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Real-time identification of yarn irregularities on the DTY machine through vibration monitoring

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Abstract
This paper presents an innovative real-time monitoring system for detecting yarn irregularities during the draw texturing process in the Drawn Textured Yarn (DTY) machine. The system uses advanced sensors to continuously measure vibration signals, which are then analyzed for anomalies. The system incorporates advanced sensors, controllers, and embedded software to continuously monitor vibration signals generated during the process. Fast Fourier Transform (FFT) in LabVIEW converts these vibration signals into their frequency-domain representation. This helps to identify anomalies that could indicate potential yarn irregularities. The results from the sensor data indicate that amplitude values serve as a reliable measure for detecting yarn irregularities. For normal spindles, the amplitude ranges on the Z axis start from 10.9 to 12.2 m/s², while abnormal spindles show significantly higher values, between 31.9 to 44.3 m/s². This distinction facilitates real-time classification of yarn quality. The system's ability to identify these amplitude variations promptly can significantly reduce waste and enhance quality control. Future developments will focus on integrating an intelligent early warning system that alerts operators immediately upon detecting irregularities, enabling quicker interventions and minimizing downtime.

Keywords:
DTY machines, yarn irregularity, data acquisition, machine performance, vibration, real-time monitoring.

1 Introduction

1.1 Background

A Draw Textured Yarn (DTY) machine (Fig. 1) is a specialized textile machine that transforms continuous filament yarn into textured yarn. This process enhances the yarn's bulk, elasticity, and overall aesthetic, making it suitable for various applications like knitwear, woven fabrics, and home textiles. There are several processes related to DTY machines, such as yarn preparation, texturizing, drawing, winding, and quality control. Yarn preparation begins by feeding continuous filament yarn into the machine, then carefully tensioning it to ensure uniformity during processing. Then, the yarn is twisted in a false-twist texturing machine, which imparts a temporary twist to create texture. The twisted yarn is then heated to set the twist, allowing it to retain the textured form once cooled [1].

The textured yarn is drawn (stretched) to increase strength and improve elasticity. This step also helps in aligning the fibers for better performance. Drawing speed and tension are carefully controlled at this stage to achieve desired properties. After the texturing and drawing process, the yarn is wound onto spools by rotating the spindles for packaging and distribution. The winding processes can also include additional checks for quality control.

Fig. 1. DTY machine.

Ensuring the high quality of yarn is paramount, as defects can lead to significant production inefficiencies and compromised product integrity. Traditional methods of yarn irregularity detection are often random and spontaneous and rely on post-production quality control. The quality inspection process humans conduct, introduces the potential for subjective judgments and errors. Factors such as fatigue, distraction, or variations in inspector training and experience can impact the consistency and reliability of inspection results [2].

The ability to detect and address yarn irregularity in real time during the DTY process is a critical advancement [3]. Real-time monitoring systems offer the potential to identify irregularities as they occur, allowing for immediate corrective actions, thus minimizing waste and maintaining consistent quality. Among the various indicators of yarn irregularity, vibration response has emerged as a key parameter. Variations in the vibration response of DTY machines can indicate issues such as x-stitch, broken filaments, and other anomalies that affect the yarn's quality [4].

1.2 Yarn Irregularities on DTY Machines

On DTY machines, yarn irregularities can significantly impact the quality of the final textured yarn. These irregularities can arise due to various factors during the texturing process. The main factors that cause yarn irregularities are machine settings, raw material quality, and maintenance issues. As an illustration, the normal (regular) and abnormal (irregular) yarn can be seen in Fig. 2 and Fig. 3.

Fig. 2. Normal (regular) yarn.

From the two images in Fig. 3, broken filaments and X-stitch (Xst) can be explained: Broken filaments in yarn can lead to several irregularities affecting yarn defects. Excessive mechanical tension during spinning or weaving can cause broken filaments. Low-quality fibers or inconsistent fiber lengths can lead to increased breakage. Other causes come from environmental factors such as humidity and temperature fluctuations affecting the integrity of the fiber and leading to breaks.

X-stitch is a term used to describe a specific defect in yarn where two or more filaments cross over each other, creating an "X" shape. This defect can occur during the spinning or weaving processes, leading to various issues in the finished fabric. Issues during the spinning process, such as incorrect tension or vibration due to misalignment, can lead to filaments crossing over one another. This defect is also caused by faulty or poorly calibrated machinery, which causes yarn to twist or cross in unintended ways. The characteristics of the fibers, such as elasticity or twist, can influence their behavior during production.

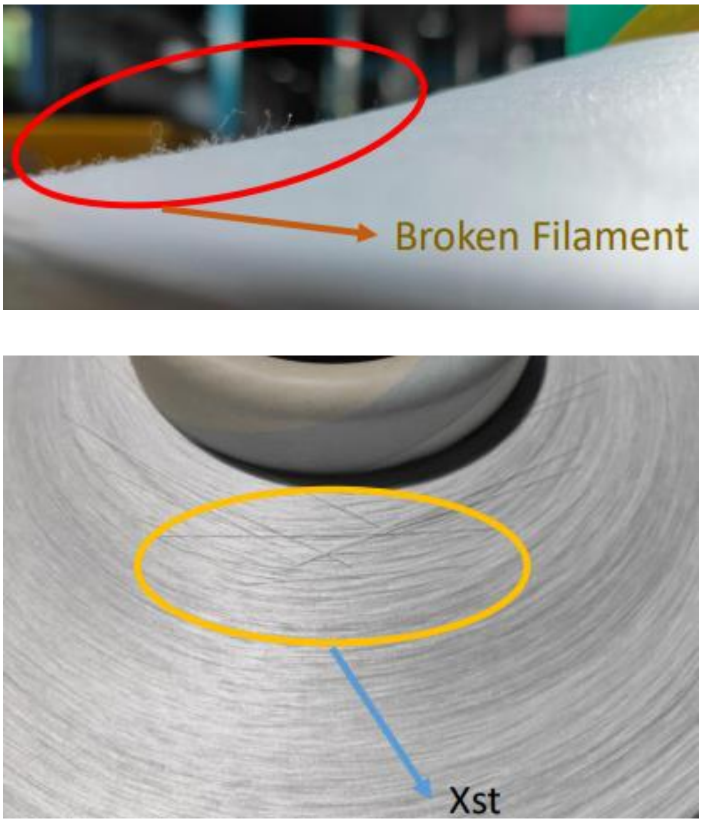

Fig. 3. The common type of irregular yarn.

In this study, both types of yarn irregularities were obtained based on the results of field observations on machines with the specifications described in Table 1.

Table 1. The type of DTY machines as research object

Specifications	Description
Model	MC DTY
Type	MURATA 33 H
Manufacturer	Japan
Production year	1990
Start operating	1990-now
Capacity/month	95-100 tons

Based on observations on the machine, data was obtained to be used as a reference in this study, so that measurements of the difference in vibration on normal and abnormal spindles can be placed at the right point.

1.3 Previous Works

Previous research closely related to the development of this system for measuring and analyzing DTY machine vibration signals was conducted several years ago. Research in 2011 on rotating machinery used the Fast Fourier Transform (FFT) and Wavelet Transform (WT) for better analysis of non-stationary signals, allowing local analysis and revealing hidden aspects of the data and describes the test rig used for studying blade and shaft vibrations, including the equipment and data acquisition methods [5].

In addition, FFT helps us analyze the frequency components of vibration signals in high-speed spindles. The system can identify and predict abnormal vibrations for early predictive maintenance. All vibration data is stored in a MySQL database and analyzed to improve spindle performance and maintenance [6]. Another technique for performing predictive and preventive maintenance on textile machines is using fuzzy logic and vibration monitoring to plan maintenance actions [7]. It also uses wavelet analysis combined with artificial neural networks and fuzzy techniques to provide more precise results in fault diagnostics [8].

However, the most recent study about vibration detection in machinery uses vibration sensors (ADXL345), a rotating speed sensor (TCRT5000), Arduino, and node-MCU for wireless data transmission. LabVIEW software displays and analyzes the vibration data in real time, with features for a graphical interface, alarm indication, and data logging [9]. Other researchers enhanced the techniques by utilizing Arduino and MATLAB for data processing and acquisition [10], and the most recent researcher used Raspberry Pi, which data displayed on a custom-built website [11].

1.4 Review and Research Questions

A comprehensive review of current literature on addressing yarn defect problems is being conducted along with developing various systems. One of the significant findings is the research to analyze and differentiate vibration responses originating from the draw texturing process indicators of yarn irregularities in DTY machines has yet to be carried out, either in the past or at present. Then, research questions can be asked, including how to design a sensor that can detect small changes in vibration patterns and how to assess and analyze real-time vibration data and relate it to the emergence of yarn irregularities as the beginning of defects, and other questions that will be answered in this research.

1.5 Objectives

This research aims to obtain a prototype of an early detection system, consisting of smart sensors, controllers, and embedded software to acquire, process, and analyze real-time vibration responses on DTY machines. There are some objectives to be achieved: to develop a sensor-based system to measure vibration quantities in the spindle axis of the DTY machine; and to compare the normal and abnormal vibration characteristics, which affect the emergence of yarn irregularities in the draw texturing process.

2 Materials and Methods

2.1 Materials

2.1.1 Vibration Meter

A vibration meter is used as a comparison as well as to calibrate the measurement results (data acquisition) from the sensor to be used. The type of vibration meter used are Lutron VB-8200 and Showa Sokki Digi Vibro 1332B (Fig. 4).

The Lutron VB-8200 has an acceleration measurement range of 0.5 to 199.9 m/s^2 and a velocity of 0.5 to 199.9 mm/s. Then the Showa Sokki has an acceleration measurement range of 0.01 to 199.9 m/s^2 and a velocity of 0.01 to 199.9 mm/s.

Fig. 4. Vibration Meter Lutron VB-8200 and Showa Sokki Digi Vibro 1332B.

2.1.2 ADXL Sensor

The ADXL sensor refers to a family of accelerometers made by Analog Devices. These sensors are commonly used for measuring acceleration, both static (like gravity) and dynamic (such as movement, vibration, or tilt). Different models are available, with various features and specifications [12]. The ADXL345 in Fig. 5 is a specific model in this family, which is a small, low-power, 3-axis accelerometer.

Fig. 5. ADXL345 sensor.

2.1.3 Arduino Nano

The Arduino Nano is a small, breadboard-friendly microcontroller board based on the ATmega328 (or ATmega168 in older versions). It is a popular choice for embedded systems and small-scale projects due to its compact size and ease of use. The Nano in Fig. 6 is similar to the Arduino Uno in terms of functionality but is much smaller, making it ideal for projects where space is a constraint [13].

Fig. 6. Arduino Nano.

The Arduino Nano is widely used due to its small form factor and compatibility with the larger Arduino ecosystem, including software (Arduino IDE) and libraries. It's an excellent choice for students, hobbyists, and professionals working on small electronics projects.

2.1.4 LabVIEW

Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is a graphical programming environment developed by National Instruments (NI), primarily used for data acquisition, instrument control, and industrial automation. Unlike traditional text-based programming languages, LabVIEW uses a visual programming language where developers create programs by connecting functional blocks (also known as Virtual Instruments, or VIs) that represent data flow.

LabVIEW is widely used in industries like aerospace, automotive, electronics, and research labs for tasks such as automated testing, process control, and data logging.

2.2 Method

The experimental setup on the DTY machine to acquire vibration response data was conducted by mounting an ADXL345 accelerometer sensor [14], [15] on the spindle arm/yarn guide and calibrated using data from the Lutron VB-8200 Vibration Meter and Showa Sokki Digi Vibro 1332B (Fig. 7). This sensor was connected to an Arduino Nano and LabVIEW as a graphical programming environment was then used for data acquisition. Fig. 8 depicts the block diagram related to the developed system.

Fig. 7. Calibration process using Lutron VB-8200 Vibration Meter.

According to Fig. 8, this experiment will collect vibration response data for various sensor positions on the spindle arm of DTY machine. This data is then further processed into a data presentation in the frequency domain. These vibration responses will indicate regular or irregular yarns in the draw texturing process.

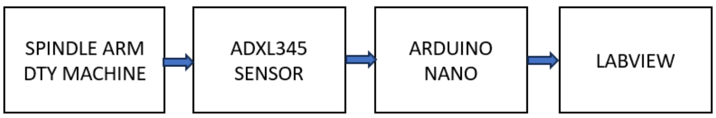

Fig. 8. Block diagram of the system.

Fig. 9 illustrates specifically how the sensor is mounted on the DTY machines.

Furthermore, the experiment was conducted in the stages: (1) the data collection technique is based on a long yarn winding cycle that lasts 8 hours from the beginning of the yarn being rolled until the finish, (2) data collection was carried out at 4 normal spindle points and 4 abnormal spindle points, (3) place the ADXL345 sensor at a position where the yarn output is normal/regular and also abnormal/irregular (Fig. 9), then collect the data, (4) ADXL sensor data is transferred to Arduino with 1024 samples in 1 minute at 100 Hz (frequency sampling), then the data is processed using FFT in LabVIEW and displayed as 512 real data on the X, Y, and Z axis. Specifically, how the experimental steps are carried out and the data flow process as shown in Fig. 10.

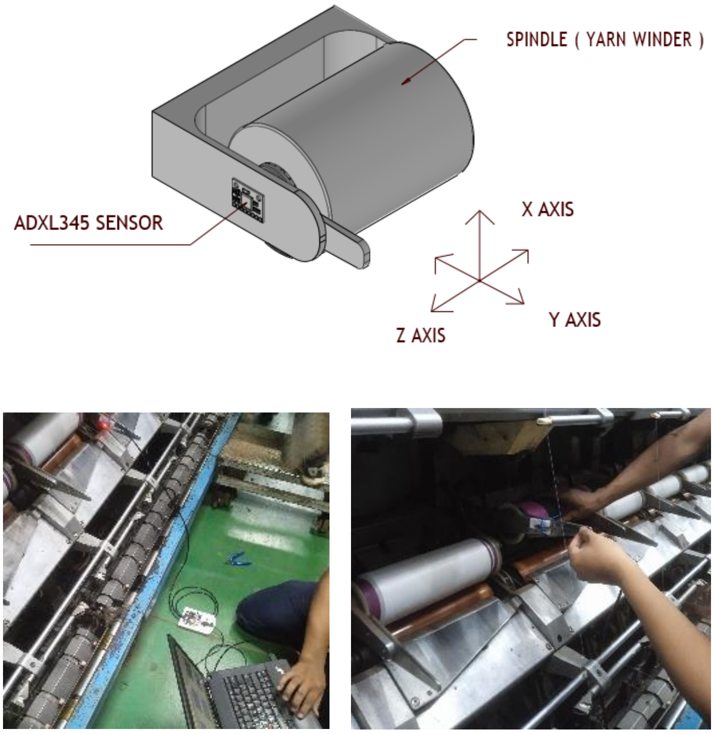

Fig. 9. Sensor mounting position on spindle arm.

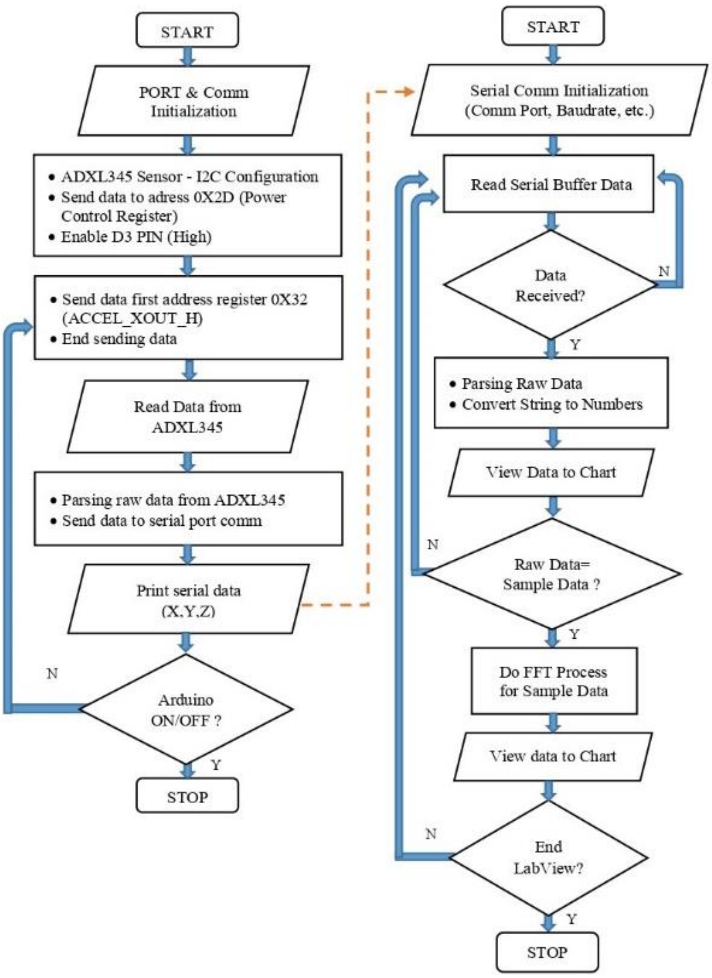

Fig. 10. Flowchart diagram.

It was evident from the flowchart in Fig. 10 that the ADXL345 sensor is utilized to identify vibrations in the DTY machine's spindle arm. The Arduino Nano receives data from the sensor through Inter-Integrated Circuit (I2C) communication [17]. I2C allows users to have several masters commanding one or more slaves, as well as the ability to attach multiple slaves to a single master [18].

In the next process, data in Arduino is sent to the OX2D (Power Control Register) address, and the first received data is transmitted to the OX32 registry. Then, the subsequent data is received by LabVIEW after being sent over communication. In this experiment, LabVIEW is used to process data using FFT.

3 Results and Discussion

3.1 Result

3.1.1 FFT and Data Acquisition on LabView

LabVIEW is used to design a Virtual Instrument (VI) for data acquisition. The accelerometers capture vibration signals, which are processed in real-time [16]. The VI includes features for signal filtering, time-domain analysis, and frequency-domain analysis.

3.1.2 Time-Domain Analysis

Time domain analysis involves examining vibration quantities on the spindle of the DTY machine as it changes over time. Time-domain characteristics include amplitude and frequency. Amplitude is the strength or magnitude of the signal at any given time, and the frequency how often the signal oscillates over time.

3.1.3 Frequency-Domain Analysis

The frequency-domain analysis processes vibration response signals from the time domain to become frequency components. Unlike time-domain analysis, which examines signals in terms of amplitude variations over time, frequency-domain analysis focuses on how the vibration responses are distributed across different frequencies. FFT transforms a signal from its time domain into its frequency domain representation.

From FFT analysis, several dominant frequencies can be identified that can be traced back to specific vibrations from DTY machine components. The measurement results using FFT can be displayed in Tables 2 and 3.

Table 2. Amplitude data on an abnormal spindle

Data sample	X-Axis Amplitudes (m/s^2)	Y-Axis Amplitudes (m/s^2)	Z-Axis Amplitudes (m/s^2)
1	48.9	64.9	44.3
2	48.8	64.5	43.6
3	48.7	59.9	40.6
4	47.9	51.7	35.2
5	47.7	36.2	34.2
6	47.6	32.1	33.3
7	47.2	27.5	32.4
8	46.9	23.8	31.9

Table 3. Amplitude data on a normal spindle

Data sample	X-Axis Amplitudes (m/s^2)	Y-Axis Amplitudes (m/s^2)	Z-Axis Amplitudes (m/s^2)
1	22.8	16.5	12.2
2	22.3	16.3	12.1
3	22.3	15.9	11.9
4	22.3	15.8	11.8
5	22.2	15.7	11.8
6	22.1	15.6	11.4
7	21.4	15.5	10.9
8	20.8	15.4	10.9

Data visualization in Tables 2 and 3 is the average data obtained from the results of data collection after going through the FFT process using LabVIEW (Fig. 11). A sample of 1024 data was processed by LabVIEW and then displayed and sampled every hour 8 times (1 data sample every hour). The results of the data samples were processed and averaged then visualized into the table.

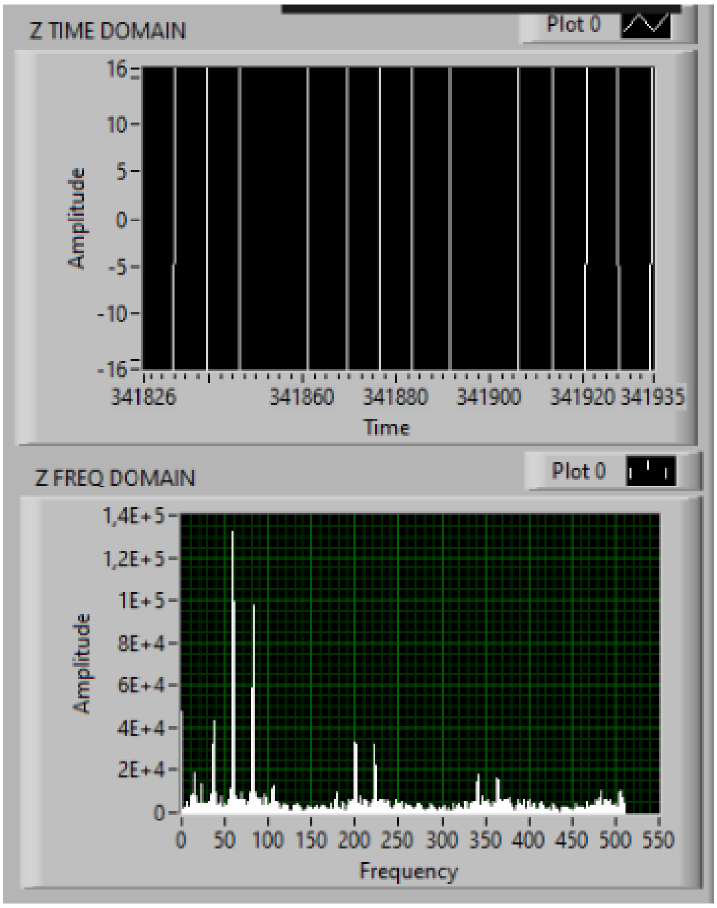

Fig. 11. FFT data visualization process in LabVIEW on the Z axis.

3.2 Discussion

The results of experiments on two places on normal and abnormal spindles on the DTY machine indicate a significant gap. The values obtained illustrate an indication of vibration changes on the spindle allowing the potential for irregularity yarn if there is a significant change in the vibration pattern on the X, Y, and Z axis. Fig. 12, Fig. 13, and Fig. 14 are visualizations that help in analyzing the vibration gaps that occur on each of the three axis.

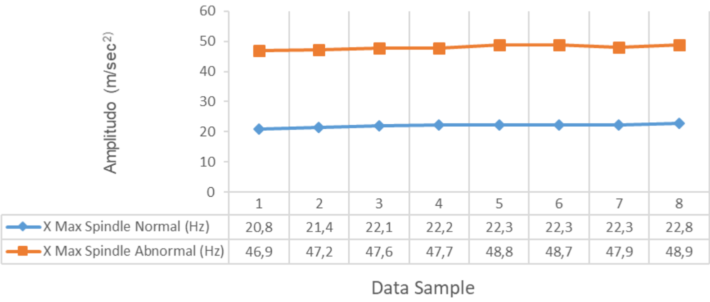

Fig. 12. Chart of the normal vs abnormal amplitude values on the X-axis.

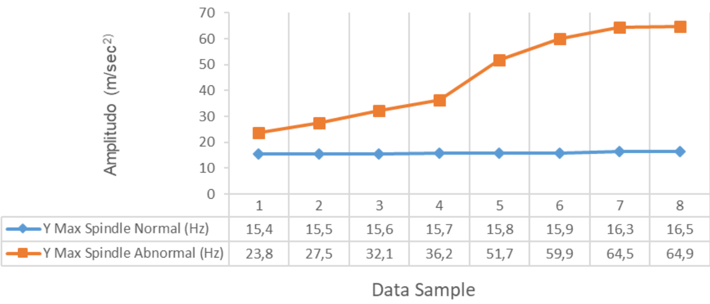

Fig. 13. Chart of the normal vs abnormal amplitude values on the Y-axis.

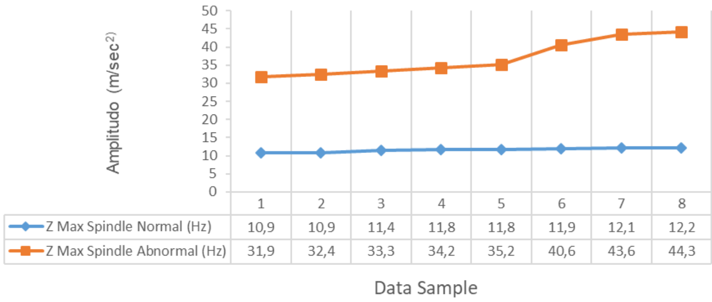

Fig. 14. Chart of the normal vs abnormal amplitude values on the Z-axis.

Because in this experiment, the root cause of the X-stitch defect is the abnormal vibration on the Z axis, so from Fig. 14 it can be discussed that the amplitude value on the abnormal spindle starts at a value of 31.9 to 44.3 m/s^2. Then the amplitude value on the normal spindle is in the range of 10.9 to 12.2 m/s^2. It means the amplitude value gap between these two conditions is very significantly different.

However, the mentioned values require further testing by increasing the number of experimental samples and data collection. Normal and abnormal vibration patterns are obtained more thoroughly. So, if AI is used to make decisions, the results will be faster and more accurate.

4 Conclusion

The research focuses on developing a real-time monitoring system for detecting vibrations during the draw texturing process on DTY machines. The system uses sensors to capture vibration data from the machine's spindles, which is then analyzed to differentiate between normal and abnormal vibrations. This capability enables immediate detection and correction of potential defects in the yarn, improving the overall quality of the draw textured yarn being produced.

5 Future Works

Future work will continue on a smart mechatronic system that can provide an early warning system. This mechatronic system processes acquired vibration data based on the Artificial intelligence approach and the Internet of Thing (IoT). In addition, integrating the LabVIEW software with machine learning algorithms and IoT connectivity can improve the system's ability to make decisions and immediate corrections when vibration responses occur that can cause yarn irregularities in the DTY machine.

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