges) and wireless data transmission (Shankam et al.,2009)

Dynamic yarn tension measurement put more restrictions on yarn tension sensor design. As textile processing speeds increase, yarn tension sensors are expected to measure yarn tension at higher speeds which require designing tension sensors with higher natural frequencies. Contact type of tension sensors have an elastic member which induces some strain due to the yarn tension affecting on it. Also, a small displacement occurs at free end of bending beam as a result of the induced strain. As the elastic member has its own mass and also some additional mass like pulleys and yarn guides attached to it, yarn tension sensor forms a spring-mass system. Its natural frequency is dependent upon spring constant and value of mass. Higher natural frequency is obtained with higher spring constant (or rigidity) and lower mass. There is an upper limit for natural frequency with these methods. This is because elastic constant can not be increased too much for detecting yarn tension at sufficient sensitivity. Also some mass has to be added to the elastic element as yarn guide. It is recommended as a "rule of thumb" in yarn tension sensor design to determine measurement frequency as 1/10th of natural frequency for less than %1 error. Measurement error reaches to %10 levels with measurement frequency of 1/4th of natural frequency (https://www.hitecsensors.com/technical/frequency-response-of-sensors/, 2009).

There is some research in the literature combining capacitive and piezoelectric sensors to enable dynamic force measurement at much larger frequency interval. Castellini et al. (2002) combined a film layer of capacitance with a piezoelectric film to design a dynamic force sensor. It is reported that between DC to 8 kHz dynamic forces could be measured by this combined sensor. Forces from DC to 400 Hz was measured by capacitive sensor and higher frequency forces were measured by piezoelectric sensor (a thin film piezoelectric element, PVDF).

In another sensor design, Crescini and Crescini (2012) developed a yarn tension sensor using thick-film piezoresistive element fixed on a cantilever beam. Cantilever element covered with piezoresistive material had the size of 5x20x5 mm. Resistance change of resistive elements is converted to output voltage by a Wheatstone bridge circuit and then amplified to obtain tension signal. It was shown experimentally that the sensor had around 1 kHz natural frequency and it was reduced to 610 Hz when additional mass for yarn guide in tension measurement was added.

Although yarn tension sensors are widely used in industry, research centers and in universities, it is not manufactured in Turkey and imported from abroad. This paper makes an attempt to develop a yarn tension sensor using available strain gauge load cells in the market.

2. MATERIAL and METHOD

Sensor body was manufactured and load cells of different types and sizes were mounted on it. Then their performance was tested using a single unit creel and a winding unit. Yarn was drawn from a bobbin in the single unit creel at speeds changed between 50 and 800 m/min and yarn tension was recorded with 1.5 msec intervals. A commercial tensiometer was also used in the measurements and recorded yarn tension to compare the performance of the developed yarn tension sensor.

Figure 6 show yarn tension sensor design and mounting steps. Mechanical structure to which load cell is fixed is shown in Figure 6.a and load cell is mounted in Figure 6.b. Mechanical structure of yarn tension sensor is seen in Figure 6.c and Figure 6.d with pulley holders and finally pulleys mounted.

a.

b.

c.

d.

Figure 6:

Mechanical structure of yarn tension sensor

a. *Sensor body* ***b.*** *Load cell mounted to the sensor body* ***c.*** *Pulley holders are fixed to the sensor body and load cell* ***d.*** *Pulleys are mounted to yarn tension sensor*

Yarn passes around 3-pulley system as shown in Figure 7. Middle pulley is mounted to load cell and other pulleys are put on pulley holders fixed to sensor frame and can only rotate around their axis. Yarn passing around 3-pulley system exerts an upward resultant force due to its tension as shown in Figure 7. This force causes strain and therefore resistance change in load cell as explained above.

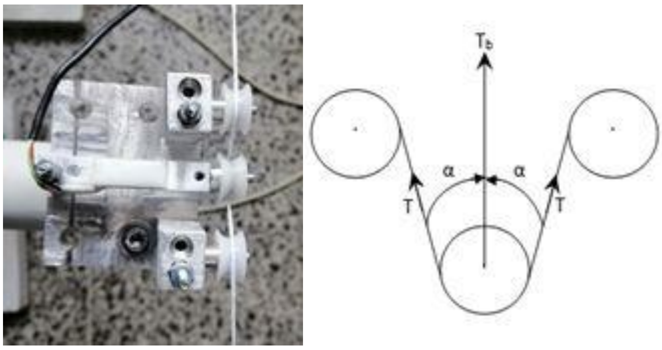


Figure 7:
Yarn passing around 3 pulleys of the sensor and resultant force (T_b) affecting middle pulley

$$T_b = 2Tcos\alpha \qquad (3)$$

Load cell output is connected to the amplifier circuit which is shown schematically in Figure 8. Technical parameters of the amplifier are given below the figure. Amplifier circuit has switch selectable analog output signals of 0-20 mA, 4-20 mA, 0-10 V, 0-5 V, ±10 V and ±5V. Output voltage was adjusted to 0-10V during this research.

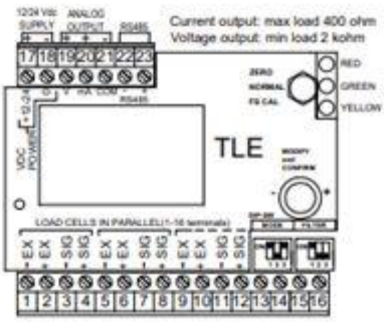


Figure 8:
Schematic view of the load cell amplifier

TECHNICAL FEATURES

Power supply and consumption: 12 - 24 VDC +/- 10% ; 3 W

No load cells in parallel and supply: max 8 (350 ohm) ; 5VDC/120mA

Linearity/Linearity of the analog output: < 0.01% Full Scale / < 0.01% F.S.

Thermal drift/Thermal drift of the analog out.:< 0.0005 % F.S. /°C < 0.003 % F.S. /°C

A/D converter: 24 bit (16000000 points) 4.8kHz

Max divisions (with measure range: +/- 10mV =2mV/V): ± 200000. Hz

Measure range: ± 39 mV

Max load cell's sensitivity: ± 7 mV/V

Max conversions per second: 300 conversions/sec

Digital filter/conversion rate: 0.003 ÷ 4 s / 10 ÷ 300

Serial port: RS485

Baud rate: 2400, 4800, 9600, 19200, 38400, 115200

Humidity (Condensate free): 85 %

Storage temperature: - 30°C + 80°C

Working temperature: - 20°C + 60°C

Performance of 2 different load cells were tested as yarn tension sensor according to the above design. Each load cell was calibrated by using 9 different dead weights. A linear calibration curve was obtained between the value of weights representing yarn tension and output voltage with a correlation coefficient of 0.9999 (R2). An experimental set up was used in the evaluation of performance of the developed tension sensors. As seen in Figure 9, the experimental set up consists of a single unit creel, a bobbin winding unit, 2 tension sensors, a DAQ card and a PC. Winding unit draws yarns from a bobbin in the creel and winds it on a new bobbin at adjustable speeds up to 800 m/min. One of two tension sensors is the developed tension sensor (Yarn tension sensor 2) and the other is a commercial tension sensor (Yarn tension sensor 1). Yarn tension changes cyclically during unwinding from a bobbin and amplitude of variation increases with increasing unwinding speed. By measuring yarn tension by the developed and commercial tension sensors in the experimental set up, it becomes possible to measure dynamic yarn tension to test and compare the performance of the developed tension sensor with the commercial one.

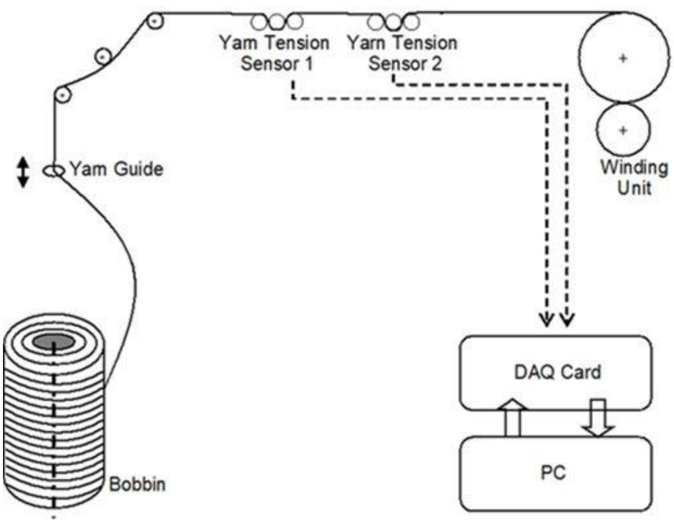
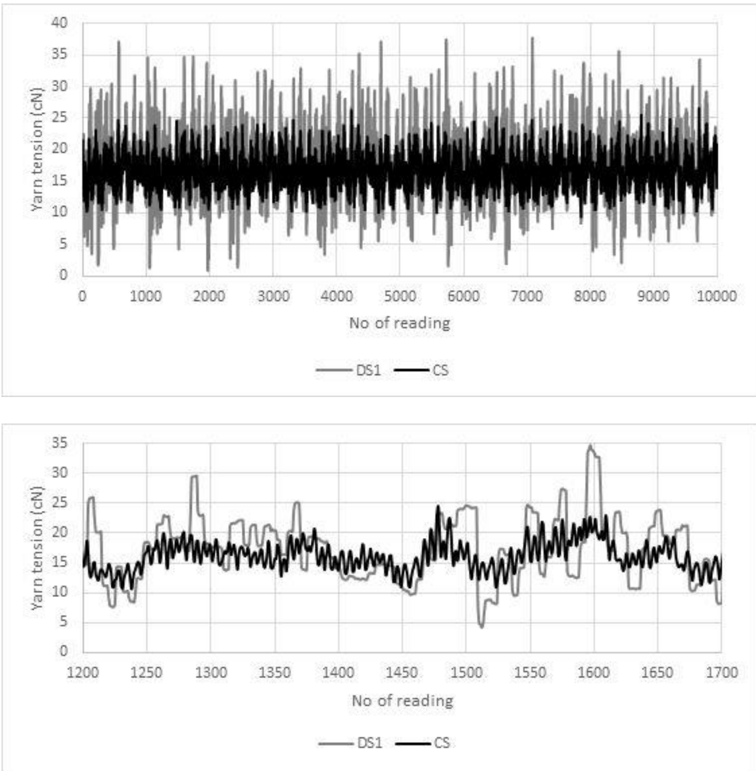


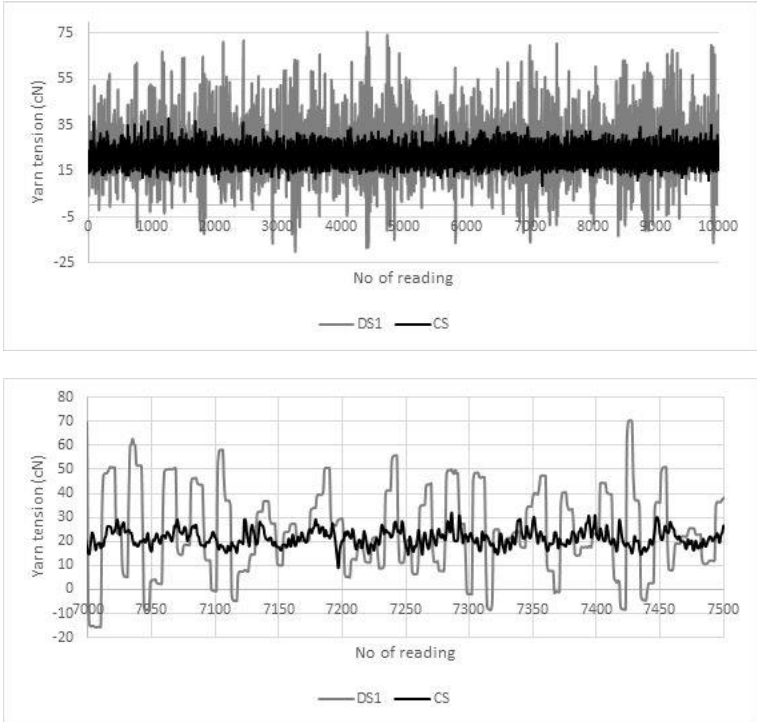
Figure 9:
The experimental set up

3. EXPERIMENTAL RESULTS

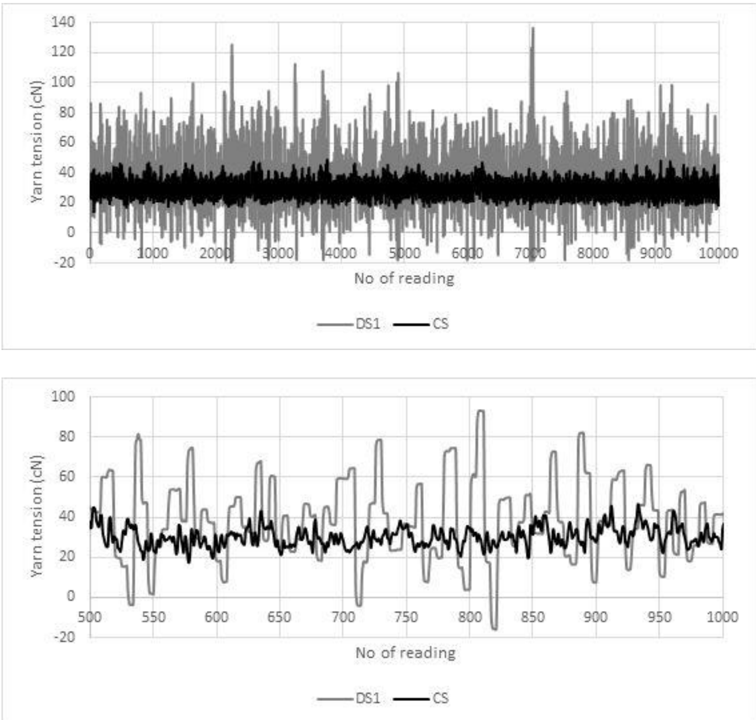
Experiments were carried out with 3 different yarn speeds of 100 m/min, 400 m/min and 800 m/min using the two developed sensors. These sensors will be named as the developed sensor 1 (DS1) and the developed sensor 2 (DS2). A more rigid and higher natural frequency load cell was used in the design of the developed sensor 2 (DS2). Figure 10 shows yarn tension measurement results taken at 100 m/min, 400 m/min and 800 m/min speeds by the commercial tension sensor (CS) and DS1 tension sensor. 10000 successive data are read and recorded. Upper tension curves represent tension changes with 10000 readings and the bottom ones show tension change in more detail with 500 tension readings. As seen from Figure 10.a, yarn tension curves of both sensors show a similar change at 100 m/min speed. But, the developed sensor (DS1) tension curve fluctuates more. At 400 and 800 m/min speeds (Figure 10.b and Figure 10.c), the developed sensor (DS1) tension curves differ significantly from those of the commercial one. Yarn tension fluctuates at a very significant amount at both 400 and 800 m/min speeds compared with the commercial sensor (CS). Because of these yarn tension fluctuations, average yarn tension difference between DS1 and commercial sensors increases together with increasing yarn speed (Figure 10.d). The difference reaches to %20-25 levels.



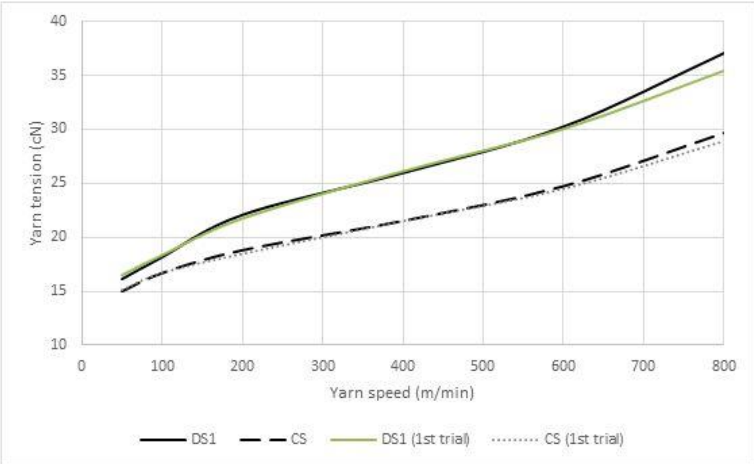
a.


Yarn tension (cN)
No of reading
DS1
CS
Yarn tension (cN)
No of reading
DS1
CS

b.


Yarn tension (cN)
No of reading
DS1
CS
Yarn tension (cN)
No of reading
DS1
CS

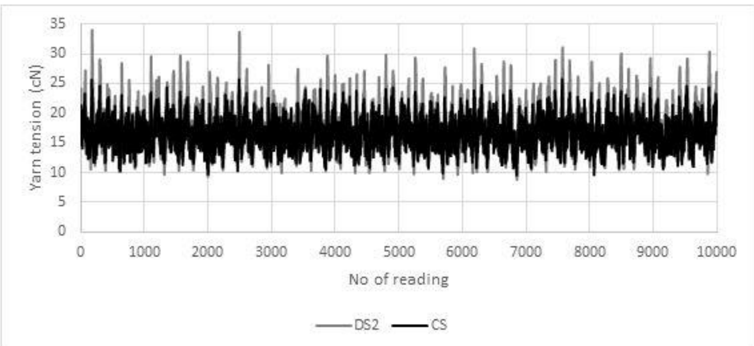
c.

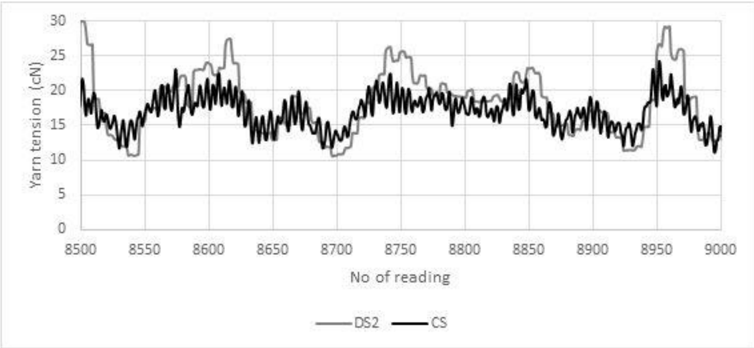


d.

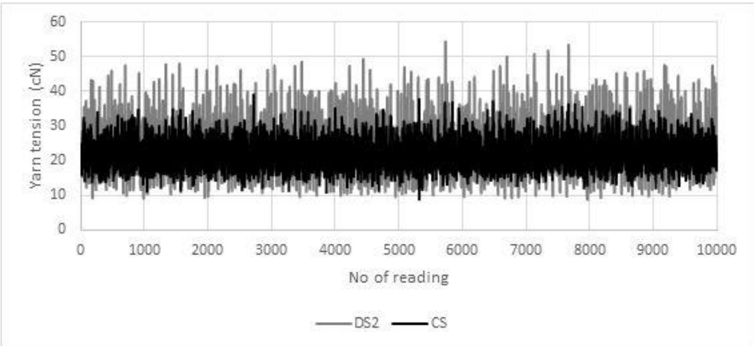
Figure 10:
Yarn tension measurement at different speed with DS1 and the commercial sensors
***a.** Yarn tension change at 100 m/min speed **b.** Yarn tension change at 400 m/min speed*
***c.** Yarn tension change at 800 m/min speed **d.** Average yarn tension change with respect to yarn speed*

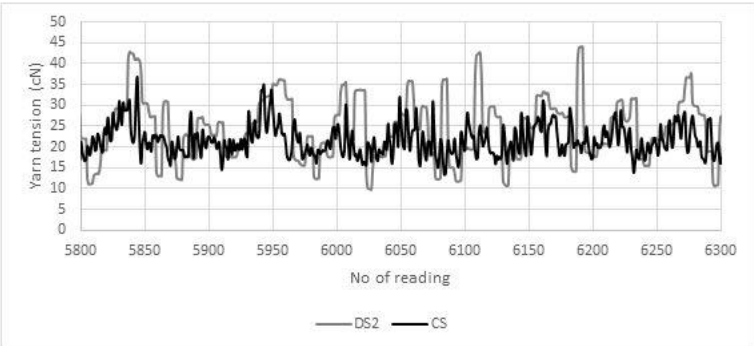
Figure 11 shows yarn tension measurement results taken at 100 m/min, 400 m/min and 800 m/min speeds by the commercial and DS2 tension sensors. Upper and bottom tension curves are as explained above. As seen from Figure 11.a, yarn tension curves of both sensor show a similar change at 100 m/min speed. But, the developed sensor (DS1) tension curve fluctuates more. At 400 m/min speed (Figure 11.b), SD2 tension measurement fluctuates much more compared to the commercial sensor (CS) but tension changes follow a similar curve. But at 800 m/min speed as shown in Figure 11.c, fluctuation of yarn tension curve of DS2 increases even further and also curve of tension change shows some deviation from that of the commercial one (CS). As in DS1 sensor, average yarn tension difference between DS2 and the commercial tension sensor increases with increasing yarn speed (Figure 11.d). The difference reaches to %20 levels at 800 m/min speed.



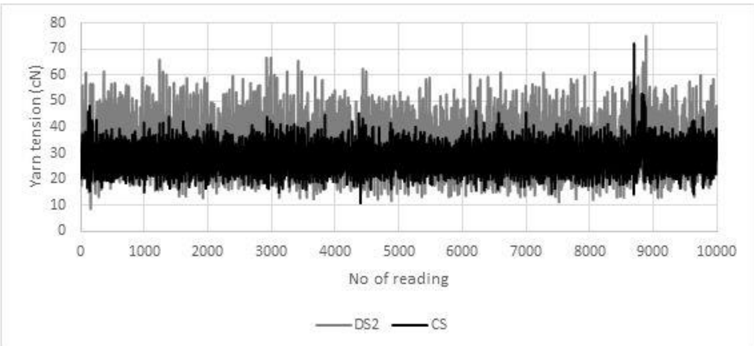

Yarn tension (cN)
No of reading
DS2
CS

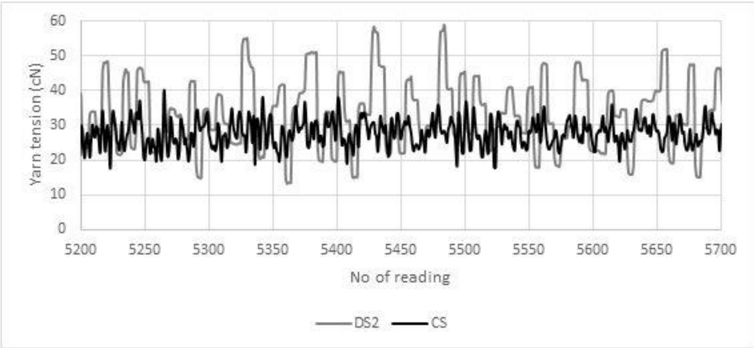
a.


Yarn tension (cN)
No of reading
DS2
CS

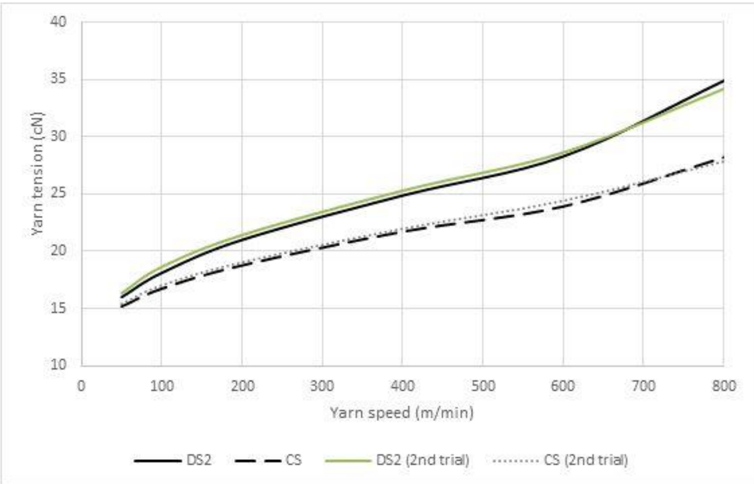

Yarn tension (cN)
No of reading
DS2
CS

b.


Yarn tension (cN)
No of reading
DS2
CS



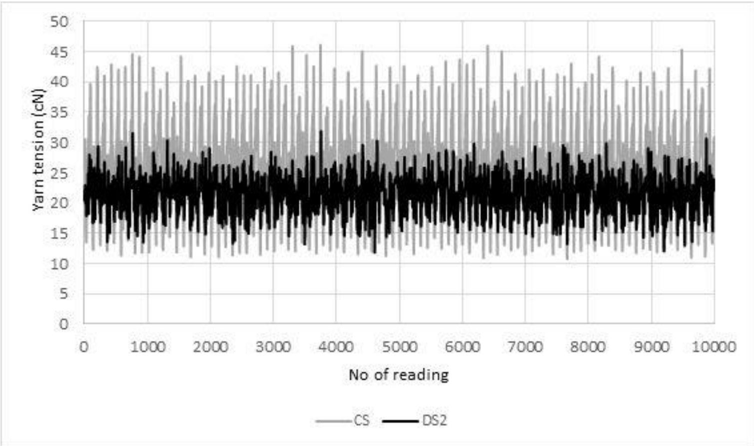
c.



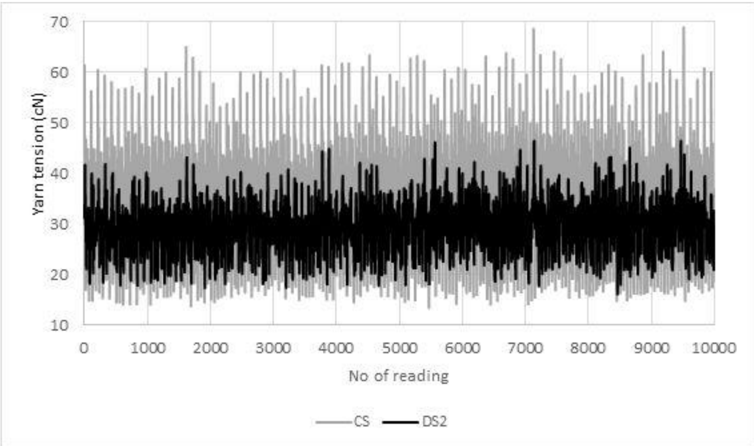
d.

Figure 11:
Yarn tension measurement at different speed with DS2 and the commercial sensors
***a.** Yarn tension change at 100 m/min speed **b.** Yarn tension change at 400 m/min speed*
***c.** Yarn tension change at 800 m/min speed **d.** Average yarn tension change with respect to yarn speed*

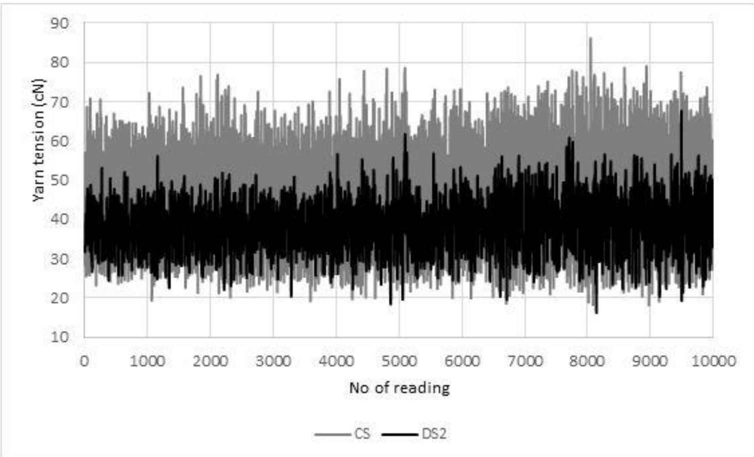
To understand the difference in yarn tension fluctuation between the commercial and developed sensors, positions of the developed sensor (DS2) and the commercial sensor (CS) changed (i.e., the developed sensor was positioned before the commercial sensor) and yarn tension measurements were carried out again. Figure 12 shows yarn tension change at 3 different speeds with the changed positions of CS and DS2 sensors. As seen from Figures 12.a, 12.b and 12.c, yarn tension measured by the commercial sensor (CS) fluctuates more at all speeds in contrast to Figure 10 and Figure 11 in which the commercial tension sensor is positioned before. Average yarn tension of the commercial sensor also increases more with increasing speed as in Figure 12.d. Around 4 cN tension difference is observed at 800 m/min yarn speed. This result shows that measurement position of yarn tension in the experimental set up affects yarn tension measurement results. Difference in tension fluctuation and increase in average tension value with yarn speed between the commercial and developed tension sensors are not caused by their design. As the distance between winding unit and the second sensor is long (around 5 m) and yarn oscillates during its motion, it is thought that this causes higher yarn tension fluctuation measured by the second tension sensor.


Yarn tension (cN)
No of reading
CS
DS2

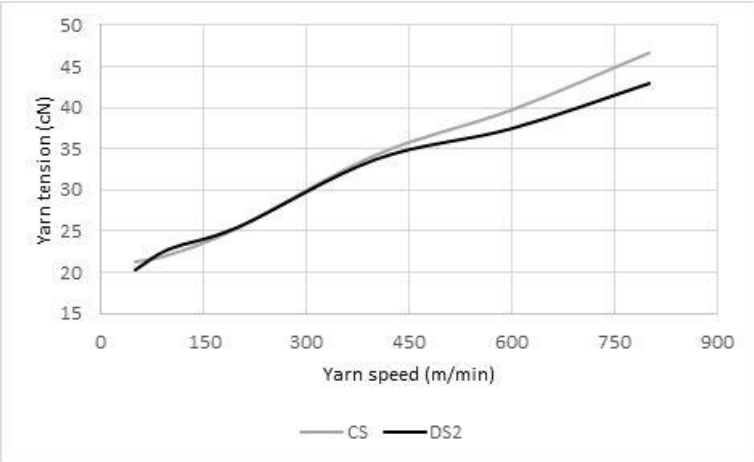
a.


Yarn tension (cN)
No of reading
CS
DS2

b.


Yarn tension (cN)
No of reading
CS
DS2

c.



d.

Figure 12:
Yarn tension measurement at different speed with DS2 and the commercial (CS) sensors
a. *Yarn tension change at 200 m/min speed* ***b.*** *Yarn tension change at 400 m/min speed*
c. *Yarn tension change at 800 m/min speed* ***d.*** *Average yarn tension change with respect to yarn speed*

4. CONCLUSION

An experimental study was carried out for the design and realization of yarn tension sensors. A detailed study was presented on the physical principles and methods used in the design of tension sensors and strain gauge type of load cell was preferred in this study as it is most widely used and easily found in the market. Sensor body was designed and manufactured firstly. Load cells of different size and features were mounted and 3-pulley measurement unit was added. An amplifier was used to amplify load cell signal.

As yarn tension changes dynamically in many textile process, an experimental set up previously developed in another project (consisting of one unwinding and one winding unit) was used and yarn was drawn and wound to a new bobbin at adjustable speeds up to 800 m/min.

One commercial and one newly developed tension sensor were added to experimental set up and measurements of two sensors were read and recorded by a DAQ unit and PC. Evaluation of tension measurement results showed a good match between the two developed sensors and the commercial sensor at low speed. As speed increased to 800 m/min, the tension curves differed. Also the tension sensor positioned to winding unit side (the tension sensor 2) measured yarn tension with higher fluctuations than the other. This was thought to be due to yarn tension fluctuation caused by yarn oscillations during its motion at higher speeds rather than measuring performance of the developed and commercial tension sensors. Comparing tension measurement results of the two developed sensors (named as DS1 and DS2), the DS2 sensor showed better agreement with the result of the commercial sensor. But at 800 m/min speed, the tension curve of DS2 sensor also differed from that of the commercial one. But, average tension values were obtained close to each other. Difference at higher speed was found to be due to the measurement position rather than tension measurement performance of the sensors. Hence the yarn tension sensors developed in this study can be used in yarn tension feedback control systems in many textile processes to measure average yarn tension. But some more research is required to obtain a precise tension measurement at higher speeds. For this purpose, mechanical design and manufacture of the tension sensor will be improved and load cells with higher natural frequency will be developed and used in the tension sensor.

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