Industrial Design of Yarn Speed Monitoring System in Positive Feed Circular Knitting Machine

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Abstract
As constant yarn feeding tension is essential in the formation of uniform stitches, the lack of a monitoring system in a circular weft knitting machine capable of measuring the uniformity of the yarn feeding speed in different driven belts and comparing the feeding rate during the knitting process has led to the use of experimental methods which are dependent on skilled operators. Additionally, in the case of any defects, the equalisation is done by the operator using the trial-and-error method, which consequently increases the risk of human error. Considering the importance of a uniform adjustment of yarn feeding speed on the quality of final fabrics, a monitoring system for measuring and reporting yarn feeding speed was designed. Following its installation on a circular weft knitting machine, the performance of the system in an industrial environment was evaluated. A comparison with the traditional system proved the functionality of the designed automation process. The current study highlights the characteristics of an appropriate sensor, the applicable installation place and direct data reception without intermediaries.

Keywords: circular weft knitting machine, positive yarn feeding system, automation, measuring system
1 Introduction

A positive feed device is a knitted loop-shape and loop-length control device which employs small pulleys moved by belts, gears etc. to exactly control the yarn feeding speed, keeping it constant.

Positive feed devices are designed to overcome loop-shape and loop-length variation by positively supplying yarn at the correct rate under low yarn tension to the knitting point instead of allowing the latch needles or loop-forming sinkers to draw loops the length of which could be affected by varying yarn input tension. In such systems, the presence of a continuous toothed belt, which is driven by a pulley, ensures the uniform and uninterrupted provision of yarn to each feeding unit. The tape speed is altered by adjusting the scrolled segments of the drive pulley (V.D.Q pulley) to produce a larger or smaller driving circumference.

The difference in feeding speeds in the pulleys of the positive feeding system causes a change in the tension of the yarn being fed and ultimately a difference in the length of loops and knitting dynamics [1–3].

The difference in the length of stitches makes the structure of knitted fabrics heterogeneous, which affects the appearance of the fabric in terms of its surface uniformity. Moreover, this unevenness is also visible on the surface of the final garment produced [4–6]. Additionally, the difference in the feeding speed of yarns prevents the yarns to be finished simultaneously in the creels, and as the operator has to change the yarn, it is time-consuming.

In a study conducted by Zhao et al., it was shown that the control of yarn tension fluctuations improves the uniformity of the fabric surface effectively [7].

In similar research, Catarino and his colleagues proved that the tension of the yarn provides useful insight into how to better control the circular knitting process in the machines. A change in the yarn feeding speed will increase or decrease the tension of the yarn, which can be recognised by the change in the vibration of the tension force [8–9].

The effect of machine speed on yarn input tension and course length was observed by Kobir [10].

Extensive research has been conducted on the automation of the yarn feeding mechanism in weaving machines and warp knitting machines, and several researchers have tried to equip these machines with control tools to increase production efficiency and improve the quality of the final product.

In their research, Jeddi et al. [11] measured the fluctuation and tension changes of warp yarn and were able to increase the efficiency of the weaving machine to obtain uniformity in the properties of the produced fabric.

Dayik and others [12] designed a program based on gene expression programming to control the yarn opening mechanism in the weaving machine. The application of this control system reduced warp tearing and increased the weaving efficiency.

Nosraty et al. [13] controlled the tension changes of weft yarns in the air jet weaving machine using an online system with a closed-loop control system and showed that by controlling tension in weft, the coefficient of variation belonging to the mechanical and physical properties of the produced fabrics significantly reduced.

In a circular weft knitting machine with a positive feeding mechanism, it is not easy to measure and compare the uniformity of the yarn feeding speed in different driven belts during the knitting process and it is usually conducted experimentally by a skilled operator. In the case of non-uniformity between the feeding speed of yarns, the equalisation is achieved
by a skilled operator via the trial-and-error method, which is highly associated with human error.

Accordingly, the importance of yarn feeding speed uniformity in the quality of the final fabric in knitting machines with a positive feeding mechanism has required the design of condition monitoring systems in these machines.

2 System design and construction

In processes where measurements are taken without standard systems and they only rely on the operator, the possibility of human error increases. These errors not only occur while taking the measurements, but they also happen during decision-making and result analysis. Errors can have an impact on quality, quantity, production efficiency, and safety and can sometimes cause life-threatening conditions.

The best results are obtained when the operator only has the supervisory and complementary role, while the measuring, processing, decision-making and result analysis are done under an integrated system. In an integrated and fully automatic system, the operator does not have an active role in system control and the measurement is taken online by the installed sensors. The output of the measurements is processed by the values that can be defined either by the operator or the system itself; the results, displayed on the screen, are sent to the operators and later modifications, if necessary, can be applied.

The fluctuations of key parameters in any mechanical system indicate the prevailing conditions of that system; consequently, it is necessary to be informed of such changes in order to monitor the state of the system and prevent the occurrence of defects or the creation of inconsistencies [14]. While designing and constructing the system, the choice of the right sensor is of particular importance. The sensor must have a timely response and provide the necessary outputs for processing. Additionally, noises and harmonics should not disturb its performance.

After examining and studying different types of sensors, it is critical to consider the superior property of proximity sensors, i.e. the ability to be used without causing mechanical interference, longer life span and lack of disruption. The usage of such sensors in the construction of the yarn feeding speed measuring system has also been taken into consideration.

At the same time, optical proximity sensors are also considered suitable candidates. However, since environmental pollution, e.g. dust, lint and vibrations, which are the byproduct of manufacturing, or the pollutants that occur during the cleaning, repairs, adjustments, are frequent in the production site, the possibility of disruption is high in these environments, which makes proximity sensors preferable over the optical type.

Activated by the presence of ferromagnetic material, inductive proximity sensors are minorly affected by environmental pollution. Additionally, the economical and cost-effective equipment is preferable for the speed-measuring system of positive yarn feeding.

2.1 Sensor installation location

In addition to not causing any disturbance in the normal function of the circular weft knitting machine, the efficient performance of the sensor should be guaranteed while designing the system. Investigations have proven that the bottom feed wheel of the positive yarn feeder is the best place to install the sensor, where the input coefficient of the yarn feeding speed can be measured directly.

A special base was needed for the installation of the sensor, which facilitated the installation on the feeder and also provided the possibility of adjusting the distance of the sensor. Figure 1 shows the view of the knitting machine. The positive yarn feeding mechanism is shown in Figure 2. Moreover, Figure 3 shows the installation location of the base on the industrial circular weft knitting machine as well as the installation location of the sensor on a positive feeder.
The system was designed and installed in a way that the assembly does not affect the structure of the knitting machine and no additional part disturbs the yarn flow while feeding. The sensor can be installed on any positive feeding unit in the knitting machine and can directly monitor the yarn feeding speed.
2.2 Data processing and display

Most circular weft knitting machines have a central control panel that acts as the human-machine interface. The control parameters of this panel include manual controls, e.g. turning the machine on and off, controlling the inverter and machine speed, controlling the brightness and operation of the fans, controlling air compression, and automatic panel controls, including stopping the machine in case of yarn breakage, stopping the machine in case of increase in temperature and oil pressure, stopping the machine when the main door of the machine is opened and stopping the machine at the end of the fabric take up.

The central electronic board of the system, capable of measuring and displaying the yarn feeding speed, is responsible for receiving and processing sensor signals, displaying the speed of yarns, receiving operator commands and generating alarm signals. The board includes a microcontroller programmed for the aforementioned purposes, a sensor isolator, speed display, setting input and an alarm driver.

The signal produced by the sensors is transferred to the central board of the device, which can by applying the necessary coefficients measure the speed of yarn feeding and display it on the screen in real time with the ability to select common speed units. In the Pulse Width Modulation (PWM) section of the microcontroller, the lack of speed coordination in different feeders can be detected and the amount will be displayed, which is accompanied by sound alarms to inform the operator.

The central electronic board uses a AVR AT-mega32 microcontroller, which has a counter with PWM capability and is used to detect the lack of speed coordination. Moreover, this microcontroller has an internal memory of FLASH type with the capability of storing the speed mismatch values. The FLASH memory has the ability to retain information even in the event of a power cut.

In order to connect the display, the remote device uses the standard RS485 serial communication of the microcontroller. In addition to applicability in long distances, RS485 communication is less effective against environmental noise, which makes it a better choice for industrial use. Furthermore, to minimise the effect of environmental noise on the performance of the central electronic board, an optocoupler is used to isolate the signals. The signal transmission from input to output is achieved by infrared radiation in optocouplers with no electrical connection, which eliminates the possibility of noise emission. Figure 4 shows the block diagram of the system and the central electronic board. Figure 5 shows the display panel of the monitoring system of the yarn feeding speed in a knitting machine.

![Figure 4: Block diagram of central electronic board of system for measuring and displaying yarn feeding speed in circular weft knitting machine](image-url)
2.3 Experiences

In order to measure the performance of the yarn speed monitoring system on an industrial circular weft knitting machine in actual working conditions, the system was installed on a Single Jersey knitting machine with a cylinder diameter of 34 inches, 26 gauges, 4 needle butts and 108 cams.

3 Results and discussion

3.1 Calculation of key performance and reliability indicators

In order to study the performance of the yarn feeding automation system, the reliability and maintenance indicators were compared in two 90-day production periods of the circular knitting machine.

The first period was performed without the presence of the automation system and the second period was performed with the presence of the yarn feeding monitoring system and under the same production conditions in terms of the type of texture, yarn count etc.

To monitor the reliability and maintainability of machines and equipment, several indicators are used in industrial engineering, and by measuring and comparing their trends, the effectiveness of the automation activities performed on the machines can be understood.

For this purpose, three well-known and widely used indicators in the maintenance and reliability of machines, including the mean time to repair (Equation 1), mean time between failures (Equation 2) and availability (Equation 3), were calculated and compared for two 90-day periods of tests on the knitting machine.

The most widely used indicator of maintainability is the mean time to repair, which expresses the average time required to perform a specific maintenance activity, adjustments or recovery, and is calculated with Equation 1 [16–18]:

\[
\bar{t}_R = \frac{\Sigma t_R}{\Sigma N_R}
\]  

where \( \bar{t}_R \) is time to repair, \( \Sigma t_R \) is total repair time or adjustment time, and \( \Sigma N_R \) is total number of repair.

Mean time to repair (and restore) is the average time that takes to repair each machine when a failure is discovered. \( t_R \) is calculated by adding the total time spent repairing and dividing that by the number of repairs.

To calculate the \( t_R \) indicator in this research, the number of times the machine was stopped due to the need of adjustments of the yarn feeding mechanism, as well as the time spent for each stop (in minutes), were recorded in two periods of 90-day tests on a circular knitting machine.

The announcement of the need to adjust the yarn feeding mechanism could be due to several reasons, e.g. the unevenness of the fabric surface due to the lack of uniformity in the feeding speed of the yarns or the announcement of changes in the fabric weight (grams per square meter of fabric) etc.
In the reliability analysis, the average time leading to failure is very useful and is calculated with Equation 2:

\[
\bar{t}_{BF} = \frac{(\Sigma t_{OH} - \Sigma t_{SH})}{\Sigma N_{TF}} \tag{2}
\]

where \( \bar{t}_{BF} \) is mean time between failures, \( \Sigma t_{OH} \) is total number of operational hours, \( \Sigma t_{SH} \) is total number of stop hours, and \( \Sigma N_{TF} \) is total number of failures.

The \( \bar{t}_{BF} \) indicator is one of the most important elements and indicators of product development and design. \( \bar{t}_{BF} \) indicates the average machine operating time until the next failure. In fact, this indicator shows the average operating time of the machine after a repair or adjustment and the need for repair or adjustment after the start-up.

In this research, \( \bar{t}_{BF} \) to calculate the indicator, the total working time of the knitting machine (in minutes) was recorded in each 90-day period with and without the presence of the yarn feeding automation system. Then, the total time of machine stops due to the adjustment of the feeding mechanism was calculated and deducted from the total time of machine operation. The numbers obtained in each period were divided by the number of times the knitting machine was stopped solely due to the adjustment of the feeding mechanism.

Availability is an important indicator that shows the accessibility of the machine. Availability is expressed as a ratio or percentage and is calculated with Equation 3:

\[
Availability = \frac{\bar{t}_{BF}}{\bar{t}_{BF} + \bar{t}_{R}} \tag{3}
\]

To calculate the indicators and the average machine stopping rate, the grading of the time unit is important. For this purpose, the unit of time in terms of minutes is used in the calculations. The results related to the calculation of indices are shown in Table 1.

**Table 1: Calculating reliability and maintenance indicators of knitting machine in presence and absence of yarn feeding speed automation system after period of 90 days of operation of knitting machine**

<table>
<thead>
<tr>
<th>Using system of measuring and displaying speed of yarn feeding</th>
<th>( \bar{t}_{R} ) (min)</th>
<th>( \bar{t}_{BF} ) (min)</th>
<th>Availability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>5</td>
<td>21595</td>
<td>99.97</td>
</tr>
<tr>
<td>No</td>
<td>15</td>
<td>10785</td>
<td>99.92</td>
</tr>
</tbody>
</table>

Based on the results obtained from the comparison of the \( \bar{t}_{R} \) indicator in two periods of tests by using the feeding speed monitoring system, the average machine stopping time to adjust the yarn feeding mechanism was reduced by 66.66%.

Examining the \( \bar{t}_{BF} \) indicator also shows a 100.2% improvement in the average continuous operating times of the knitting machine without the need to stop due to the adjustment of the feeding mechanism using the automation system to measure the yarn speed.

Stoppages generally occur due to the inaccuracy in the initial setting of the feeders by the operator, which was greatly reduced by using the yarn feeding automation system.

A comparison of indicators between two operating periods of the circular weft knitting machine in the presence and absence of the measurement system and the display of the yarn feeding speed indicate appropriate response of the reliability and maintenance indicators of the knitting machine to the designed automation process.

### 3.2 Economic analysis and calculation of machine production parameters and operator

Considering the importance of the uniformity of yarn feeding speed in circular weft knitting machine, the use of a speed monitoring system improved the production process and efficiency parameters, which leads to the reduction of production costs. Table 2 shows the state of improved production parameters (the numbers in the table are rounded).
Table 2: Improved parameters of machine and operator production

<table>
<thead>
<tr>
<th>Row</th>
<th>Parameter</th>
<th>Condition</th>
<th>Improvement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The amount of remaining yarn in the form of non-knit cones due to</td>
<td>Reduction</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>the lack of uniformity in the speed of feeders</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>The duration of the adjustment and equalisation of the speed of the</td>
<td>Reduction</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>positive yarn feeding system by the operator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Total production efficiency</td>
<td>Increase</td>
<td>0.3</td>
</tr>
</tbody>
</table>

4 Conclusion

In this research, a new system was designed and built to measure and display the yarn feeding speed in circular weft knitting machines. This system accurately measures and displays the yarn feeding speed in the positive feeding mechanism of knitting machines.

The results of the comparison between two 90-day test periods in the same production conditions with and without the presence of the measuring system and the display of the yarn feeding speed on the industrial knitting machine proved the successful application of the machine key performance and reliability indicators to the designed automation process.

One of the construction advantages of this automation system is its proper accuracy and cost-effectiveness, which makes its use in the status measurement of knitting machines possible without incurring exorbitant costs.

Another advantage of this system is that it does not affect the natural flow of yarn feeding and does not change the basic structure of the knitting machines. In addition, this system can be installed on any type of a circular weft knitting machine and at different speeds without any special settings. This feature indicates the possibility of upgrading and equipping the existing knitting machines with a yarn feeding automation system without the need for fundamental changes in their structure.

References


