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Effect of Knitted Loop Length on the Fluctuation Amplitude of Yarn Fed into a Circular Weft-Knitting Machine using a New Opto-Electro Device

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Abstract
The present paper investigates the effects of knitted loop length on yarn fluctuation amplitude during feeding into a circular knitting machine. Variation of yarn tension causes a change in the loop length and yarn fluctuation amplitude. In order to study the behaviour of the yarn fluctuation amplitude during the feeding process, a new optical IR electronic monitoring system was designed and developed. Experiments were carried out on an industrial single jersey knitting machine with a plain knitted pattern and polyester 150 denier continuous filament yarn for three different knitted loop lengths. Evaluating the fluctuation amplitudes recorded by analysis of variance revealed that an increase in the loop length will cause a highly significant decrease in the yarn fluctuation amplitude.

Key words: *knitted loop length, circular knitting machine, opto-electro monitoring system, IR sensor, yarn fluctuation.*

Introduction

Research on the dimensional properties of weft knitted fabrics started in the early 20th century. There are reports emphasising that the loop length will affect the knitted fabric dimension and other relevant properties such as the fabric weight [1 - 3].

In their literature survey Araújo, Catarino and Hong [4] mentioned that knitted fabric defects can be classified into two main categories, including horizontal and vertical variations. While the first category is mainly due to the loop length or yarn, the second is related to the knitting elements. Consequently in order to increase productivity and reduce cost and waste, the design and implementation of a monitoring system on industrial circular weft knitting machines is a crucial need.

With the objective of studying the loop length effect, different methods are used, each one exploring a specific approach. One of them is the inspection of knitted fabric as it is being produced. For that approach, vision and optical devices are used for detecting fabric defects, which basically search for a pattern on the fabric [5].

Another approach is to investigate the process control for total quality on circular knitting machines based on yarn input tension analysis [6].

Fluctuation variations in a mechanical system is simply counted as a measure of the state variation, hence it is very important to always consider such variations while monitoring the system's conditions and preventing future problems [7]. Due to the dynamic nature of the mechanical system's behavior, the machine's response to inside and outside stimulus forces or other disturbances will change the displacement, velocity and acceleration, etc. in various parts. Thus measurements of these parameters enables the recording of the trend of changes and the machine's state [8, 9]. Kazzaz and Singh [10] investigated the problem of fault detection using different signal processing techniques applied with vibration and current signals in the time or frequency domain. They suggested that signal analysis in the time domain provides a general and schematic view of faults, and that the frequency domain tends to be useful for details of fault detection. Orhan, Akturk and Celik [11] evaluated real machines with an experimental approach using fault detection of the outer ring and bearing clearance. In addition, Wang, Kang, Shen, Chang and Chung [12] applied a neural network approach for monitoring vibration conditions of circular machines and fault detection of an unbalanced bearing and its clearance.

The study presented addresses a new approach using yarn fluctuation analysis to investigate the effects of loop length variation during yarn feeding. This technique can also be used for maintenance prediction and the design of fault detection systems.

Fluctuation measurement system

In order to measure yarn fluctuations during feeding into a circular knitting machine, a system capable of recording

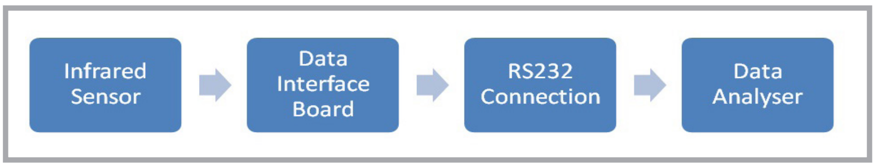

***Figure 1.** Schematic diagram of data acquisition and transfer process.*

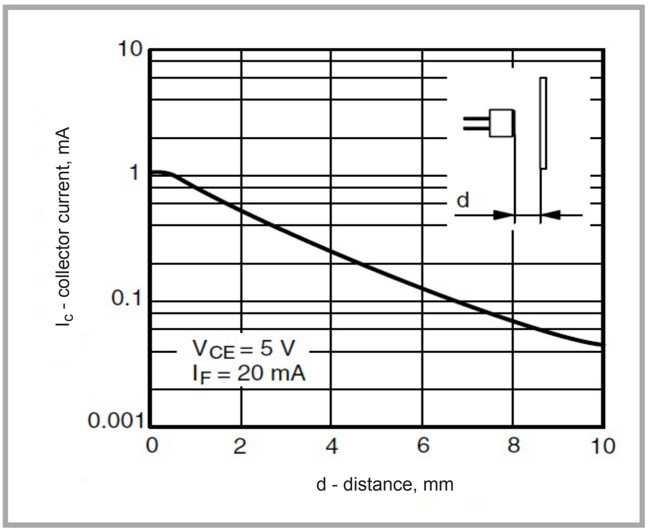

Figure 2. *Collector current vs. distance.*

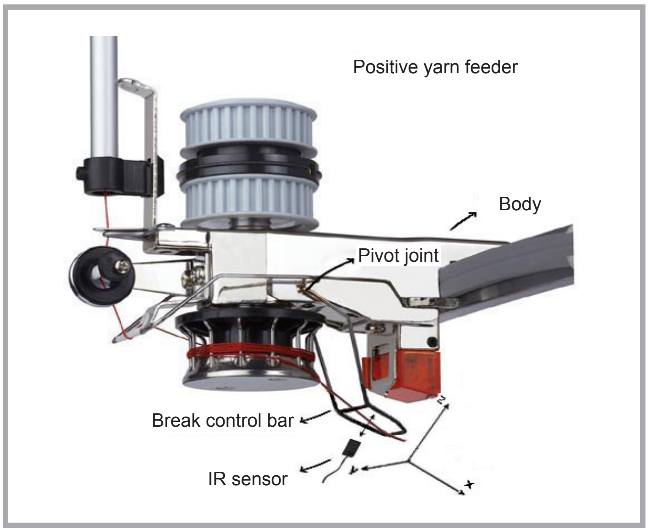

Figure 3. *Location of sensor relative to the yarn break control bar on the YZ plane.*

the fluctuation and transferring data to a PC was designed and developed. The system is able to display the fluctuation of yarn or any other mechanical components with considerable precision and no direct contact.

This system utilises an ATMEGA32 processor, where the voltage for the desired level and distance is provided by a CNY70 reflective infrared sensor, and then the processor converts the voltage values into (8-bit) digits. Data is transferred to the computer and stored by means of a RS232 connection. Meanwhile the data preparation task is carried out by MAX232. A schematic diagram of the data acquisition process is shown in ***Figure 1.***

MATLAB software is used for data collection and processing. By default, the system has a 1000 Hz sampling rate, adjustable by the program proposed.

As seen in ***Figure 2,*** in the range 0 to 0.5 mm, the current passing through the receiver reaches the maximum value and remains constant. Therefore the sensor is mounted so that it preserves the initial distance of 0.5 mm from the opposite test-bed. Respecting the limiting values in the diagram and the maximum yarn fluctuation amplitude, data collection is done within the accepted region of sensor operation.

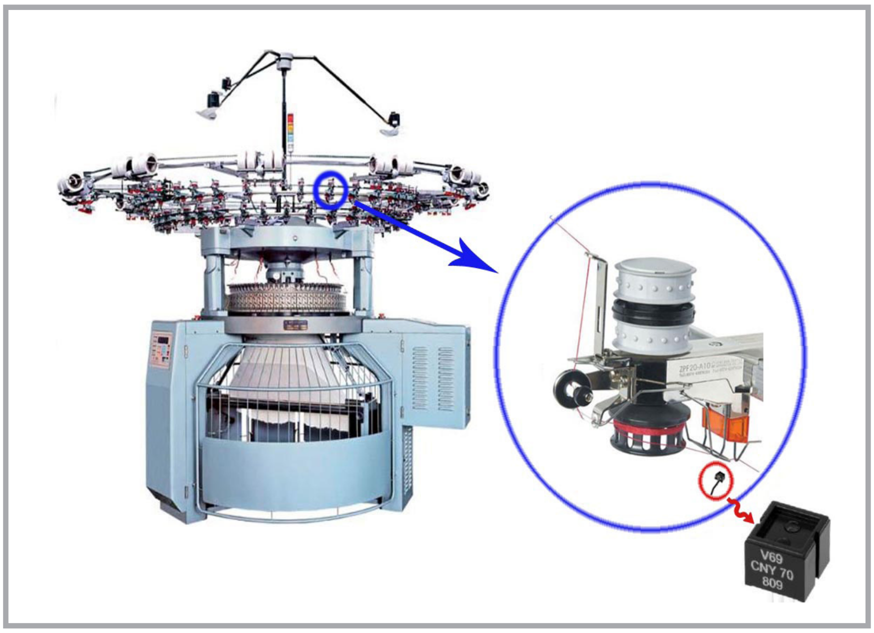

Figure 4. *Sensor and positive yarn locations on an industrial circular knitting machine.*

System installation - location

The IR sensor was installed on a fixture solidly fixed to the body of the positive yarn feeder on an industrial knitting machine, measuring the orthogonal projection on the Z axis of the last yarn break control bar's (This bar is pivoted to the body of the positive yarn feeder) fluctuation amplitudes, as shown in ***Figure 3,*** in relation to the sensor's position fixed on the YZ plane. Since the last yarn break control bar is in complete contact with the yarn, any radial displacement of this bar is due to yarn movement flow during feeding to the knitting machine.

The sensor can be installed on any (or all of) positive yarn feeders of a circular knitting machine, to allow direct monitoring of yarn variations in an individual cam box, see ***Figure 4.*** From the functional properties point of view, the good repeatability and reproducibility of results obtained under similar conditions may be referred to. Due to the particular design features of this optical sensor-based device, as well as the method and location of the installation, it does not interfere with the knitting machine's components, while a sensor only detects relative fluctuations of the yarn in relation to the positive yarn feeder's body and has no effect on yarn feeding movement.

Furthermore the system can be installed on all types of circular weft knitting machines running at different speeds, with no need for particular adjustments.

Material and methods

Knitting machine

All experiments were carried out on a single jersey circular knitting machine - model 2002 (WELLKNIT Co.), with 108 positive yarn feeders, 108 cams, 2734 needles and sinkers, 34” (0.864 m) cylinder diameter, and a top speed of 40 r.p.m.

The yarn used was polyester 150 denier continuous filament (because of its regularity) as raw material, which was knitted into plain fabric.

Data acquisition

In order to increase the confidence level of sampling, experiments were carried out simultaneously using two sensors. By default the sample rate was 1000 Hz (for the first sensor set up), but to increase the operation region a second sensor with a 500 Hz sampling rate was also used. Considering the test conditions above, data collected from each sensor were stored and referred to their corresponding frequency range.

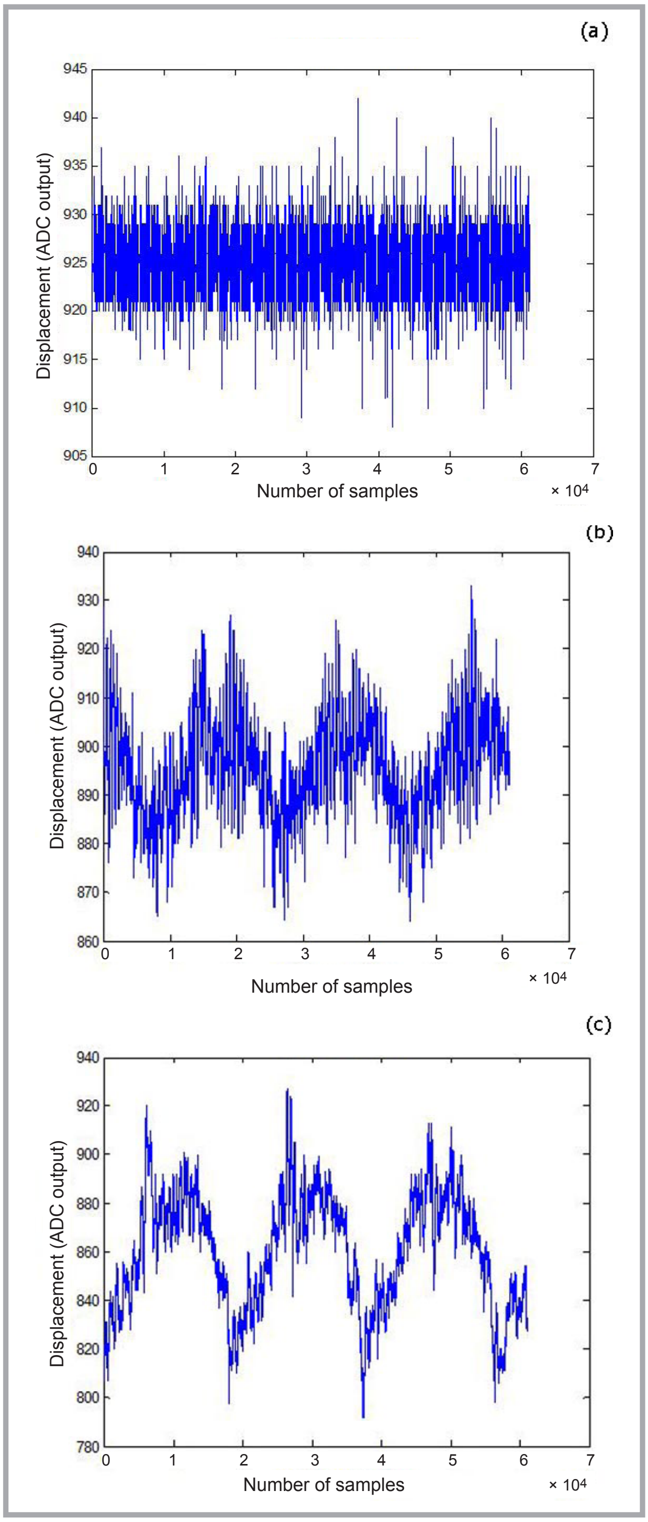

***Figure 5.** Raw signals collected by the sensor (500 Hz): a) 3.12 mm loop lengths, b) 2.20 mm loop lengths, c) 1.78 mm loop lengths.*

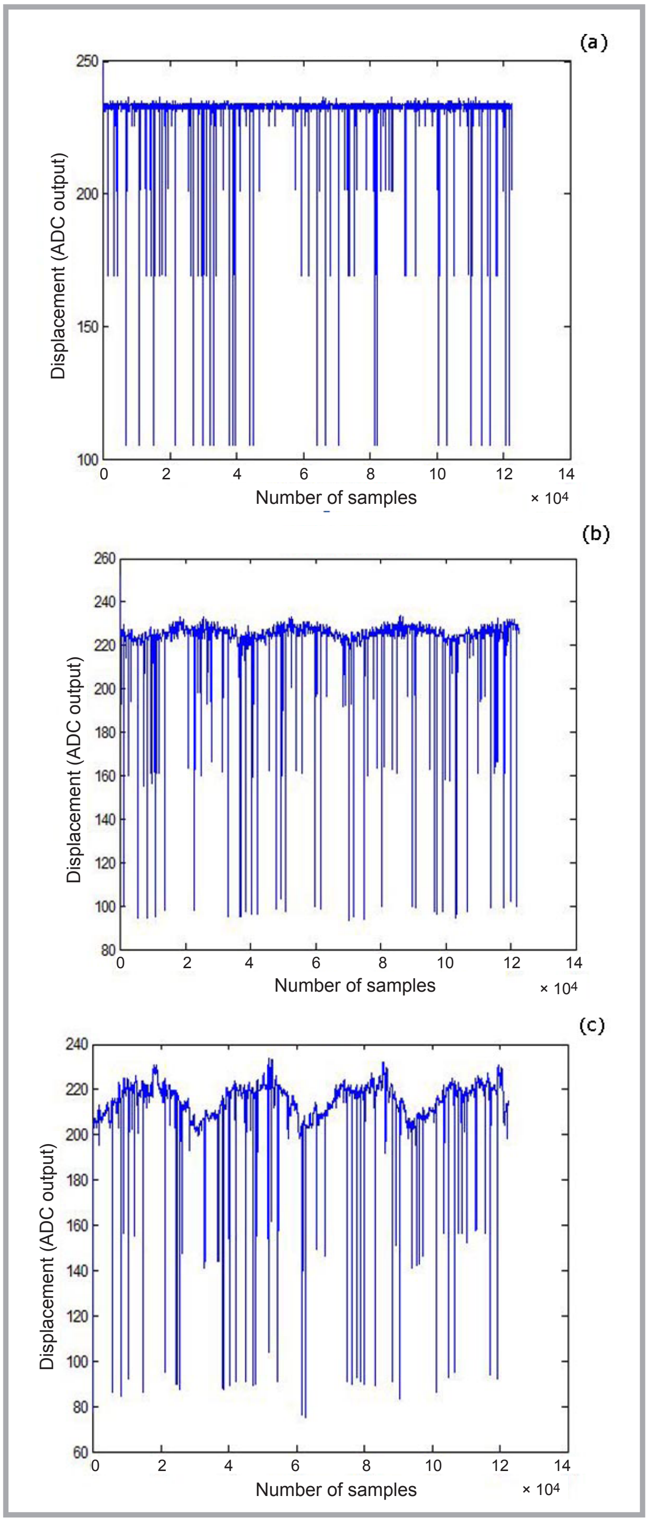

***Figure 6.** Raw signals collected by the sensor (1000 Hz): a) 3.12 mm loop lengths, b) 2.20 mm loop lengths, c) 1.78 mm loop lengths.*

Table 1. Raw value of ADC signals and related yarn tension values for three different loop lengths (500 Hz).

Loop length, mm	Surface mass, g/m^2	ADC output				Yarn tension, cN
		mean	range	minimum	maximum	
3.12	80.65	925.27	0.38	925.07	925.45	11 – 12
2.20	106.03	893.55	18.57	883.56	902.13	4.5 – 5.5
1.78	137.87	858.94	54.08	828.06	882.14	0.5 – 1.0

Table 2. Raw value of ADC signals and related yarn tension values for three different loop lengths (1000 Hz).

Loop length, mm	Surface mass, g/m^2	ADC output				Yarn tension, cN
		mean	range	minimum	maximum	
3.12	80.65	232.94	0.17	232.83	233.00	11 – 12
2.20	106.03	225.32	5.37	222.32	227.69	4.5 - 5.5
1.78	137.87	216.30	17.82	204.84	222.66	0.5 – 1

Table 3. Fluctuation amplitude (A) values for three different loop lengths (500 Hz).

Loop length, mm	N (number of samples)	ADC output (A)			
		mean	std. deviation	minimum	maximum
3.12	61,183	1.246	1.012	0.25	17.25
2.20	61,183	7.960	6.224	0.27	37.27
1.78	61,184	20.22	12.61	0.15	67.85
Total	**183,550**	**9.807**	**11.31**	**0.15**	**67.85**

Table 4. One-way ANOVA test for comparison of the mean of the yarn fluctuation amplitude (500 Hz).

	Sum of squares	Df	Mean square	F	Sig.
Between groups	11,320,000	2	5,660,850	85,381	0.000
Within groups	12,170,000	183,547	66.30		
Total	23,490,000	183,549			

Both sensors were placed in the same location on the positive yarn feeder, but each was plugged into a different PC. The experiments were performed and data recorded in parallel and simultaneously by both computer-aided systems.

Experiments

Experiments were conducted on a circular knitting machine with the speed set at 15 r.p.m., repeated 30 times. In each case data were recorded for variations in yarn fluctuation from both individual sensors. Using a stitch cam on the knitting machine, the loop length was changed at two different stages so that the length of the loop became smaller and larger in size in relation to the initial one. It should be noted that the positive feed rate of the yarn was kept constant for all three loop length adjustments.

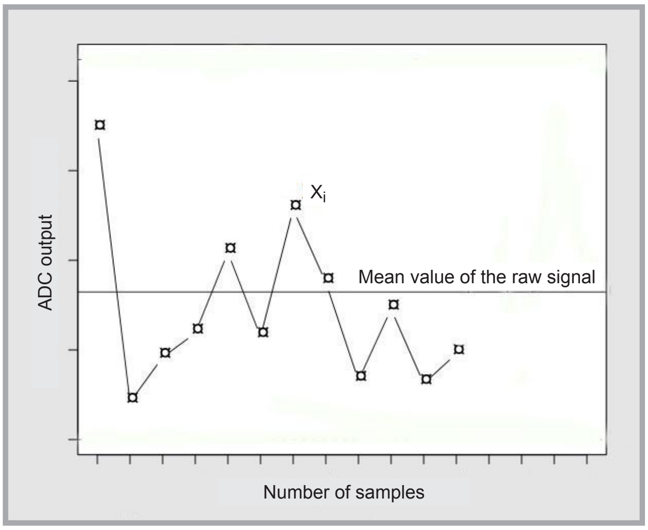

Figure 7. Schematic diagram of the raw ADC signal.

Figures 5 and 6 show typical examples of raw signals recorded. These data were recorded simultaneously by two sensors (with individual calibration set points) at 500 and 1000 Hz, respectively. The signals were collected from the machine during an industrial knitting process.

As yarn tension is one of the most important parameters to regulate the feeding of yarn on a knitting machine, a SCHMIDT tension meter (ZF2) was used to measure yarn tension for three adjusted loop lengths. The measurement was repeated 5 times.

As seen in ***Figures 5 and 6*** (see page 83) the displacement fluctuation is represented as raw signals recorded in accordance with the digital outputs of the A/D converter. In order to facilitate data analysis, the values obtained above will be classified as an index for yarn fluctuation.

Influence of environmental conditions

Many factors such as temperature, humidity, air conditioning, light intensity, machine vibrations etc., will, of course to different degrees, affect the accuracy of data collected during experiments. To avoid this, the following considerations were observed:

1. Experiments are designed so that in any condition a normal operational state is first selected based on an expert operator of the machine's assessment or the manufacturer's operational guide. Then the fluctuation of the break control bar is recorded and assigned as the system's normal signal. Any deviation of the signals collected from this condition is taken as a sign of a change in the normal condition.
2. During experiments all machine settings are kept constant. Only the loop length was allowed to change according to the order of experiments.
3. The sensor's position and location is selected so that only fluctuations of the break control bar are sensed in relation to the body of the positive yarn feeder. This will not allow any fluctuation or displacement of the machine to affect the measurements.
4. Two sensors with different sampling rates and setting points were used to check the validity of results and also examine the effect of probable exter-

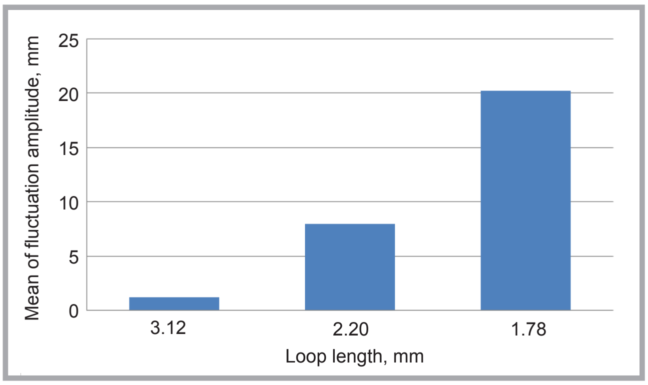

Figure 8. Relationship between the mean of the fluctuation amplitude and loop length (500 Hz).

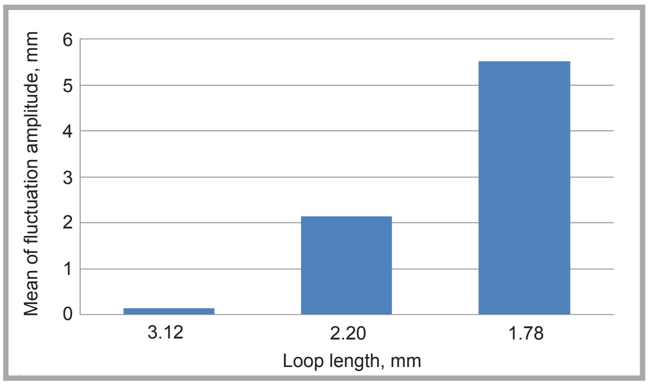

Figure 9. Relationship between the mean of the fluctuation amplitude and loop length (1000 Hz).

nal disturbances, including the data acquisition system.

5. Experiments were carried out maintaining similar environmental conditions for all tests.

Results and discussion

The results obtained from the yarn tension measurements recorded confirmed the loop length variations. These indicate significant variations in yarn tension when the loop length is changed.

Four criteria including the max, min, range and mean values of raw values of ADC signals recorded by each sensor and also yarn tension variations recorded for three loop lengths are represented in ***Tables 1 and 2***.

In order to evaluate the fluctuation amplitude (A) of the yarn in three different loop lengths, it is necessary to find the dispersion around the mean values of the raw signals. As shown in ***Figure 7***, the ADC value of each signal point on the signal variation curve is termed X_i; therefore A is calculated as follows:

$$A = |X_i - X_0| \quad (1)$$

where X_0 - mean value of the raw signal.

Then a comparison is made using one-way analysis of variance (ANOVA). ***Table 3*** summarizes the results of descriptive statistics for the fluctuation amplitude (A) of the 500 Hz sensor.

As shown in ***Table 3***, the mean value of the fluctuation amplitude (A), which shows the variations in yarn fluctuation, represents the lowest and greatest values for the longest and shortest loop lengths, respectively. It means that variations in the yarn fluctuation increases as the loop length decreases.

According to ***Table 4***, the yarn fluctuation amplitude is affected by the loop length. Therefore since the significant value 0.000 calculated is less than the significant level of 0.01, it can be said that at a 99 percent confidence level, the yarn fluctuation amplitude at three different loop lengths adjusted on the knitting machine is not the same and there are significant differences between the three groups. To determine such differences, Duncan's test was used, the results of which are listed in ***Table 5.***

Since three separate columns are assigned for the mean value of each group, it can be concluded that the yarn fluctuation amplitude (A) for each loop length is different. The variation in fluctuation amplitude against loop length for the 500 Hz sensor is plotted in ***Figure 8***.

A similar statistical analysis was performed for the fluctuation amplitude of the 1000 Hz sensor, the results of which are depicted in ***Tables 6 and 7.***

According to ***Table 7*** (see page 86) the significant value 0.000 calculated is less than the significance level of 0.01, thus it can be said that at a 99 percent confidence level the yarn fluctuation amplitude is not the same in each of the three loop length groups. ***Table 8*** (see page 86) shows the results of Duncan's test for the fluctuation amplitude of the 1000 Hz sensor.

Once again the results indicate that the mean values of yarn fluctuation for each loop length are different. See ***Figure 9.***

The variation trends of the fluctuation amplitude against loop length can be explained by vibrating-string theory. Methods which utilise the principle of a string vibrating at its resonant frequency for determining fiber fineness ("Vibroscope") or for monitoring thread tensions are well known in textile physics [13 - 16]. The equation expressing the physical relationship of thread fluctuation is written as follows:

Table 5. *Results of Duncan's test for mean values of the yarn fluctuations amplitude for three different loop lengths (500 Hz).*

Loop length, mm	N	Subset for alpha = 0.05		
		1	2	3
3.12	61,183	1.246		
2.20	61,183		7.960	
1.78	61,184			20.22
Sig.		1.000	1.000	1.000

Table 6. *Fluctuation amplitude (A) values for three different loop lengths (1000 Hz).*

Loop length, mm	N (Number of samples)	ADC output (A)			
		mean	std. deviation	minimum	maximum
3.12	122,880	0.144	2.267	0.06	127.9
2.20	122,880	2.147	2.926	0.37	132.6
1.78	122,880	5.520	4.271	0.45	139.4
Total	368,640	2.604	3.946	0.06	139.4

Table 7. *One-way ANOVA test for comparison of the mean of the yarn fluctuation amplitude (1000 Hz).*

	Sum of squares	Df	Mean square	F	Sig.
Between groups	1,814,812	2	907,406	85,224	0.000
Within groups	3,924,970	368,637	10.65		
Total	5,739,782	368,639			

Table 8. *Results of Duncan's test for the mean value of yarn fluctuation amplitude for three different loop lengths (1000 Hz).*

Loop length, mm	N	Subset for alpha = 0.05		
		1	2	3
3.12	122,880	0.144		
2.20	122,880		2.147	
1.78	122,880			5.520
Sig.		1.000	1.000	1.000

$$A = f\sqrt{\mu}/F \qquad (2)$$

In which ***F*** is the yarn tension, μ the yarn fineness, *f* the resonant frequency and ***A*** is the vibration amplitude [15, 16].

Based on ***Formula (2)***, with an increase in the yarn tension force, the amplitude of fluctuation (***A***) decreases. This hypothesis is in agreement with the result obtained in this work. As depicted in ***Tables 1 and 2***, with an increase in the loop length, the yarn tension increases, which, in turn, leads to a decrease in the fluctuation amplitude (***Tables 3*** & ***6, Figures 8*** & ***9***).

The results obtained using two sensors with two different frequency rates (500 & 1000 Hz) revealed that the system is highly reproducible and acceptable to record yarn fluctuations in the feeding zone of yarn on a knitting machine.

Conclusions

This research aimed to design, construct and install a new optical IR monitoring system in order to record fluctuations in yarn fed into industrial circular knitting machines and to investigate the effect of the knitted loop length on yarn movement flow. The system proposed is able to display low fluctuation of the break control bar and, consequently, yarn fluctuation with considerable precision, low error and non-direct contact. It was shown that the loop length exhibits an obvious influence on the fluctuation amplitude of the yarn being fed, as well as on its tension. The result shows that an increase in the loop length leads to a rise in yarn tension; while it decreases the fluctuation amplitude, which, in turn, would create a horizontal line defect over the knitted fabric surface. Based on the results of the analysis of variance, it was found that at a 99 percent confidence level there is a significant inverse relationship between the loop length and fluctuation amplitude. Also the statistical analysis revealed that there is no difference in the accuracy and efficiency of the 500 and 1000 Hz sensors, both achieving the same result trend at the maximum confidence level, which indicates the high capability of the sensors to record yarn fluctuations.

Finally it can be suggested to apply the system proposed, with slight modifications, as an appropriate monitoring system for fault detection on circular knitting machines. Compared to current fault detection systems, due to its particular design features and method of installation, the system designed and proposed does not interfere with the knitting machine's components and thus can provide useful information about fault detection during the knitting process.

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