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# Design and Development of Smart Workbench for Ball Bearing Defect Identification by using PSoC Microcontroller and Labview Virtual Instrument

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**Abstract.** One of the most important components of any industrial machine is ball bearings, which keep the equipment life as well as the smooth running of the machinery operations. Keeping the ball bearing in good working condition is maintaining constant productivity. The bearing faults, which took place in the consequence of necessary equipment, caused the machinery to be pulled down. The productivity loss entailed great money loss in addition to safety risk. A test workbench was constructed to diagnose the ball bearings working condition by getting the amplitude of the power spectrum, as well as the wavelet pattern. A combination of a PSoC embedded design with a virtual instrumentation workbench can be considered a technological solution in terms of the detection and precise diagnosis of ball bearing faults. In this work, the power spectrum and wavelet patterns were identified for the good working conditioned bearings; the wavelet patterns were identified by using 6000 series ball bearings. This work explores the application of PSoC technology coupled with virtual instrumentation in the monitoring of ball bearings in an industry setting and analyzes the future direction of the industry in the utilization of new-age technologies in the monitoring and diagnosis of ball bearings.

## 1 Introduction

The manufacturing industry has used various kinds of motors in recent years to produce components and parts. Most machining uses induction motors, single-phase motors for light-dutyuse, and three-phase motors for heavy-duty use [1]. The industry needs to run the motors failure-free so that the production capacity is metout. To achieve this, motor components have to conduct difficulty-free operations, but in due course of time, when the motors are made to run for a longer amount of time, it produces wear among the parts. When evaluating the problematic parts, bearing wear is one important issue. This causes the motor to suffer as well; should this occur, the whole motor must be fixed or replaced [2]. Many fault detections techniques and approaches have been used; various methods of bearing fault identification are being carried out. Ball bearings are critical components in rotating machinery, ensuring

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smooth operation with minimal friction and mechanical losses [3]. Their failure can lead to excessive vibration, increased wear, and catastrophic breakdowns in industrial systems. Early detection of bearing defects, including inner/outer race defects, ball defects, and lubrication failures, is crucial. It is essential to prevent unplanned downtime and costly repairs. Traditional fault diagnosis methods, including vibration analysis, time-frequency domain techniques, and wavelet transforms, have been widely studied [4].
However, many existing approaches rely on complex signal processing algorithms, expensive instrumentation, and offline analysis, limiting their real-time applicability in industrial environments [5]. To address these challenges, this research proposes the design and development of a Smart Workbench for Ball Bearing Defect Identification using a Programmable System-on-Chip(PSoC) microcontroller and LabVIEW Virtual Instrumentation [6]. The PSoC microcontroller enables real-time data acquisition and signal conditioning, while LabVIEW provides an intuitive graphical user interface [7]. This integrated system aims to offer a cost-effective, portable, and automated solution for bearing fault detection, reducing dependency on high-end vibration analyzers and manual interpretation. The proposed workbench incorporates accelerometer-based vibration sensing, Fast Fourier Transform (FFT) analysis, and machine learning-based fault classification to identify common bearing defects [8, 9]. Unlike conventional methods that require extensive computational resources, this system leverages embedded signal processing within the PSoC, ensuring rapid response times. Additionally, the LabVIEW GUI facilitates real-time visualization, data logging, and predictive maintenance alerts, making it suitable for both industrial and educational applications [10].

This research connects the gap between theoretical fault diagnosis models and real-world application by presenting an affordable, scalable, and easy-to-use diagnostic tool. The sections that follow examine current literature on bearing fault detection techniques, emphasizing the demand for a smart workbench that combines embedded systems with virtual instruments to boost both reliability and efficiency [11]. The researchers have investigated combining wavelet analysis with machine learning in hybrid models to improve fault diagnosis. Another essential problem of fault detection in bearings is the extraction of a good fault signature using a noisy vibration signal. Denoising methods have become vital toward this effort, especially advanced methods. SVD in combination with Hankel matrix-based denoising has been effective specifically in the detection of defects within bearing inner races [12]. It allows the analysis of vibration signals as they change with time and can detect faint fault signatures that are otherwise buried in noise.

In cases with very poor signal-to-noise ratios, the time-frequency manifold (TFM) reconstruction method is extremely revolutionary around detecting transient faults [13]. Such a technique is remarkably more efficient than classical wavelet transforms and can be especially useful in the situations where low-level early-stage faults are observed that generate faint signals. Designing user-friendly analysis tools has been of importance too. Signal envelope decomposition has developed interfaces based on MATLAB to separate the frequencies of bearing faults and background noise. To detect spectral content, such tools use band-pass filters and the Hilbert transform and are shown to be quite useful in the detection of outer raceway damage in bearings [14].

Wavelet analysis has become a breakthrough technology behind the identification of bearing faults. The wavelets have been found to offer better speed at measuring defects in outer races than FFT-based traditional techniques [15]. This method excels in detecting small known defects that conventional frequency analysis might miss. Wavelet-based denoising is especially appealing to real-time applications due to the computational efficiency of such a method. Speed comes in handy in applications, mostly in industrial applications where there is an urgent need to act on fault detections [16]. Recent developments involve autoencoder-based denoising procedures that can boost faint fault signals in a noisy industrial setting. In practice, these strategies have worked better compared to standard FFT analysis whenever tested on actual bearing datasets, and thus there is the promise of integrating traditional signal processing methods with contemporary machine learning techniques. The need to achieve real-time fault allocation has motivated the creation of embedded systems dedicated to bearing monitoring. Fault diagnosis systems with a microcontroller are a major improvement in the field. Such systems can read vibration signals in real-time and send the results via IoT systems, demonstrating incredible increases in efficiency. Some implementations have minimized processing delays by 60 percent or more compared to traditional PC-based analysis processes [17].

The concept of mixing between traditional signal processing and machine learning has created new ground in the sphere of fault detection accuracy. Wavelet packet transform along with Support Vector Machines (SVM) is one such successful hybrid. In this approach, feature extraction occurs based on wavelet packet transform, and fault classification is achieved with SVM with a maximum accuracy of 96 percent reported on standard bearing datasets. The area has not been left behind by deep learning, which has contributed to the emergence of deep wavelet neural networks (DWNN). These systems are self-taught on optimal wavelet bases to detect a fault, so there is no requirement of manual selection of features, nor is there much expertise necessary to deploy the system [18].

The Programmable System-on-Chip (PSoC) and Field-Programmable Gate Arrays (FPGAs) have emerged as the most significant technologies with the ability to provide high-speed processing and the re-configurability facility. Vibration analyzers that use PSoC are capable of FFT analysis (in real-time) and sending information to monitoring interfaces via wireless data transmission. Such systems have already been tested successfully on industrial motors and have addressed the issue of early fault detection. The FPGA implementation is specifically useful for high-speed monitoring machines. These systems eliminate huge delays incurred in the computations through parallelization of wavelet decomposition processes and thus are suitable in an application that requires a fast response [19].

Improvements in user interface and visualization have played a large role in the practical application of the fault detection systems. The graphical programming flexibility and real-time visualization capability have made LabVIEW-based condition monitoring more popular. These systems combine different methods of analysis, kurtosis, and envelope analysis giving a complete method of bearing fault detection. Newer implementations tend to incorporate cloud-based notification systems to immediately notify them of a fault, allowing timely responses to issues as they arise. The ability to integrate LabVIEW and Python-based machine learning models has only added to these functionalities to allow the real-time classification of bearing faults based on techniques such as Random Forest [20].

A new smart workbench, built using PSoC and LabVIEW, aims to fill the gap between expensive industrial equipment and affordable, portable options. This makes advanced fault diagnosis available to small and medium-sized businesses and schools. Research really highlights the demand for a clever, budget-friendly workbench that combines embedded processing with virtual instruments. This system uses PSoC and LabVIEW to offer a real-time, adaptable solution for diagnosing bearing faults, fitting in perfectly with the smart maintenance ideas of Industry 4.0 [21].The Smart Workbench for Ball Bearing Defect Identification rectifies these deficiencies by employing embedded signal processing via a PSoC microcontroller for real-time Fast Fourier Transform (FFT) and feature extraction, thereby diminishing reliance on external computing systems, while integrating discrete wavelet transforms (DWT) with streamlined machine learning models to enhance accuracy, all supported by a LabVIEW graphical user interface (GUI) that offers an interactive dashboard for immediate fault diagnosis and predictive maintenance notifications[22].

## 2 Design and development of workbench

This research framework examines the brief transient vibrations elicited by the impact of a small hammer on the test specimen that result in a mechanical disturbance. Throughout the operational phase, a MEMS accelerometer affixed to the exterior surface of the ball bearing records vibration signals over a designated temporal span, thereby furnishing essential insights regarding the condition of the bearing's health. Figure 1 delineates the schematic representation and underlying principles of the impulse excitation methodology utilized for the identification of bearing faults.

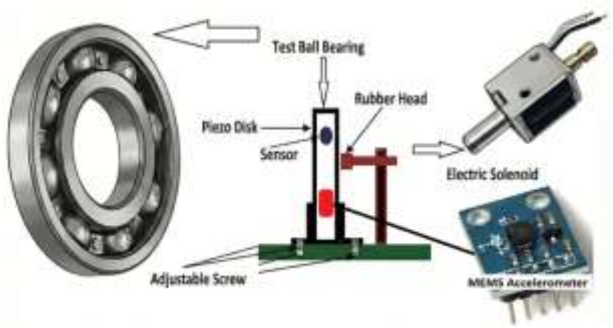


**Fig. 1.** Schematic view of the impulse excitation technique used in the bearing fault detection system

### 2.1 Design of Workbench in CATIA

The experimental configuration was meticulously designed and developed by using CATIA software. The elements were generated through part modeling and subsequently integrated in the assembly workbench. The configuration encompasses several pivotal components base plate that serves as the structural foundation, brackets designed for support and mounting, the ball-bearing subject to testing, a solenoid valve adjustable fixture to ensure precise positioning, and an assortment of nuts and bolts to facilitate secure assembly and integration of components. Figure 2 base plate, it act as the foundational element for the comprehensive experimental configuration, incorporating methodically positioned apertures for the attachment of brackets. It was conceptualized in accordance with defined measurements, initially originating as a two-dimensional diagram within the sketching workbench prior to its evolution into a three-dimensional component design. The design methodology employed linear and rectangular commands within the sketching workbench, while the ultimate modeling was executed utilizing Pad and Pocket commands to fabricate the exact structural base necessitated for the experimental apparatus.

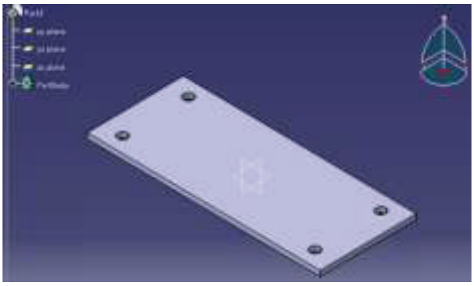


**Fig. 2** Design of Base Plate

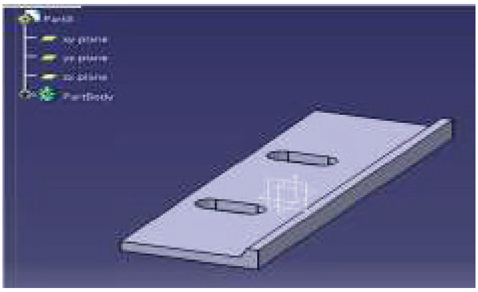


**Fig. 3** Design of Brackets

Figure 3 shows the brackets, design of brackets configuration incorporates two distinct types of brackets: one specifically engineered to secure the bearing, while the other serves the purpose of mounting the solenoid valve. Each bracket is equipped with elongated apertures that facilitate the accommodation of bearings with varying dimensions, thereby enhancing testing versatility. The design methodology employed line, arc, and fillet commands within the sketching workbench, whereas the solid components were generated utilizing pad and pocket commands to fabricate robust, adjustable mounting elements that guarantee proper alignment and stability throughout the testing processes.

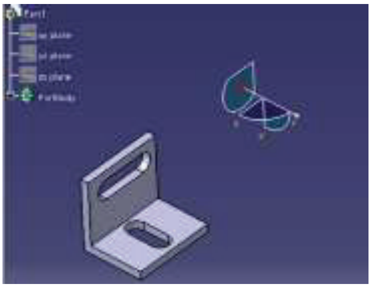


**Fig.4** Design of Side support plate

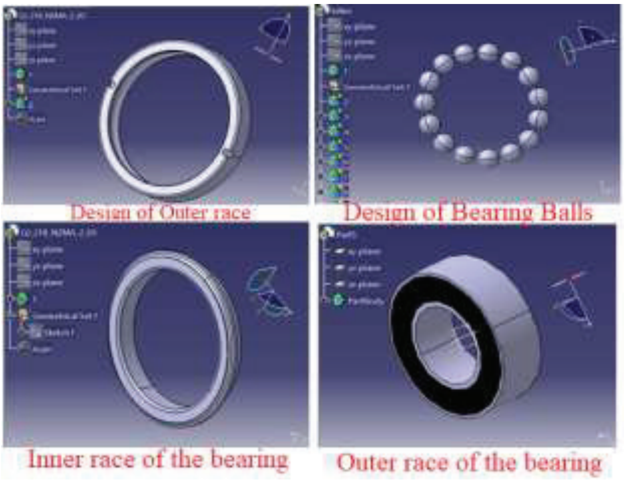


**Fig. 5** Design of Ball bearing components

The ball bearing components design are shown in the figure 5, the inner race, outer race, and balls are conceptualized in the part modeling phase utilizing pad, pocket, and revolve commands; subsequently, these sub-components are integrated within the assembly workbench. The solenoid valve is used to give the trigger input on the inner race of the bearing, the designed figure is shown in the figure 6. The valve is designed as per the dimension in the part design workbench. In this design, the plunger end is designed with a rubber push.

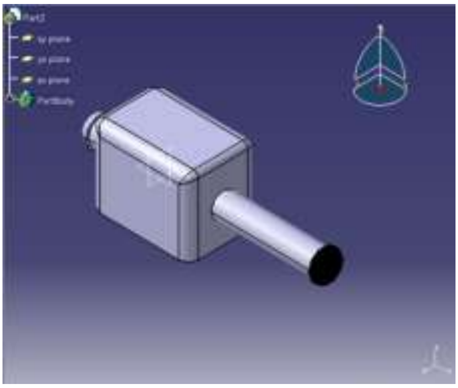


**Fig. 6** Designed view of the solenoid valve

### 2.2 Assembly of the Experimental Setup

The components used for the experiments are assembled in the CATIA model assembly workbench, as shown in figure 7. Here the constraints like fix component, fix together, offset constraint, coincidence constraint, and contact constraint are used for the experimental setup. The test bench assembled view is shown in figure 8.

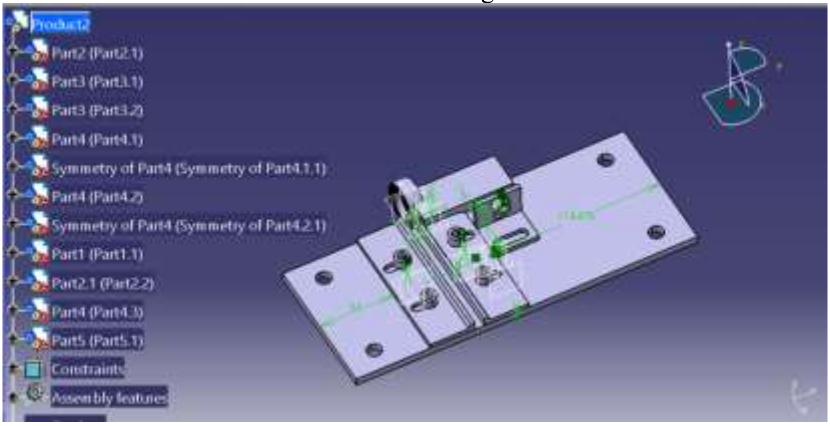


**Fig. 7** Basic assembly of the workbench

## 3 Experimental setup

The workbench of ball bearing tests has been designed and developed to aim at the overall analysis of the ball bearing conditional monitoring. This test workbench was justified by the 6000 series ball bearings, i.e., 6201, 6203, and 6300. A carefully prescribed environment is obtained by means of a solenoid valve to contact the ball landing with the ball bearing to validate bearing performance under different operation conditions. The defect-free bearings have excellent mechanical contact properties and make ideal interfaces between the rolling elements and raceways. This optimum contact state removes surface irregularities that have the potential to produce undesirable vibration patterns. This smooth resultant rotational movement gives rise to vibration patterns consisting largely of the fundamental excitation frequency and little harmonic content or sideband activity. Mechanical integrity of the new bearings helps to specify that the only primary excitation frequency can be seen in the spectrum, meaning even distribution of the loads and no surface flaws or contamination. The whole-of-bearing approach to diagnostics allows this advanced technology to bear fruit in the form of reliability in operations and safety promotion accompanied by cost savings during the usage of such technology in industries.

**Fig.8.** Work bench assembled view

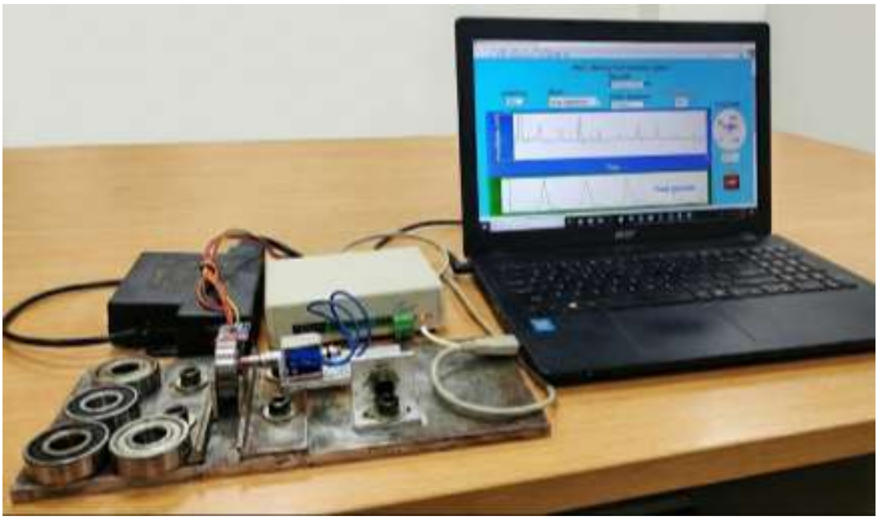


**Fig.9** LabVIEW controlled PSoC embedded test bench for bearing fault detection system

Fig.9 shows the designed and developed indigenously built test work bench that uses an adjustable mounting clamp, which can receive bearings of different sizes and types. The apparatus consists of an electrically driven solenoid which acts as a hammer; the tip mounted on rubber is adjustable to give controlled blows to the inner race of the test bearing. This design uses a tri-axial accelerator of ADXL335 on the outer race of the bearing to obtain vibrations in the housing and the performance of the bearing to controlled impact stimulation can be analyzed comprehensively.

The study article describes an extensive embedded system that applies a MEMS-based approach to vibration analysis and bearing fault detection, utilizing a programmable system on a chip (PSoC) structure. The fundamental piece of the sensing involves the triaxial accelerometer ADXL335, a high-precision MEMS sensor with a minimum range of +/-3g in both static and dynamic acceleration along X, Y and Z axes. It has a complex micro-machined polysilicon sensor architecture, including built-in signal conditioning circuitry; the signal conditioning circuitry analysis is based on a differential capacitor design where the two plates that form the capacitor (one is the proof mass) move apart (change capacitance balance) due to acceleration. This analog signal which is proportional to the acceleration magnitude is also especially useful in monitoring low-level vibrational patterns, which may be evidence of bearing faults. Through mechanical alignment, the cross-axis sensitivity of the sensor has been minimized, so any remaining cross-axis errors are well within the capacity of system-level calibration.

To produce controlled excitation of test bearings, the system uses a solenoid-actuated impulse actuator, which provides repeatable mechanical shocks. This actuation system requires a 24 V power source to activate the solenoid while it operates on a 5 V supply that powers the sensors and control electronics. The data acquisition and processing central hub is centered on the PSoC 3 microcontroller from Cypress Semiconductor, which exemplifies the hardware-software co-design principle by integrating configurable analog and digital blocks along with built-in microcontroller functionality. The PSoC architecture combines some key functions: a 12-bit Delta-Sigma ADC with high-resolution vibration signal (x2 gain buffer input), an accurately synchronous PWM module to control the solenoids and USB-UART interfaces with high-speed data routing to the host PC.

The development of the system is based on the PSoC Creator 3.0, an effective build-in design environment capable of configuring the hardware with ease using schematics and a friendlier drag-and-drop interface. In this environment, there is a library of pre-certified components (ADCs, PWMs, communication modules) and one can easily add them to any design. The tool computes optimal hardware configurations and associated software APIs automatically, saving much development time and possible mistakes. In operation, it acquires real-time signals from the MEMS accelerometer and also coordinates with the impulse actuator simultaneously, which therefore collects the reliable data used in its analysis.

Data processing is done on two levels: a local level at the embedded system and a remote level using PC-based analyzing. Field diagnostics are possible via real-time LCD module feedback for important vibration data, and distributed raw data may be sent to a LabVIEW virtual instrument on another computer via USB-UART. Such a hyper-phase processing scheme enables fast on-site analysis and detailed offline analysis with LabVIEW, offering a higher degree of signal processing and fault diagnosing techniques. Its programmability allows the signal conditioning parameters (filter cutoffs and sampling rates) to be customized to be able to cope with varying bearing types and fault conditions using a PSoC.

The article highlights some of the innovative features of the design, especially its monolithic design, where sensing, processing, and control capabilities are integrated in one chip design. Such integration makes the system less complex, powerful, and footprint-heavy than the discrete-component alternatives. This flexible I/O system in the PSoC that incorporates eight different drive modes per pin also adds the adaptability in the interface to a variety of sensor needs. Furthermore, the system indicates how the embedded hardware can be naturally integrated with virtual instrumentation (LabVIEW) to design a robust diagnostic testament which distinctively draws together not only the reliability of dedicated hardware but also the analytical advantages of PC-based software.

From an implementation view, the research outlines the entire development process of a research work, including schematic design to firmware implementation. The PSoC creator development system can powerfully simplify the configuration process, using graphical tools, the clock systems, the interconnection of the peripherals, and I/O assignments; all low-level implementation details such as handling interrupt routing and timing constraints are performed automatically. The APIs created abstract complexity of the hardware to enable developers to work on ‘C’ application logic. Such a method is found to be a great way to shorten development cycles without compromising system reliability and performance.

The article ends with an indication of the wider applicability of the system other than bearing fault detection. Other capacitive sensing applications (pressure, humidity, fluid monitoring), using the same architecture, are possible with analog front-end adjustments to the PSoC. The study shows how contemporary programmable system-on-chip technologies could bridge the gap between discrete component and application-specific integrated circuits to achieve the best compromise between flexibility and performance and cost to suit industrial sensing applications. This combination is successful, and MEMS devices with reconfigurable mixed-signal electronics and virtual instrumentation provide an attractive model of the next-generation embedded monitoring systems.

## 3.1 Pseudo Code

From the generated component API’s, the pseudo code of the ‘C’ programming written for the required function of this work. The program demonstrates a typical embedded system pattern with polling-based interaction between different peripherals.

```
// Pseudo code for ADC and UART Communication Program
Constants:
  TRANSMIT_BUFFER_SIZE = 16

Main Function:
  Initialize ADC and UART modules
  Set all data transmission flags to OFF
  Start ADC conversion
  Send "COM Port Open" message via UART

  Infinite Loop:
    // Check for user commands from UART
    Read incoming character from UART

    If character is 'C' or 'c': Set flag to send one ADC sample
    If character is 'S' or 's': Set flag to continuously send ADC samples
    If character is 'X' or 'x': Stop continuous sending
    If character is 'E' or 'e': Set flag to send test data

    // Process ADC data when ready
    If ADC conversion is complete:
      Read ADC value and convert to millivolts

      If single or continuous sending is active:
        Format and send ADC reading via UART
        Turn off single-send flag
```

```
    If test data sending is active:
        Format and send test counter value via UART
        Increase test counter
        Turn off test-data flag
End Function
```

The application debugging process enables full access to contemporary cross-debugging capabilities through PSoC Creator. The program displays an exclusive peripheral debug window which reveals health information for built-in chip components. The program allows breakpoints to be set in the code before executing the debugger. The MiniProg 3 permits the debugger creates an interface between the PC's USB port and the device's JTAG interface to perform of host-to-device connection. PSoC Creator enables functional design reuse through its mechanism that converts functional design elements into reusable components. The development process speeds up dramatically and becomes simpler to create new designs. The method simultaneously decreases mistakes and leads to simplified schematic diagrams. It can authorize the work and use the hardware and software designs to create components, which you can also keep in company-wide component libraries for future projects.

## 3.2 HARDWARE MINIPROG

The hardware requirements for PSoC programming consist of a PSoC Programmer device such as MiniProg3. It enables direct debug functions for PSoC 3 and PSoC 5 architectures and serves as a USB-I2C Bridge for I2C serial debugging of PSoC devices. This tool serves developers through its economical design for building purposes. The MiniProg3 programmer/debugger lets developers choose between different programming and debugging connections. MiniProg3 supports all 8-bit and 32-bit PSoC devices; users can use MiniProg3 to communicate with target devices, it operates between 1.5 to 5.5 volt I/O levels through a connection to USB.

## 3.3 PSOC3 BOARD

A visual diagram of PSoC hardware kit appears in Figure 10. The board links to PC through its built-in USB interface. Standard 5 pin JTAG connector on the device enables MiniProg3 to establish Program debugging connections. The PSoC board draws its power from USB which connects to CPU and lets PC acquire data using USB communication.

**Fig. 10** Indigenously developed PSoC3 Development Board

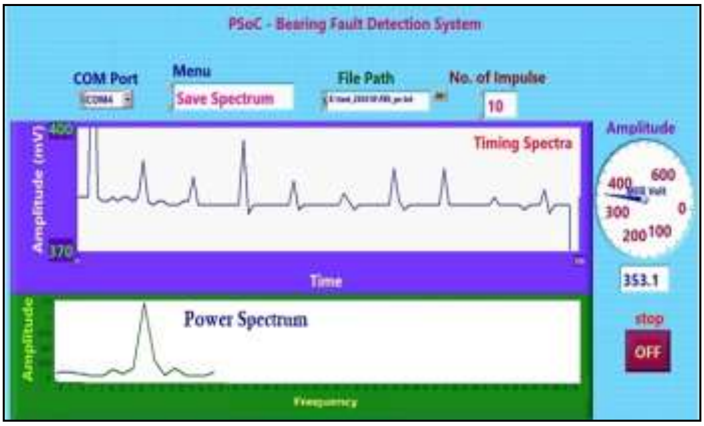
One special capability PSoC offers its users against traditional integrated circuits consists of processing analog along with digital signals within a single integrated device. A single PSoC device brings together numerous capabilities which require several discrete units along with point-and-click programming capabilities as well as adaptable message transfer speeds and module-to-module integration. The extensive functionality of PSoC makes it a perfect choice for demanding embedded platforms since it optimizes system space use and simplifies design with power-efficient results.

### 3.4 LabVIEW Programming

The process control automation which operates remotely relies on virtual instrumentation (VI) as a graphical language for monitoring automated processes. This enhances VI dominance in terms of instrument applications and sensor interface systems. LabVIEW, Laboratory Virtual Instrumentation Engineering Workbench, operates with numerous intelligent hardware elements, including programmable system on chip (PSoC), Microcontrollers, FPGA, and VLSI design based embedded systems. This application develops programs through graphical icons instead of standard text-based programs. LabVIEW functions using a data flow technique to operate as a development environment-based system design platform. The LabVIEW platform allows users to execute data acquisition systems and system monitoring along with system parameter control together with simple data analysis. The vibration signal requires simulation through LabVIEW as well as the execution of signal processing operations within this development environment.

The LabVIEW virtual instrument program sits in PC memory to acquire vibration signals while simultaneously generating two real-time plots which display the signal versus time data and auto-calculated power spectra of the acquired vibration waveform. The system contains a locally built mechanical platform that connects with PSoC embedded design and the LabVIEW virtual instrument program (VI) to implement the impulse excitation technique (IET) for bearing health assessment under static motor conditions for any rotating element. The impulse excitation technique stands as a simple approach to measure material elastic properties quickly through its implementation. The testing of composite materials becomes feasible through this measurement method. LabVIEW's front panel menu-driven program contains, VISA configuration of the USB port for enabling communication between PSoC design and LabVIEW menu-driven program residing in the PC. The user required menu selection button to select Measurement mode, Save data mode, Load data from a saved file location, Clear Graph etc., File path selection for data storage and Number of Impulse required for the measurement, i.e., striking inner race of bearing with solenoid mounted hammer and acquiring. Vibration data from MEMS accelerometer, ADXL335 is used as a function of time.

The acquired vibration data through time appears in the top graph while the bottom graph displays the online Power Spectrum created from first graph's vibration data inputs through the power spectrum palette in the LabVIEW program (figure 11). The icon enables the retrieval of an averaged auto power spectrum of a time signal based on vibration data measured by the MEMS accelerometer. The Test Bench hardware design aims to achieve high precision detection of small trigger-induced vibrations by using sensors. After fabrication the workbench serves as a base to install both control hardware and the sensor module for operational use. The hardware operation can be controlled through the embedded PSoC designer by processing data from the virtual instrumentation LabVIEW workbench. The accelerometer and signal input are used in the power spectrum palette analysis of LabVIEW to detect bearing fault signatures.



COM Port
COM4

Menu
Save Spectrum

File Path

No. of Impulse
10

Amplitude
353.1

**Fig.11** Front Panel Diagram of LabVIEW

## 4 Validation

The developed bearing test bench must validate new system designs using experimental testing, which either demonstrates parity to commercial benchmarks or matches predictions. The fabricated test bench enables defect monitoring in ball bearings through a user-friendly setup while performing tests rapidly without generating excessive discomfort. This presents experimental findings obtained from the test bench that confirm the success of the designed system. The amplitude wave pattern of brand-new bearings is shown in figure 12 and the Power spectrum wave pattern of brand-new bearings is shown in figure 13.

The 6201 bearing installed on the workbench can be activated through a solenoid action. The signal activation produces vibration data that gets recorded through the accelerometer, which later gets processed by LabVIEW amplitude plots while conducting frequency spectrum analysis. The impact of shock waves produces a smooth spectrum with small amplitude during the workbench validation of defect-free new bearings. The defect-free bearings' mechanical contacts form perfectly without any deformation due to the consequences of smooth rotation, which leads to the appearance of excitation frequency alone.

The workbench contains a brand new 6203 bearing that receives power through solenoid activation. The triggered signal allows data collection from the accelerometer to produce vibration information that then may be analyzed through LabVIEW amplitude plots and frequency spectrum analysis. Typical workbench validation utilizes defect-free new bearings to show that shockwave impacts produce smooth spectra while presenting high-amplitude spikes along their sidebands. The quality of its operation can be observed from this evidence. A smooth rotational motion occurs when bearings maintain perfect mechanical contact without any deformation, as only the excitation frequency will be present.

A new 6300 bearing has been installed on the workbench as a part of the solenoid activation process. The signal trigger causes vibration measurements to be captured by the accelerometer, resulting in analysis through LabVIEW amplitude plotting and frequency spectral analysis. A newly manufactured defect-free bearing on the workbench produces a smooth frequency spectrum with distinct amplitude peaks and minimal sideband points. The perfect mild mechanical contact between bearings leads to a smooth rotation that shows only the excitation frequency.

The 6000 bearing operates as a workbench component, which turns on through solenoid activation. The triggered signal produces vibration data that the accelerometer records, while LabVIEW uses the amplitude plot and frequency spectrum analysis to analyze this data. When subjected to shockwaves, the validation process shows a smooth spectrum along with a high amplitude and no sideband when the new bearing lacks defects. The defect-free bearings make mechanical contacts without any deformation, leading to a smooth rotation, which results in the observation of only the excitation frequency.

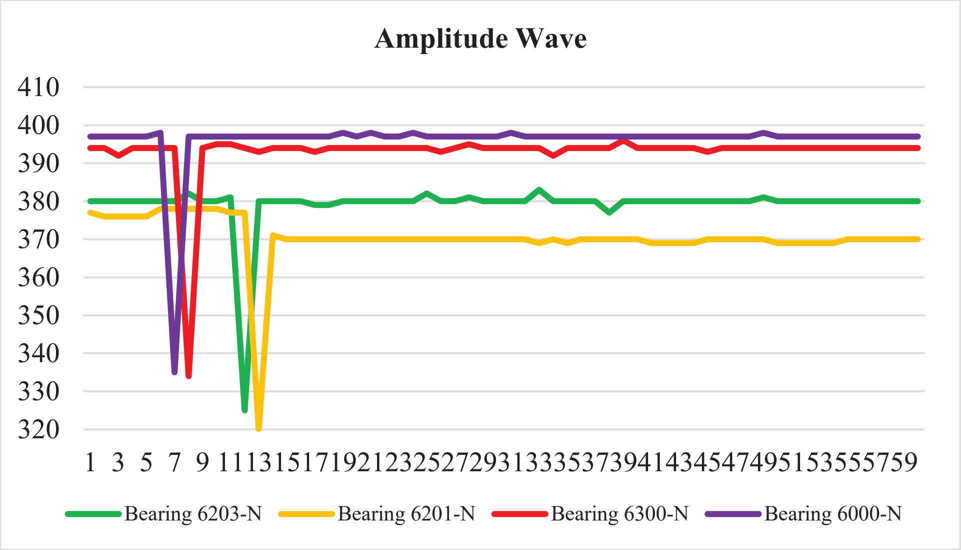


**Fig.12** Amplitude wave pattern of Brand-new bearings

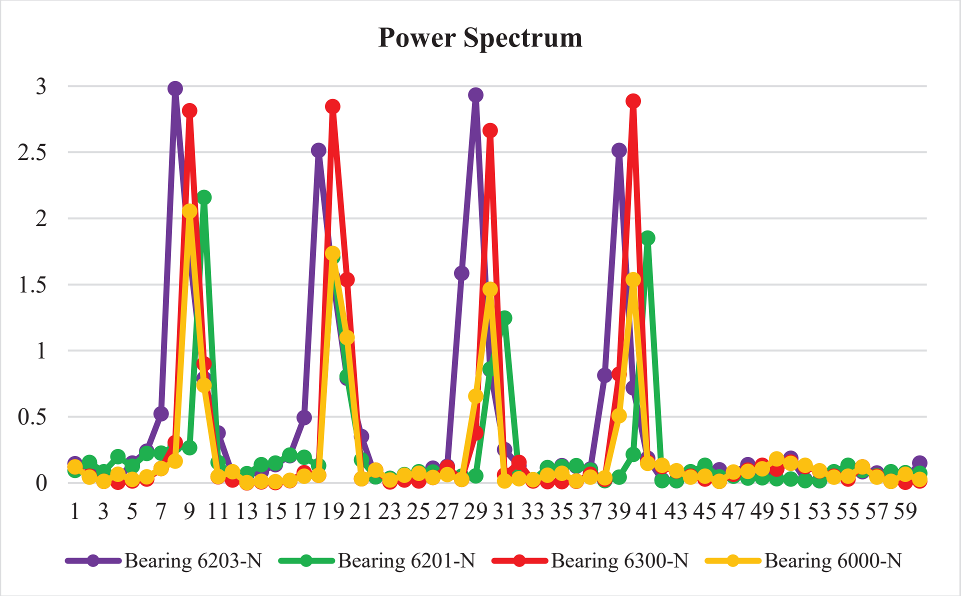


**Fig. 13** Power spectrum wave pattern of Brand-new bearings

## 5 Conclusion

This experimental research work involves the design and development of a ball bearing condition monitoring test bench that integrates an embedded system. The developed test bench analyzes the vibrations and detects faults on the bearing using the MEMS sensors and the Programmable System-on-Chip (PSoC).The results enable validation of the workbench signal and detection of a particular pattern. The power spectrum output from different good bearings exhibits identical patterns across different amplitude ranges, featuring a distinct peak when operating properly, yet occasional minimal variations appear. Power spectrum results between operating bearings and new bearings demonstrate comparable patterns. The test workbench validated with the new 6000 series ball bearings and developed analog output voltages are conditioned and converted to digital for further processing, and its cross-axis interference is minimal as its mechanical design is well calibrated. The wavelet pattern of amplitude of power spectrum waves for the brand new 6000 series ball bearings was determined by using the ADXL335 triaxial accelerometer, which is a high-precision MEMS chip with good sensitivity that can detect dynamic and static acceleration along three dimensions. The sensing mechanism of the sensor allows high-resolution vibration measurements; thus, subtle bearing mechanical faults can be detected well using the sensor. The successful integration of PSoC technology with virtual instrumentation establishes a technological framework that addresses current industrial needs while providing scalability for future technological evolution.

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