Enhancing the Safety of Milling Machines through Machine Condition Monitoring with Graphical System Design Programming Software

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Abstract: **Throughout every machining operation, it is essential to monitor the condition of the cutting tool in order to improve accuracy and prevent unexpected machining problems. The application of vibration analysis in the processing procedure is demonstrated in this study as a method of identifying the occurrence and progression of decision-making process and tool damage. The scheduling strategies in temporal and frequency domains were linked to the resulting oscillation of the cutting tool to obtain diagnostic information. It has been discovered that in close proximity to significant noise, both are more proficient than average in demonstrating the characteristics of both localized and dynamic deficiencies. The condition of the machine is achieved through the utilization of various strategies; however, none of them can successfully complete the task due to the complex parameter variability in the machining process. In this work, the wear status of apparatuses is analyzed by utilizing a few sensors for flag estimation. Furthermore, this study proposes a coordinated approach for milling machine condition and control, in addition to acquiring diverse parameters.**

***Keywords:* Data Acquisition, Fault Diagnosis, Multisensory, Condition Monitoring, Vibration Analysis**

I. INTRODUCTION

1.1 Machine Condition Monitoring

High speed machining (HSM) is highly regarded for its exceptional accuracy and precision in the machining process. The primary concern in HSM is the deterioration of product quality caused by wear and the rising cost of products due to frequent tool replacement. The tool wear data acquired from previous experiments is used to estimate the tool life, which in turn determines the deformation or damage of the sharp edge of a cutting tool during machining. These interactions are influenced by the tool changing policies. The failure of cutting tools leads to an increase in cost and maintenance time, as well as a decrease in production rate, in manufacturing industries. The Tool Condition Monitoring system (TCMs) proves to be highly beneficial for manufacturing industries by minimizing downtime and enhancing productivity. The monitoring procedure aids in preventing harm to both the tool and work piece, enhancing productivity and the quality of the machined item, as well as forecasting tool deterioration. Evaluating the condition of cutting tools can be challenging due to the fact that each manufacturing process involves non-linear time variant systems.

1.2 Fixture Desigh for Milling Machine

The milling fixture comprises several components including the base, clamps, rest blocks or nest, locating points, and gauging surfaces. The base plate, which forms the main body of the fixture, is flat and precise, providing a solid foundation for mounting various elements. The alignment of this surface corresponds to the surface of the mill table, establishing the reference plane in relation to the movement of the mill feed. The material used for construction can vary between steel plate and cast iron, depending on the size and intricacy of the component. The base is equipped with slots that allow for the fixture to be securely clamped to the mill table. The base plate is equipped with keyways that run along its length, allowing for the insertion of two keys. These keys serve the purpose of aligning the fixture on the table of the milling machine. The fixture is equipped with key ways at both ends where the keys are inserted and secured in place using socket head cap screws. To achieve the desired position, it is essential to make adjustments to the table by utilizing feed movements. The cutting forces in a milling machine can vary when the cutter enters or exits the work piece, resulting in additional stress on the clamps. Vibrations should not be allowed to loosen the clamps, especially when they are caused by the mill cutter's interrupted cutting at the start and end of the cut. The clamps must be positioned opposite the bearing surfaces and locating points, and should be designed for easy operation by the operator.

1.3 Fault Diagnosis of Milling Machine

The maintenance and fault diagnosis of milling machines revolve around the machine tool's product specifications. Along with gathering data on milling machine malfunctions and maintenance procedures, there is a thorough examination of the diagnosis and repair techniques for issues in Numerical Control (NC) machine tools. The practice's diagnosis and repair tips are an invaluable resource for maintenance technicians, offering them valuable insights and inspiration. These tips aid technicians in generating ideas for fault analysis and treatment approaches, ultimately mitigating potential losses that could occur due to errors in the repair process.

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II.LITERATURE REVIEW

2.1 Introduction

Fault diagnosis in numerical control machines is crucial for maintaining manufacturing quality. Utilizing multisensory tool condition monitoring can offer valuable insights into the tool's condition, although there is a possibility of information overload with redundant data. Currently, the extraction of the most efficient feature information from multisensory signals is a widely discussed subject. Most of the existing feature selection methods consider the correlation between the feature parameters and the tool state, but they fail to examine the impact of feature parameters on prediction accuracy.

2.2 Machine Condition Monitoring

The research conducted by Achmad Widodo Bo-Suk Yang et.al. [1] delved into the importance of machine condition monitoring and fault diagnosis within maintenance systems. This subject has garnered worldwide interest because of its numerous advantages, such as lower maintenance expenses, improved efficiency, and heightened machine uptime. The paper offers a comprehensive look at support vector machine-based machine condition monitoring and fault diagnosis, with the goal of summarizing and assessing the most recent developments and studies in this area.

The significance of machine condition on machining performance was investigated by Julie Z. Zhang, Joseph C. Chen et.al. [2]. They highlighted the potential economic benefits in machine tools and machining processes through the implementation of a machine condition monitoring system. Developing such a system requires precise machining data that can effectively depict machining procedures. This study presents a technique for monitoring tool condition in end-milling operations by analyzing vibration signals collected through a cost-effective, microcontroller-based data collection system.

Z.K.Peng [3] examined the impact of wave propagation with reflection and absorption on the acoustic performance measurements of automotive mufflers. Consequently, the measured signal can exhibit both linear and non-linear interactions among its wave components. The bispectrum, a measure of the phase relationship between three spectral components, has proven to be a valuable tool in investigating the study of linear and non-linear wave interactions. S.Kurada [4] outlined that the monitoring of machine conditions has become increasingly crucial in the manufacturing sector in the last twenty years, as it plays a significant role in both the efficiency of the production process and the quality of the finished product. The continuous progress in image processing technology has resulted in the creation of different vision sensors that can assess the tool condition during the machining process.

In their study, Sultan Binsaeid, Shihab Asfour et.al. (2015) [5] examined the significance of monitoring conditions in signal processing and information technology. They highlighted the importance of employing multiple sensors to effectively monitor tool conditions, as this feedback information is vital for the process controller.

Sohyung Cho [6] explored the topic of the Machine Condition Monitoring System, which has received little attention in terms of reducing complexity and enhancing robustness. This study focuses on developing an efficient multisensor-based approach for machining steel using a multilayer-coated carbide end mill cutter. The sensors examined in this research encompass force, vibration, acoustic emission, and spindle power sensors to collect data in both the time and frequency domains.

In the paper by H. Ozturk [7], the significance of monitoring the condition of cutting tools in machining operations is emphasized as a crucial step to prevent unforeseen machining issues and enhance machining precision. The study introduces the application of vibration analysis in milling to detect and track the development of damage in an end mill.

P.A. H. Vardhini [8] explored the aim of integrating a direct sensor (vision) and an indirect sensor (force) to develop an advanced integrated machine condition monitoring system for real-time monitoring of flank wear and breakage in milling, leveraging the unique capabilities of both sensor types.

P.A.Tsai [9] examined and forecasted the cutting force by utilizing a geometrical model. Empirical findings demonstrate that this fusion of sensors is both viable and efficient for executing real-time tool condition monitoring during milling operations, regardless of the cutting parameters employed.

Astakhov,V.P.[10] conducted research on evaluating the wear of cutting tool materials. The machining process and cutting conditions of tools in milling are highly complex and susceptible to errors. The importance of monitoring the machining process has been highlighted by Dong-Woo Choa, Sang Jo Leeb et.al.[11] This is essential for the effective implementation of automated or unmanned plant operations, such as FMS, CIM, CAPP, among others. Numerous researchers in Korea have acknowledged this need, and despite the relatively brief period of research in this field, many promising outcomes have been documented.

III. GRAPHICAL SYSTEM DESIGN PROGRAMMING SOFTWARE

3.1 LabVIEW Introduction

LabVIEW is software created for systems engineering, particularly for tasks requiring test, measurement, and control functionalities, with easy access to hardware and data analysis. It is recognized as Laboratory Virtual Instrument Engineering Workbench (LabVIEW) and acts as a foundation for system design and a programming environment for a visual language developed by National Instruments. LabVIEW is commonly employed for activities like data acquisition, instrument control, and automation of industrial procedures on various operating systems including Microsoft Windows, various Unix versions, Linux, and others.

LabVIEW integrates the inclusion of user interface creation, referred to as front panels, into the development process. Virtual instruments (VIs) are the subroutines of LabVIEW programs. Each VI is composed of three elements: a block diagram, a front panel, and a connector pane. The connector panel serves to depict the VI in the block diagrams of other VIs that invoke it. The front panel is established through the use of controls and indicators. Controls function as inputs, allowing users to input information to the VI. On the other hand, indicators act as outputs, showcasing the outcomes derived from the inputs received by the VI. The back panel, which is a block diagram, houses the graphical source code. Any objects positioned on the front panel will manifest as terminals on the back panel.

The back panel of the virtual instrument is equipped with a variety of structures and functions that carry out operations on controls and provide data to indicators. These structures and functions can be accessed from the Functions palette and placed on the back panel. Controls, indicators, structures, and functions are collectively referred to as nodes, which are interconnected using wires. For example, by connecting two controls and an indicator to the addition function, the sum of the two controls will be displayed on the indicator. This enables the virtual instrument to function as a program, with the front panel serving as the user interface. Alternatively, when the virtual instrument is added as a node on the block diagram, the front panel defines the inputs and outputs for the node through the connector pane. This flexibility allows each virtual instrument to be easily tested before being integrated as a subroutine into a larger program.

The visual approach enables users with no coding background to effortlessly develop programs by simply dragging and dropping virtual models of lab tools they are already acquainted with. LabVIEW software, supported by its sample codes and guides, simplifies the process of crafting basic applications. Nevertheless, there is a danger of overlooking the level of skill required for top-notch G programming. When dealing with intricate algorithms or lengthy code, it is crucial for a developer to possess a deep comprehension of the unique LabVIEW language and its memory handling complexities. The most sophisticated LabVIEW development platforms offer the capability to construct independent applications.

3.2 LabVIEW based Condition Monitoring

This paper presents experimental findings that demonstrate the effectiveness of motor current signature analysis (MCSA) in detecting shorted turns in low voltage stator windings of three phase induction motors through the use of LabVIEW. The diagnostic approach is outlined, and factors affecting the diagnosis are examined. Detailed analysis is conducted on current spectra obtained from motors with short-circuited turns, both with and without short circuit current limiting resistors. Findings from tests conducted on motors until failure are documented. The study includes results obtained from industrial motors with varying pole numbers and different winding configurations, such as concentric and lap wound designs. Given that stator failures are a significant cause of motor breakdowns, the outcomes of this research hold particular importance for the industry. Electric drive system operators are under constant pressure to reduce maintenance costs and prevent unforeseen downtime, which can result in reduced production and financial losses. Many operators currently employ condition monitoring techniques to help achieve these goals. [1].

In order to minimize machine downtime and enhance stability, it is imperative to integrate diagnostic features with drives. In today's industrial landscape, numerous machines rely on collaborative functioning, and the repercussions of unforeseen breakdowns can be exorbitant. Hence, fault diagnosis and prognosis hold significant importance in the industrial sector and are receiving growing recognition. Based on the preceding analysis, it is evident that the occurrence of different faults is solely determined by the values of the stator current in the motor.

Typically, stator currents and voltages are preferred for monitoring purposes as the necessary sensors are usually already present in the relevant drive. Condition monitoring holds significant importance across various industries such as railways, power delivery, and electrical machines and motors. It involves the practice of monitoring a machine's operational characteristics to detect changes and trends in the monitored signals. This enables the prediction of maintenance requirements before any breakdown or significant deterioration occurs, or to assess the current condition of the machine. To illustrate, let's consider the example of Induction Motor Bearing Damage, which highlights the extensive research conducted on condition monitoring of induction motors.

There are various approaches to identifying failures among the extensively researched methods in bearing condition monitoring, vibration, acoustic noise, and temperature measurements are commonly employed. Vibration and stator-current based techniques have gained significant popularity. When monitoring bearing damage in induction motors, the characteristic frequencies associated with bearing damage are often utilized to track specific frequency components in either vibration or stator current signals. However, conventional monitoring systems have certain limitations, such as being inflexible, costly, and reliant on specialized instruments. In recent years, there has been a shift from traditional techniques to AI-based methods for fault detection in electrical machines. Incipient faults are frequently observed in induction motors.

VI. DATA ACQUISITION CARD (DAQ) INTERFACINGWITH LabVIEW

4.1 DAQ Card

Data acquisition is the process of sampling signals to record real-world physical conditions and converting these samples into digital values that can be analyzed by a computer. Data acquisition systems also referred to as DAS or DAQ, typically convert analog waveforms into digital data for in-depth analysis.

The elements of data acquisition systems consist of:

- Transducers, which transform physical parameters into electrical signals.
- Signal processing circuitry, which converts sensor signals into a format suitable for conversion into digital values.

- Analog-to-digital converters, which change processed sensor signals into digital values.

In addition, there exist open-source software packages that offer the essential tools for obtaining data from various hardware equipment, often of a specific nature. These tools originate from the scientific community, where intricate experiments demand software that is swift, versatile, and adjustable. While these packages are typically customized to suit specific needs, more universal Data Acquisition (DAQ) packages such as the Integrated Data Acquisition System can be readily customized and are employed in numerous physics experiments across the globe.

A data acquisition system comprises software and hardware components enabling the measurement or control of physical attributes in the physical world. It includes DAQ hardware, sensors, actuators, signal conditioning hardware, and a computer with DAQ software. In cases where timing is crucial, a distinct compensated distributed timing system is essential. The measurement of various properties in an acquisition system relies on the appropriate sensors capable of detecting those properties. In cases where the signal from the transducer is not compatible with the DAQ hardware, signal conditioning may be required. This typically involves filtering, shaping, or amplifying the signal. Other examples of signal conditioning include bridge completion, providing current or voltage excitation to the sensor, isolation, and linearization. To minimize noise interference, single-ended analog signals can be converted to differential signals for transmission purposes. Once the signal is digitized, it can be encoded to minimize and rectify transmission errors.

V.INTERFACING OF SENSORS TO COMPUTER THROUGH LabVIEW SOFTWARE

5.1 Sensor Interfacing Steps

1. Begin by launching LabVIEW and opening a new blank VI.
2. Next, connect the USB cable to the USB DAQ (NI USB 6008), ensuring that the other end of the cable is securely connected to the computer.
3. Now, navigate to the desktop of the computer and open the Measurement and Automation Explorer.
4. Within the Measurement and Automation Explorer, verify the proper operation of the compact DAQ card by conducting a test.
5. Connect the thermocouple to the NI USB 6008 DAQ card using the appropriate connectors.
6. Proceed to develop a program within the LabVIEW front panel to create a warning system.
7. Once the program is complete, click the run button to execute it.
8. In the event that the temperature acquired by the DAQ card exceeds the set point temperature, a blinking red LED will be displayed on the LabVIEW front panel.

VI. SENSORS USED FOR MONITORING

- Temperature sensor
- Vibration sensor
- Proximity sensor

6.1 Temperature Sensor Interfacing

NI myDAQ is a LabVIEW component that serves as a cost-effective portable device for data acquisition (DAQ). It is utilized to measure and analyze real-world signals using software devices. NI DAQ is ideal for on-the-go electronics and sensor measurements. When combined with NI LabVIEW on a PC or laptop, students can analyze acquired signals and control simple processes at their convenience. Refer to figure 1.0 for the physical depiction of the NI myDAQ device.

Temperature regulation plays a crucial role in the separation and return procedures, as it is essential to maintain the temperature within specified limits in order to ensure the safe and reliable operation of the process equipment. To prevent any interference or damage to the temperature sensor, it is shielded from the process materials by a carefully chosen barrier that is both physically robust and chemically resistant. The LM35 integrated circuit accurately measures temperature by providing an output voltage that is directly proportional to the temperature in degrees Celsius. Unlike other temperature sensors that use Kelvin, the LM35 eliminates the need for complex voltage conversions to obtain the temperature in Celsius. It offers precise readings of ±1/4 °C at room temperature and ±3/4 °C across a wide temperature range from -55 °C to 150 °C without requiring any additional adjustments. The LM35 sensor has three pins: pin 1 for power supply from the NI DAQ at +15V, pin 2 connected to analog pin A0 of the NI DAQ, and pin 3 connected to the ground of the NI myDAQ.

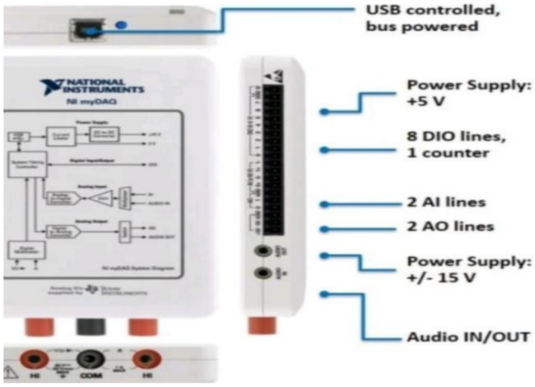

Figure 1.0 DAQ Card Interface the LabVIEW Using Temperature

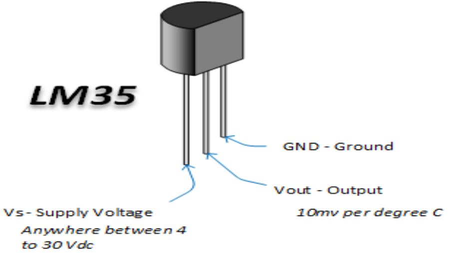

Figure 2.0 Temperature Sensor Using Machine Monitoring

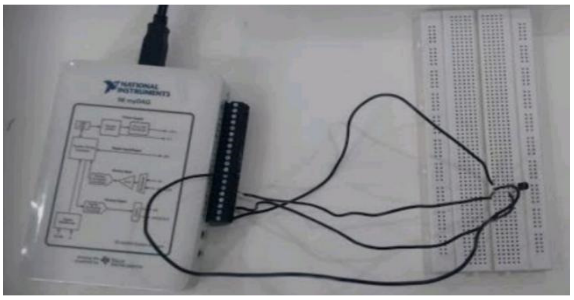

Figure 3.0 Temperature Sensor Connect with Data Acquisition

6.2 Vibration Sensor Interfacing

The piezoelectric sensor, commonly known as the vibration sensor, is a versatile device utilized for monitorin a variety of processes. It operates by converting changes in acceleration, pressure, temperature, force, or strain into an electrical charge through the piezoelectric effect. Additionally, this sensor can accurately detect scents in the air by promptly measuring capacitance and quality.

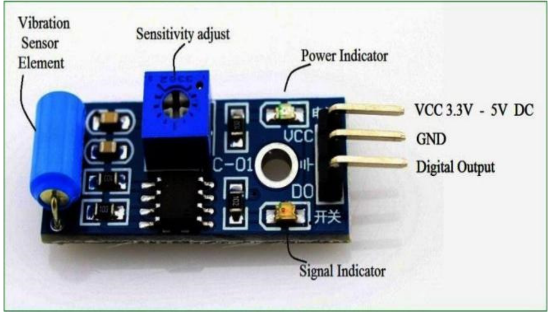

Figure 4.0 Vibration Sensor with Interface Module

6.2.1 LabVIEW based DAQ System for Vibration Analysis

LabVIEW has gained significant popularity as a graphical programming language, especially for tasks related to data acquisition and measurement. The reason for its widespread use is attributed to its compatibility with various data acquisition cards and measurement systems, as well as its user-friendly approach to programming advanced software. One notable application of LabVIEW is its utilization in the monitoring and analysis of vibration signals. This involves the examination and tracking of signals to identify faults and facilitate predictive maintenance. In this document, we introduce a LabVIEW based system for data acquisition and analysis, specifically designed for vibration monitoring and utilized alongsid Vibration Fault Simulation Systems (VFSS). The system offers an intuitive interface that presents real-tim representations of the vibration signal in both the time an frequency domains.

Different sound and vibration transducers generate intricat time series waveforms, containing numerous distinc signatures. It is crucial to comprehend these divers vibration signatures and effectively extract them for tren analysis. By having accurate signature information, becomes feasible to compile specific metrics that ca influence plant maintenance or production schedules Various signal complexities exist, corresponding to different sound and vibration phenomena. Some signals have a long time duration but narrow bandwidth such as rub & buzz noise.

1. Certain signals exhibit a brief duration yet possess a broad bandwidth, like impacts or transients.
2. Certain signals display a short duration and a narrow bandwidth, such as decayed resonance.
3. Certain signals showcase a bandwidth that varies over time, like an imbalanced shaft producing noise that is RPM or machine speed-dependent..

The initial stage in any sound and vibration application involves monitoring the sound and vibration signals within it. Once this is established, the subsequent stage is selecting the appropriate algorithm for isolating the signal feature of interest from the raw signal. National Instruments offers various algorithms for extracting these features, as illustrated in Figure 2.

National Instruments offers a variety of algorithms to cater to different analysis needs. These include standard frequency analysis, order analysis for monitoring rotating components like gearboxes, time-frequency analysis for analyzing time-varying sound and vibration signals, frequency analysis for detecting harmonics, and wavelet and model-based analysis for transient detection. With this comprehensive collection of algorithms, users can effectively analyze and monitor their specific machines or devices.

Frequency analysis is widely utilized for examining vibration signals. The primary form of frequency analysis is through FFT, or Fast Fourier Transform, which changes a signal from the time domain to the frequency domain. The outcome of this transformation is a power spectrum that displays the energy present in particular frequencies of the complete signal. This proves to be beneficial for evaluating stationary signals with consistent frequency components.

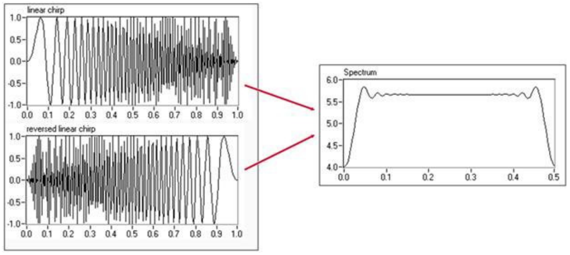

Figure 5.0 Vibration Sensor Interfacing

6.3 Proximity Sensor Interfacing

A proximity sensor is a type of sensor that can detect the presence of objects in close proximity without making any physical contact. It typically emits an electromagnetic field or a beam of electromagnetic radiation, such as infrared, and then analyzes the changes in the field or the return signal. The object that is being detected is commonly referred to as the target of the proximity sensor. Different types of proximity sensors are required for different target materials. For instance, a capacitive proximity sensor or a photoelectric sensor may be suitable for detecting a plastic target, while an inductive proximity sensor always requires a metal target.

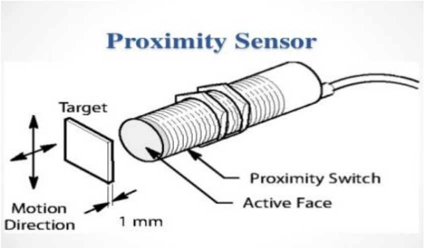

Figure 6.0 Proximity Sensor Using Condition Monitoring

6.3.1 LabVIEW Interface with DAQ and Proximity Sensor

The system is managed by a computer through a control application developed in LabVIEW, which can operate either through cable or wirelessly. This application is responsible for presenting all the data collected from the acquisition system and storing it in a file for the purpose of creating a record of measurements. Throughout the research project, different sensors such as Infrared sensor, Light Dependent Resistors (LDR), and Analog POT are utilized, with their data being collected through LabVIEW assisted DAQs. The GPIB, short for General Purpose Interface Bus, was created by Hewlett Packard during the 1960s. In this setup, a controller card is inserted into the computer, allowing for proprietary commands to be transmitted to various instruments for independent data collection. These instruments, produced by multiple manufacturers, are linked to the controller via individual 16-core cables.

Utilize the SparkFun (SEN-08959) Infrared Proximity Sensor in conjunction with myDAQ within LabVIEW. Gather data through the DAQ Assistant tool available in LabVIEW alongside the NI-DAQmx device drivers, and then transform the data into distance by employing interpolation and fundamental programming techniques in LabVIEW. The digital display on the user interface provides information about the distance, while the progress bar visually represents the distance. The top left corner of the front panel displays the frequency, sample rate, and number of samples, which are used as inputs for configuring the filter and data acquisition tasks. Additionally, there is an indicator that shows the average value of voltage samples for each set of data obtained from the DAQ. The waveform graphs are utilized to display both the raw data and a filtered version of the data obtained from the DAQ.

VII. MACHINE CONDITION MONITORING EXPERIMENTAL SETUP

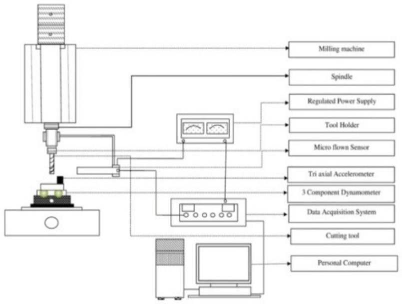

Figure 7.0 Experimental Setup

7.1 Block Diagram of Front Panel

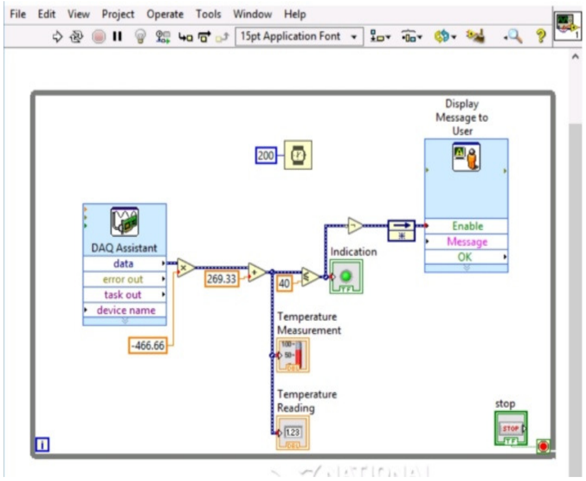

Figure 8.0 Block Diagram of Milling Machine Connect With DAQ Card with LabVIEW

7.2 Data Acquisition Program in LabVIEW for Interfacing the Sensors

Creating programs in LabVIEW can be made quite straightforward by utilizing the built-in functions and examples. This webpage demonstrates a method for accomplishing this when developing a data acquisition program. The software is designed for sensor calibration purposes. The user inputs a series of known values into the sensor before instructing the program to measure the voltage output. Multiple readings are taken and averaged over time to obtain accurate data points. Users can view the time/voltage data to assess signal cleanliness before logging the points. Additionally, the average and standard deviation of the time/voltage data will be shown and recorded upon user request. A graph will be updated after each data point is logged to illustrate the correlation between the input and output.

LabVIEW functions as an oscilloscope by continuously gathering time/voltage data and presenting it on a screen to demonstrate the consistency of the data. It also verifies if the user wishes to record the data after each collection and performs data manipulation. The processes of data collection, display, user requirement verification, and data manipulation should be handled as distinct tasks. This cycle is repeated until instructed to cease. The structure of PC-based DAQ systems, the function of DAQ cards, and the involvement of LabVIEW in this scenario are crucial components to consider.

Creation of basic Virtual Instruments (VIs) in LabVIEW involves utilizing fundamental features like arithmetic and logic operations. Advanced VIs are built by incorporating program flow control operations such as the while loop and case structure. VIs are designed to facilitate interaction with external hardware, enabling tasks like signal acquisition through DAQ card input channels and function generation via DAQ card output channels. These functionalities are crucial for utilizing LabVIEW in a laboratory environment. Further exploration of LabVIEW's capabilities in signal processing will be covered in the following chapter.

7.2 1. Temperature Sensor Interfacing

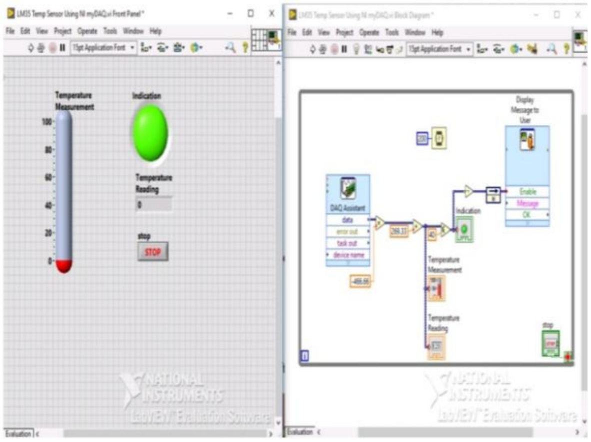

Figure 9.0 LabVIEW Code for Temperature Sensor Interfacing

7.2.2 Vibration Sensor Interfacing

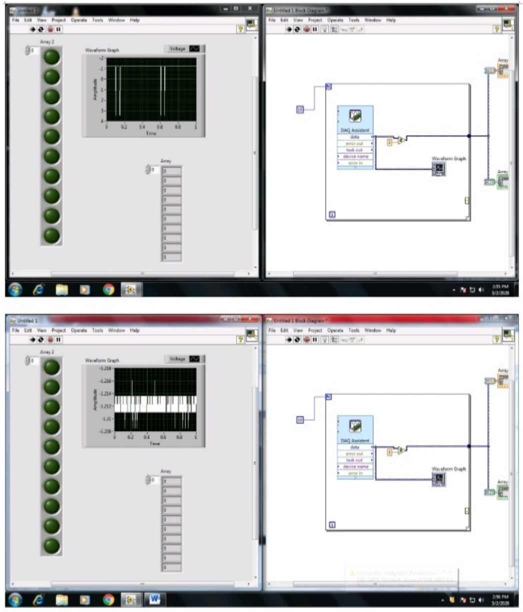

Figure 10.0 LabVIEW Code for Vibration Sensor Interfacing

7.2.3 Proximity Sensor Interfacing

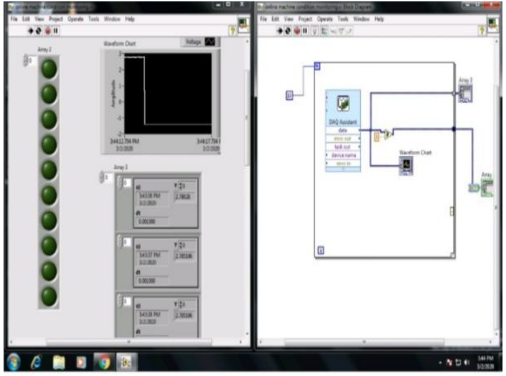

Figure 11.0 LabVIEW Code for Proximity Sensor Interfacing

7.3 DAQ CARD – Data Acquisition NIUSB-6008

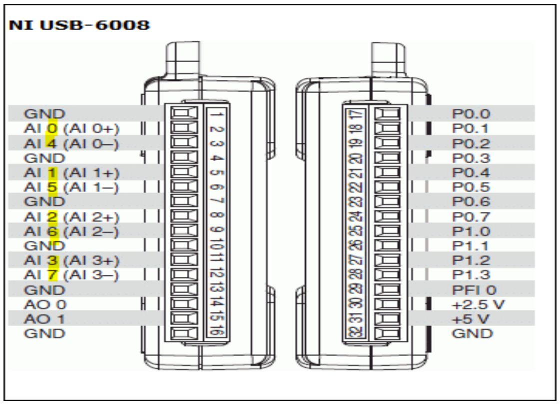

Figure 12.0 DAQ Card Pin Connections

VIII. CONCLUSION

Monitoring applied to machining processes has the potential to enhance the overall process by prolonging tool life and improving surface quality, while also reducing electric energy consumption and waste material. However, selecting the appropriate monitoring method necessitates careful consideration of implementation costs, requirements, and the specific objectives to be analyzed. In certain cases, monitoring tool wear using a dynamometer can be just as effective as using an accelerometer, which is a more cost-effective option. Additionally, signal interpretation plays a crucial role in the monitoring process. The user must choose the most suitable method of analysis based on the objective at hand. For instance, if the machining process involves variable revolution, monitoring vibrations or sound in the frequency domain may not be suitable unless the user adjusts the revolution/frequency ratio accordingly. Despite the need for careful attention, monitoring machining processes yields excellent results for both industrial and academic research endeavors.

The preliminary test involving the rotation of unbalanced objects on turn tables clearly demonstrates that the linear position encoders detect vibrations caused by the unbalance. The angle depicted in the diagram exhibits a significant relationship with the intensity of the vibrations. Various unbalanced scenarios also resulted in distinct patterns in the final outcomes. The examination conducted on two types of milling processes, namely disc-milling and slot-milling, reveals that the encoder feedback includes specific frequencies related to the operation, such as the cutter frequency and tooth-passing frequency. The modulation signal derived from the S1-axis appears to be more erratic compared to the modulation signal from the feed axes. To determine the delay in reconstruction using the mutual information function (MI) of the S1-axis modulation signal, it is necessary to prefilter the signal to achieve a stable MI function.

The reconstruction delay value, determined by the value corresponding to the first minimum in the MI function, is influenced by the segment of the time series utilized in the algorithm, as well as the length of the chosen sequence of samples from the time series. In certain scenarios, the response from machining operations necessitates a higher dimensional embedding space (up to 4 or 5) for proper embedding, ensuring no self-intersection of the phase space trajectory. Currently, embedding is conducted in a three dimensional space, resulting in the presence of false neighbors (unrelated points in the chosen dimension). Dealing with higher-dimensional sections remains ambiguous at this point.

The large negative value of the exponent indicates that the response from encoders during machining is not chaotic and the process is highly dissipative. As a result, the calculation of exponents and chaotic invariants has been excluded from the analysis. To create a clear pattern, the sectioning technique necessitates a significant accumulation of intersection points with the surface of the section. These aforementioned issues are not addressed in this thesis, which focuses solely on well-controlled experiments and offline signal analysis. Nonetheless, it is crucial at this point to establish a general method for analyzing encoder signals. If the temperature, vibration, or position of the milling machine exceeds the set limit, the sensors will emit a light signal.

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