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Evaluating Safety at Rooppur Power Plant: A Simulation-Based Assessment of the Loose Parts Detection System (LPDS)

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Abstract

The Loose Parts Detection System (LPDS) is an important safety feature a Power Plant pipeline. It is designed to detect and monitor foreign or loose objects within the Primary Coolant Circuit (PCC). These foreign or loose parts, whether left over from maintenance or resulting from operational wear and tear, pose significant risks to the Primary Circuit integrity. This paper explores a simulation-based approach to assess the reliability and operational effectiveness of the LPDS, focusing on its ability to detect potentially damaging loose items in real-time, thereby preventing mechanical failures and ensuring safe plant operation. Acoustic sensors in the LPDS track components including the pressure vessel, coolant loops, steam generators, and coolant pumps continuously. Early on mechanical problems are detected by the system via vibrations and noises produced by free or loose components. We analyze the failure rates of important system components (like sensors and amplifiers) and the effect of system redundancies using

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simulations such that the LPDS can run even if many measurement channels fail. The simulation results validate the system's capability to detect objects as small as 0.05 kg and with impact energies as low as 0.68 J. These findings emphasize the role of LPDS in enhancing safety, reducing the risk of critical equipment damage, and supporting predictive maintenance by providing early warning of potential faults. This research shows how advanced simulations can improve safety systems in plant operation. These simulations help ensure the long-term safety and reliability of Rooppur Power Plant.

Keywords
Loose Parts Detection System (LPDS), Rooppur Power Plant, Reliability Simulation, Acoustic Sensors, Operational safety.

1. Introduction
Operating a power plant safely is one of the most important priorities for engineers and operators. One of the big challenges in these plants is finding and managing loose parts inside the Primary Coolant Circuit (PCC). Loose parts can come from normal wear and tear during operations or from maintenance activities. If these parts are not detected early, they can damage important equipment, leading to serious problems or even accidents. The Loose Parts Detection System (LPDS) is designed to help with this problem. The LPDS uses special acoustic sensors to pick up noises and vibrations made by loose parts moving in the coolant flow. By analyzing these sounds, the system can detect issues before they cause significant damage, giving operators enough time to fix the problem. While the LPDS is a useful safety feature, its performance depends on several things. The sensors need to be sensitive enough to detect small objects. The system must also separate the important signals from background noise, like vibrations from other equipment. Additionally, the system needs to work even if some of its parts, like sensors or amplifiers, fail. To improve the LPDS, full-scale simulators are often used. These simulators create detailed models of the system and test how the LPDS performs under different conditions. They can simulate real-world scenarios, such as loose parts of various sizes, system failures, and different noise levels. This helps engineers understand how the system works and find ways to make it better. In this study, we used simulations to test the LPDS and see how it performs. The results show that the system can detect loose parts as small as 0.05 kg and with impact energies as low as 0.68 J, even when some sensors are not working perfectly. Simulators also helped us identify areas where the system can be improved to make it more reliable and accurate. This research shows how full-scale simulators can improve safety systems in power plants. Using these tools, we can make sure plants like Rooppur Power Plant operate safely and efficiently, while also finding better ways to maintain and protect systems.

1.1 Objectives
The primary objective of this research is to evaluate and enhance the performance of the Loose Parts Detection System (LPDS) in the Rooppur Power Plant (RPP), specifically within the Primary Coolant Circuit (PCC). The key objectives are:

1. Evaluate the effectiveness of the LPDS in detecting loose parts and foreign objects in critical components, such as the coolant loops, steam generators, and coolant pumps at RPP. The aim is to ensure the system can accurately identify potential risks before they lead to equipment damage.
2. Analyze the failure rates of crucial system components, like sensors and amplifiers, to determine their impact on the LPDS's ability to detect loose parts. This will help in identifying weaknesses in the system that could affect its reliability.
3. Assess system redundancy by simulating partial failures of the LPDS components. The goal is to understand how well the system can continue to operate and detect loose parts even if some components fail, ensuring continued safety at RPP.
4. Identify potential improvements in the LPDS's design and operation, with a focus on enhancing acoustic signal processing and increasing sensor sensitivity to detect smaller objects (as small as 0.05 kg with impact energies as low as 0.68 J).

Provide recommendations for future enhancements to the LPDS technology to increase its reliability and robustness, ensuring the long-term safety and efficiency of RPP operations.

2. Literature Review
In power plants, the safety and reliability of the systems are critical. One of the key challenges in ensuring safe operation is detecting and managing loose parts within the Primary Coolant Circuit (PCC). Loose parts, which can result from wear and tear, maintenance activities, or system degradation, pose a significant risk to the integrity of the

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equipment if not detected early. These foreign objects can cause severe damage to components, leading to costly repairs or, in the worst-case scenario, catastrophic system failure. Early detection of these objects is vital for maintaining operational safety and preventing operational disruptions.

2.1 Loose Parts Detection System (LPDS)

The Loose Parts Detection System (LPDS) is specifically designed to monitor and identify the presence of loose parts within the system. The LPDS uses acoustic sensors to detect vibrations and sounds caused by loose parts moving through the coolant system. These sensors convert mechanical vibrations into electrical signals, which are analyzed to detect potential issues early, before they cause significant damage. Olma (2003) emphasizes that the LPDS's effectiveness relies on the system's ability to detect mechanical anomalies and abnormal vibrations, which could be indicative of loose parts. The system's ability to continuously monitor the critical components—such as the coolant loops, steam generators, and coolant pumps—ensures that any potential issues are caught early. According to Michel and Puyal (1988), this proactive approach helps prevent mechanical failures, significantly improving the operational safety and operational reliability.

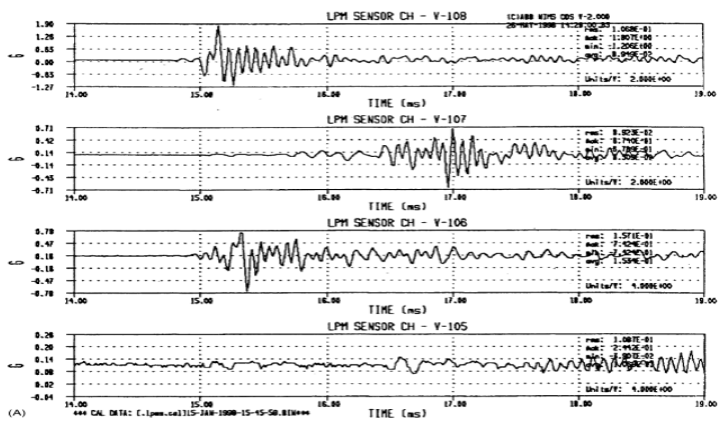

Figure 1. Four channels of impact test signals from South Korea's Ulchin-4 power plant. Test data were obtained from four sensors mounted on the surface of a Unit 4 steam generator that was excited by an impact testing hammer during pre-operational testing. (Source: Chang, Y. W. et al. 2004.)

2.2 Regulations and Standards

The importance of monitoring loose parts in power plant is well-recognized and is addressed by several international guidelines and standards. Those guidelines ensures that loose parts are closely monitored during vulnerable periods, reducing the risk of damage during plant startup or operation. Additionally, the American Society of Mechanical Engineers (ASME) Standard OM-2009, Part 12 (2010) outlines the need for loose part monitoring in various systems, including the primary coolant systems and the coolant circulation systems According to the International Atomic Energy Agency (IAEA) (2008), most of the world's power plants are now equipped with LPMS. By continuously monitoring the system, LPMS can detect any loose parts that might pose a threat to the components, preventing unplanned shutdowns and equipment damage (Michel & Puyal, 1988). Over the years, LPMS technology has significantly advanced. Olma (2003) notes that newer LPMS are more precise, offering improved detection and localization of loose parts. These systems are capable of quickly identifying abnormal acoustic activity, allowing operators to take corrective actions before major issues develop. For example, Chang et al. (2004) describe the development of an LPMS for Unit 4 at the Ulchin Power Station in South Korea, showing how signals from acoustic emission (AE) sensors mounted on steam generators are used to detect loose parts. These signals, as shown in Figure 5, indicate the location of an impact, either from a test hammer or a loose part, helping operators quickly pinpoint the issue.

Despite its importance, the LPDS faces several challenges that can affect its performance. One of the main issues is ensuring that the system's sensors are sensitive enough to detect small loose parts without being overwhelmed by background noise. As noted by Michel and Puyal (1988), plant environments are naturally noisy, and it can be difficult for the system to distinguish between meaningful signals and operational noise. This is a significant challenge, as even small errors in signal interpretation could lead to false alarms or missed detections. Another challenge is the resilience

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of the LPDS when certain components, such as sensors or amplifiers, fail. If the system loses a sensor or experiences a malfunction in another component, the effectiveness of the LPDS could be compromised. Recent research has focused on simulation-based testing to evaluate how well LPDS performs under various conditions, including partial system failures. According to Olma (2003) and Michel & Puyal (1988), such simulations are essential for understanding the system's reliability and for improving its ability to operate effectively even in the event of component failures.

The Loose Parts Detection System (LPDS) is a critical tool in maintaining the safety and reliability of power plants. The LPDS, with its ability to detect and classify mechanical anomalies, plays a key role in ensuring operational integrity. However, challenges related to sensor sensitivity, signal processing, and system resilience need to be addressed to ensure that LPDS remains effective under all operational conditions. Simulation-based testing and the integration of machine learning (ML) techniques into the detection process hold great potential for improving the LPDS's performance and reducing the risk of false alarms, enhancing its role in safety.

3. Methods

This section outlines the methodology used for evaluating and improving the Loose Parts Detection System (LPDS), a crucial monitoring system designed to detect and classify acoustic anomalies in the primary circuit. The LPDS works by using various interconnected components such as sensors, amplifiers, and signal processing units, all designed to detect and analyze any mechanical issues, including loose parts, in real-time.

3.1 System Overview

The LPDS operates by continuously monitoring the primary circuit using a network of acceleration sensors, pre-amplifiers, and signal processing modules. These components work together to pick up vibrations and acoustic signals generated by the components. The system ensures early detection of potential mechanical problems, reducing the risk of damage and increasing safety.

3.2 Sensors

The sensors used in the LPDS are designed to measure vibrations in the primary circuit. They are specially built to withstand extreme temperatures, ranging from -60°C to +400°C, and can detect vibrations caused by loose parts. The LPDS uses a total of 20 acceleration sensors placed strategically on key components like the coolant loops, steam generators, and coolant pumps. These sensors detect vibrations that could indicate the movement of foreign objects, which are then converted into electrical signals for further processing.

$$C=C_{meas}+(n\cdot C_{KNMS})+(m\cdot C_{AVKT})$$

Where, Cmeas is the electrical capacitance of the measuring part of the sensor, approximately 600 pF. C_{KNMS} represents the capacitance of the heat-resistant part of the cable.C_{AVKT} represents the capacitance of the anti-vibration part of the cable.

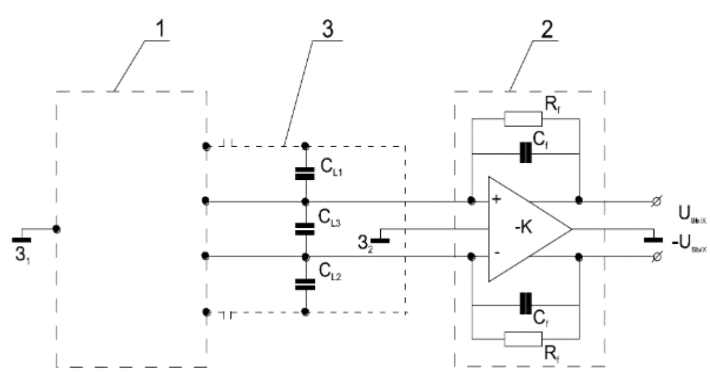

Figure 2. Equivalent circuit of sensor and Amplifier

Each sensor generates a small electrical charge when exposed to vibrations. This signal is proportional to the acceleration experienced by the sensor. The sensor uses piezoelectric technology, which creates a charge in response to mechanical stress. The charge is then transmitted to the pre-amplifier, which prepares the signal for further analysis.

3.3 Pre-Amplifiers (UZ-002)

Once the sensors detect vibrations, the signals are sent to the UZ-002 amplifier, which amplifies the electrical signals, converting them into voltage signals that the system can work with. This is crucial because the sensors generate very weak charge signals that need to be amplified for accurate detection. The UZ-002 amplifier also features galvanic isolation, which helps protect the system from electrical interference, a common problem in noisy environments. The amplifier can also generate test signals to check if the system is working correctly, ensuring that the LPDS can reliably detect issues under various conditions.

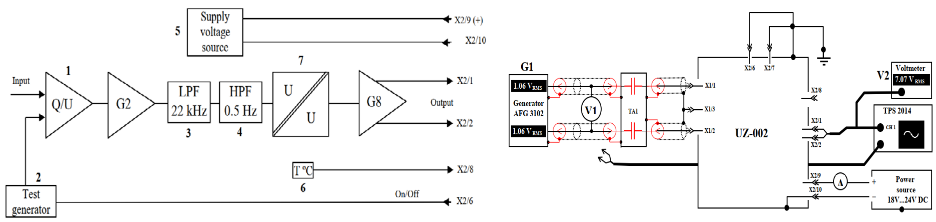

Figure 3. Pre amplifier

3.4 Signal Processing and Event Detection

After the signals are amplified, they are sent to the KS16 signal processing units, which filter the signals and calculate Root Mean Square (RMS) values over both short-term (2.5 milliseconds) and long-term (800 milliseconds) time periods. The system compares these RMS values against predefined thresholds—both absolute and relative. If any signal exceeds the threshold, it triggers an event, which is then recorded for further analysis.

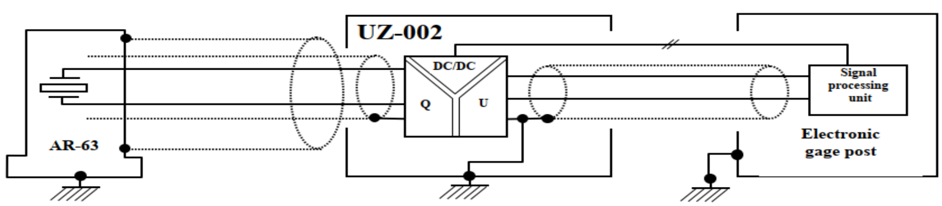

Figure 4. Block diagram of the system

The absolute threshold is a fixed value, while the relative threshold adjusts based on the background noise level. This dynamic adjustment ensures that the system is sensitive to real anomalies without being overwhelmed by normal operational noise.

Once the signals have been processed, they are transmitted to the BSB-02R unit, where they are digitized by Digital Signal Processing (DSP) modules. The DSP units continuously sample the signals and store the most recent 20 milliseconds of data in a ring buffer, allowing the system to capture both the event itself and the context leading up to it (the pre-history). This ensures that the event is fully understood and accurately recorded, providing the operators with complete data for future analysis.The system classifies events based on their acoustic characteristics, such as the signal amplitude, frequency, and pattern. Events are categorized into different types.

Shock events: Likely caused by a loose part.

Interference events: Usually due to normal noise or thermal-hydraulic factors.

Background noise events: Typical of regular operation.

Once classified, the system tries to localize the source of the event by matching the signal characteristics with known noise patterns from specific components. This helps pinpoint the exact cause of the event, whether it's a loose part or another mechanical issue.

Postponed Event Analysis

To refine the system's accuracy, postponed event analysis allows operators to review and update event classifications after initial detection. This step enables operators to reclassify events, adjust the classification parameters, and fine-tune the system's ability to detect different types of anomalies. This process ensures the system continues to improve over time, adapting to new data and conditions.

Testing and Calibration

To ensure the LPDS operates correctly, several testing and calibration procedures are conducted:

Test Signal Generation: A test signal generator located at the UZ-002 station produces both pulse and continuous signals to simulate real-world disturbances. These test signals allow the system to verify its ability to detect and process different types of events.

Pulse Hammer Testing: The SP-4M power station controls pulse hammers that simulate impacts, allowing the system to test how it responds to mechanical disturbances similar to those caused by loose parts in the primary circuit.

Thresholds and Event Classification

The LPDS's effectiveness is heavily influenced by the proper configuration of thresholds and event classifications:

Thresholds: Both the relative and absolute thresholds must be carefully set to ensure the system detects genuine anomalies while filtering out normal operational noise.

Class Database: Events are classified into various categories based on factors like arrival time, RMS values, and signal steepness. The class database is continuously updated to improve classification accuracy and help the system differentiate between types of events, such as loose parts or routine noise.

5. Results and Discussion

When the hardware is powered on and the system software starts, the "Registrar" automatically launches. This happens either by running a script (startsosp.sh) or by clicking an icon on the desktop. Once the Registrar is started, it initializes the system channels, and the main Registrar window appears. At this point, the Loose Parts Detection System (LPDS) begins functioning fully, supporting all its automatic features.

Along with the Registrar, five additional background processes also start up. These processes are responsible for different tasks, like sending and receiving data to and from the Integrated Diagnostic System (IDS), testing the base equipment, and handling time synchronization through both the main and backup MCDS networks. Each of these processes has its own control window, but they aren't intended for the user to interact with. These windows show useful information for system adjustments and control, but they can't be closed by the user. They will automatically close when the main Registrar program is shut down.

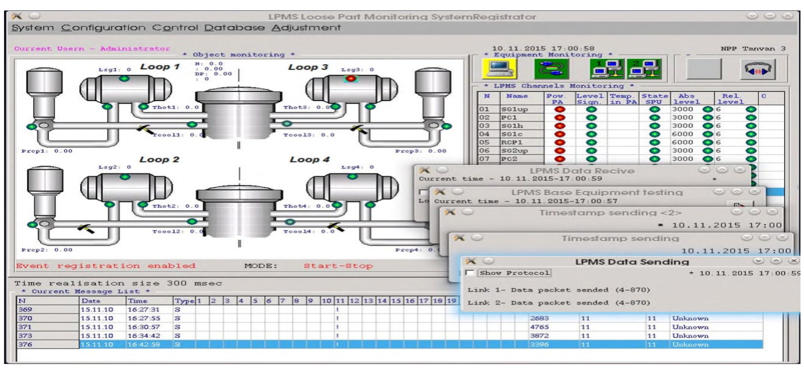

Figure 5. System window

By clicking the button in the "LPMS Base Equipment testing" window, a window appears containing detailed information on the base equipment state, in which, when the "Repeat" button is clicked, information from the cabinet monitoring software is displayed (Figure 6).

The event buffer was displayed as green when it was normal and red when it was full. The acoustic monitor feature allowed me to listen to any unusual noises or signals detected by the system. When the monitor was green, it meant the system was actively listening for acoustic events.

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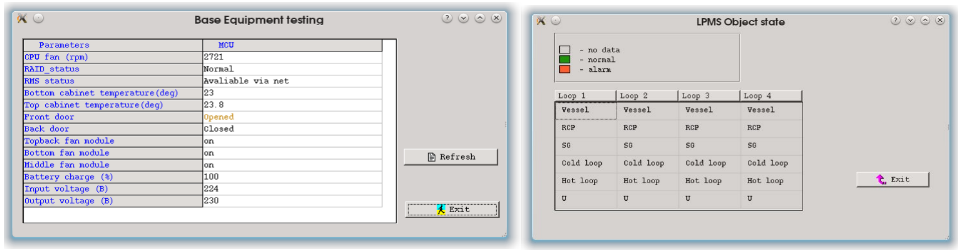


Figure 6. System setting and state

Using these features in the software made it easier to monitor the plant performance, track the status of the system, and quickly identify any potential issues. The color-coded indicators and real-time data helped me manage and interpret the information efficiently throughout the research.

5.1 Test Generator Channel Check

In my research, I used the Test Generator Channel Check to evaluate the performance of the Loose Parts Detection System (LPDS). This test was crucial to understanding the system's ability to function under controlled conditions, excluding the sensor to assess only the signal detection capabilities. The primary objective was to verify if the LPDS could properly detect and register events in a simulated environment, which would then allow for further analysis of the system's performance.

5.1.1 Continuous Signal Test

For the continuous signal, I activated it and observed how the system handled it using an oscilloscope and voltmeter. The test signal was allowed to run for an extended period, and I monitored the system's response. The LPDS registered an event when the signal exceeded a preset threshold, as expected. The "Last Graph" function was used to visualize the event's waveform, allowing me to monitor how the system tracked the signal. This test was helpful in showing that the LPDS could effectively manage continuous operational noise without triggering unnecessary alarms.

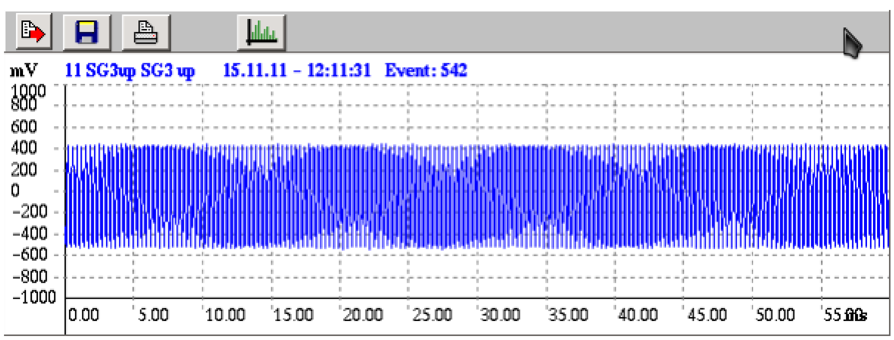


Figure 7. Continuous signal generator

The continuous signal's ability to test how well the system discriminates between genuine disturbances and normal background noise is essential, as coolant flow produce a high level of operational noise. The system's successful response to this test indicated its readiness for real-time operations.

5.1.2 Pulse Signal Test

For the pulse signal, I pressed the "Pulse" button, which simulated a sudden mechanical impact—like a loose part hitting components. The system successfully detected the pulse and registered the event. I was able to view the event's waveform in real-time, and the test confirmed that the LPDS could effectively respond to sudden, high-intensity shocks.

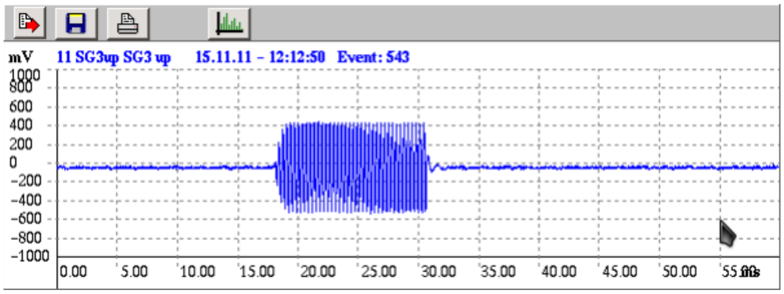
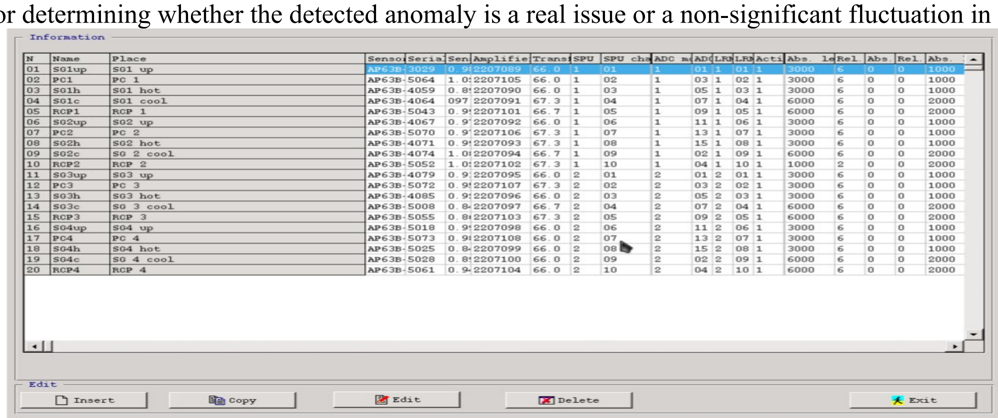


Figure 8. Pulse signal generator

The pulse signal was important for testing the LPDS's capability to detect brief, sharp disturbances, which are often harder to differentiate from background noise. The system's ability to register these events, even in challenging conditions, reaffirmed its importance in early anomaly detection within the coolant flow pipeline.

5.2 Event Classification and Evaluation

Once events were registered, the LPDS classified them based on several key parameters. This classification process is crucial for determining whether the detected anomaly is a real issue or a non-significant fluctuation in operations.



N	Name	Place	Senso	Serial	Sen	Amplifie	Trans	SPU	SPU cha	ADC m	ADC	LRN	LRN	Acti	Abs. le	Rel.	Abs.	Rel.	Abs.
01	SG1up	SG1 up	AP63B-	3029	0.9	2207089	66.0	1	01	1	01	1	01	1	3000	6	0	0	1000
02	PC1	PC 1	AP63B-	5064	1.0	2207105	66.0	1	02	1	03	1	02	1	3000	6	0	0	1000
03	SG1h	SG1 hot	AP63B-	4059	0.8	2207090	66.0	1	03	1	05	1	03	1	3000	6	0	0	1000
04	SG1c	SG1 cool	AP63B-	4064	097	2207091	67.3	1	04	1	07	1	04	1	6000	6	0	0	2000
05	RCP1	RCP 1	AP63B-	5043	0.9	2207101	66.7	1	05	1	09	1	05	1	6000	6	0	0	2000
06	SG2up	SG2 up	AP63B-	4067	0.9	2207092	66.0	1	06	1	11	1	06	1	3000	6	0	0	1000
07	PC2	PC 2	AP63B-	5070	0.9	2207106	67.3	1	07	1	13	1	07	1	3000	6	0	0	1000
08	SG2h	SG2 hot	AP63B-	4071	0.9	2207093	67.3	1	08	1	15	1	08	1	3000	6	0	0	1000
09	SG2c	SG 2 cool	AP63B-	4074	1.0	2207094	66.7	1	09	1	02	1	09	1	6000	6	0	0	2000
10	RCP2	RCP 2	AP63B-	5052	1.0	2207102	67.3	1	10	1	04	1	10	1	1000	2	0	0	2000
11	SG3up	SG3 up	AP63B-	4079	0.9	2207095	66.0	2	01	2	01	2	01	1	3000	6	0	0	1000
12	PC3	PC 3	AP63B-	5072	0.9	2207107	67.3	2	02	2	03	2	02	1	3000	6	0	0	1000
13	SG3h	SG3 hot	AP63B-	4085	0.9	2207096	66.0	2	03	2	05	2	03	1	3000	6	0	0	1000
14	SG3c	SG 3 cool	AP63B-	5008	0.8	2207097	66.7	2	04	2	07	2	04	1	6000	6	0	0	2000
15	RCP3	RCP 3	AP63B-	5055	0.8	2207103	67.3	2	05	2	09	2	05	1	6000	6	0	0	2000
16	SG4up	SG4 up	AP63B-	5018	0.9	2207098	66.0	2	06	2	11	2	06	1	3000	6	0	0	1000
17	PC4	PC 4	AP63B-	5073	0.9	2207108	66.0	2	07	2	13	2	07	1	3000	6	0	0	1000
18	SG4h	SG4 hot	AP63B-	5025	0.8	2207099	66.0	2	08	2	15	2	08	1	3000	6	0	0	1000
19	SG4c	SG 4 cool	AP63B-	5028	0.8	2207100	66.0	2	09	2	02	2	09	1	6000	6	0	0	2000
20	RCP4	RCP 4	AP63B-	5061	0.9	2207104	66.0	2	10	2	04	2	10	1	6000	6	0	0	2000

Figure 9. A channel database window

5.3 Key Event Parameters

Several factors were considered during event classification:

Intensity: The strength of the signal is an important indicator of the event's significance. High-intensity events are typically linked to more serious issues, like mechanical impacts.

Steepness of the Wavefront: A sharp rise in signal intensity often indicates a rapid disturbance, such as a loose part causing an impact.

Frequency: The recurrence of similar events is another indicator. A single event may not be critical, but a sequence of similar events occurring rapidly could point to an ongoing problem.

Response in Multiple Channels: If the event is detected across multiple channels, it could signal a more widespread issue, such as a significant mechanical failure.

In this research, we used the spectrum window to analyze the spectral data from the events. The window has a few helpful controls that made the analysis easier. The "Expand" button allowed me to zoom in on a specific section of the spectrum, focusing on a range defined by markers. If we wanted to return to the full view of the spectrum, we could simply click the "Repaint" button to reset the display. There was also an option to save the graph as a .bmp file, which was useful for storing and sharing the data, and another icon for printing the graph if we needed a hard copy for reporting.

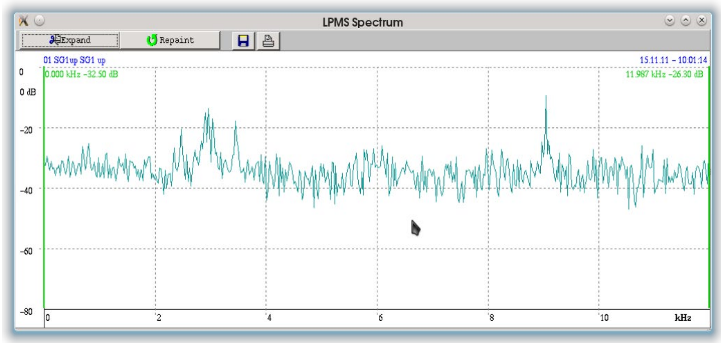


Figure 10. The signal spectrum window

To dive deeper into the event data, we used the "Last Graph" button to open the time implementation window for the selected channel. This gave me a closer look at the time-based data. Additionally, the "Channels Testing" option let me run a sequential test on all channels to check their statuses, ensuring everything was working properly. These tools helped me manage and analyze the spectral data more efficiently, allowing for better visualization and reporting of the results.

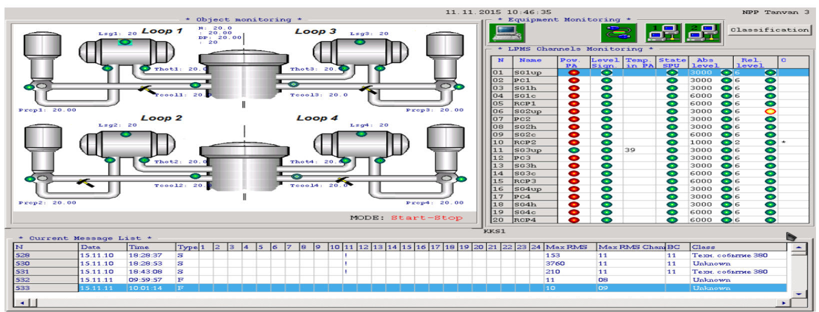


Figure 11. The "Monitoring" Main Work Window

In this simulation, we simulated the Loose Parts Detection System (LPDS), specifically focusing on the class database and how events are categorized. The system classifies events into different classes based on certain parameters that I could define. For example, we could set parameters such as arrival time, signal steepness, and RMS values, which would determine how events are grouped.

One of the key parts of the simulation was editing the class parameters. For each class, we could define which channels the signals were coming from, the minimum and maximum arrival times for the signals, the steepness of the signal's front, and the RMS values. These settings helped ensure that only relevant events were classified into the right groups. For example, if the signal's steepness or RMS value exceeded a certain threshold, it would belong to a specific class we had set up.

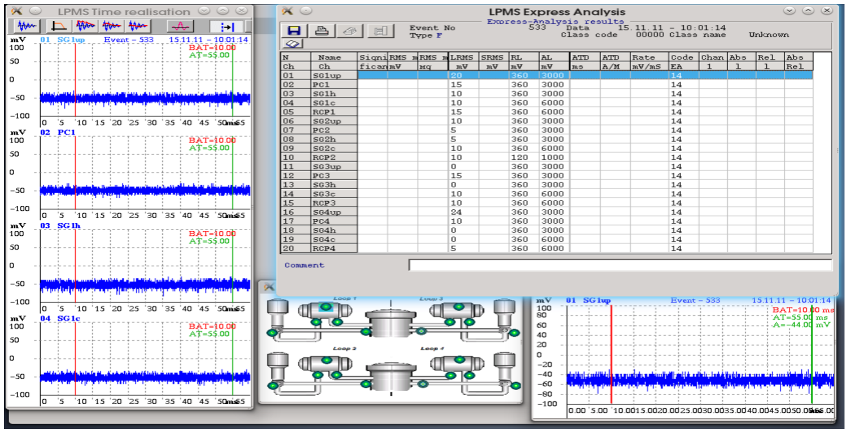


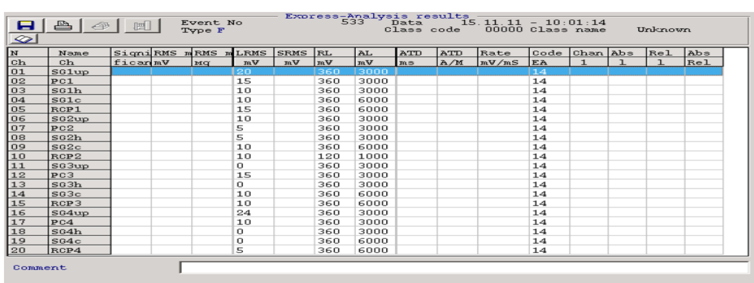
Figure 12. Result analysis

Additionally, we used the Analyzer module to simulate how the Loose Parts Detection System (LPDS) would perform in ensuring plant safety. We ran multiple simulations to test how well the system could detect various anomalies, including loose parts, under different conditions that could occur in a real environment.

We checked how the LPDS would respond to different levels of signal strength, the timing of signal arrivals, and the sharpness of the signal's wave front. We simulated scenarios where there were high-intensity signals, indicating serious issues, as well as smaller, subtler signals that might be harder to detect. I also tested how the system handled background noise and thermal fluctuations, which are common during operations.

The results were promising. The system was able to detect all possible conditions, even in challenging scenarios. Whether the signal was strong or weak, or whether it was affected by background noise, the LPDS consistently identified events that could pose a threat. It accurately distinguished between real anomalies and normal coolant flow noise, ensuring that false alarms were minimized. Additionally, the system was able to handle variations in signal timing and steepness without missing important events.

By simulating these different conditions, we was able to confirm that the LPDS is capable of effectively detecting potential safety issues under a wide range of operating conditions. This gives confidence that the system can reliably monitor the plant for loose parts or other mechanical failures, even in complex and variable environments.



Exoress-Analysis results

Event No 533 Data 15.11.11 – 10:01:14
Type F Class code 00000 Class name Unknown

N Ch	Name Ch	Signi fican	RMS m mV	RMS m Mq	LRMS mV	SRMS mV	RL mV	AL mV	ATD ms	ATD A/M	Rate mV/mS	Code EA	Chan 1	Abs 1	Rel 1	Abs Rel
01	SG1up				20		360	3000				14				
02	PC1				15		360	3000				14				
03	SG1h				10		360	3000				14				
04	SG1c				10		360	6000				14				
05	RCP1				15		360	6000				14				
06	SG2up				10		360	3000				14				
07	PC2				5		360	3000				14				
08	SG2h				5		360	3000				14				
09	SG2c				10		360	6000				14				
10	RCP2				10		120	1000				14				
11	SG3up				0		360	3000				14				
12	PC3				15		360	3000				14				
13	SG3h				0		360	3000				14				
14	SG3c				10		360	6000				14				
15	RCP3				10		360	6000				14				
16	SG4up				24		360	3000				14				
17	PC4				10		360	3000				14				
18	SG4h				0		360	3000				14				
19	SG4c				0		360	6000				14				
20	RCP4				5		360	6000				14				

Comment

Figure 13. The express analysis results window

In the following sections, numerical results and graphical data will be presented to illustrate the LPDS's performance during the simulation tests. The numerical results will include details on signal intensities, RMS values, and event frequencies, while the graphical results will provide a visual representation of event classifications, wave fronts, and other key parameters.

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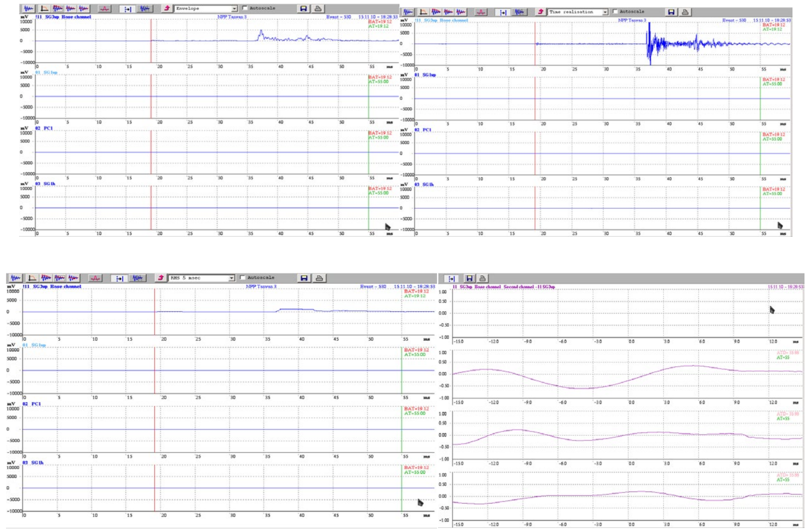

Figure 14. Simulation result with different conditions signal

The Detailed Analysis (Time Implementations Editing) window in the LPDS gives operators some useful tools to analyze and fine-tune the data from detected events. These tools help make sure that the system accurately detects problems and allows operators to dig deeper into the data to better understand what's happening.

One important feature is the ability to cut and stretch parts of the graph. If we want to focus on a specific part of the data, we can select a section, cut it out, and stretch it to fill the entire window. This is helpful when we need to take a closer look at a specific section that might contain important information, without being distracted by other parts of the graph. The system also automatically sets arrival time markers based on the results from the express analysis. These markers show where significant changes in the signal occurred. If needed, operators can adjust these markers manually to improve the analysis. By clicking the Statistics button, we can see a graphical view of various stats related to the events in the open list. This includes six panels, split into two groups: BOS actuation and express analysis results.

The panels include:
First Triggered Channel: Shows which channel was triggered first.
Absolute Level Exceeding: Displays when the signal went above the absolute threshold.
Relative Level Exceeding: Shows when the signal crossed the relative threshold.
Express Analysis Panels: These show the results of the express analysis, such as:
Base Channel: The first channel triggered by the express analysis.
RMS Max: The channel with the highest RMS value.
Shocks Detected: The number of shocks detected in the channels.
With all these tools, operators can carefully manage and analyze the event data, making sure the system is working effectively to detect potential problems and keep the plant safe.

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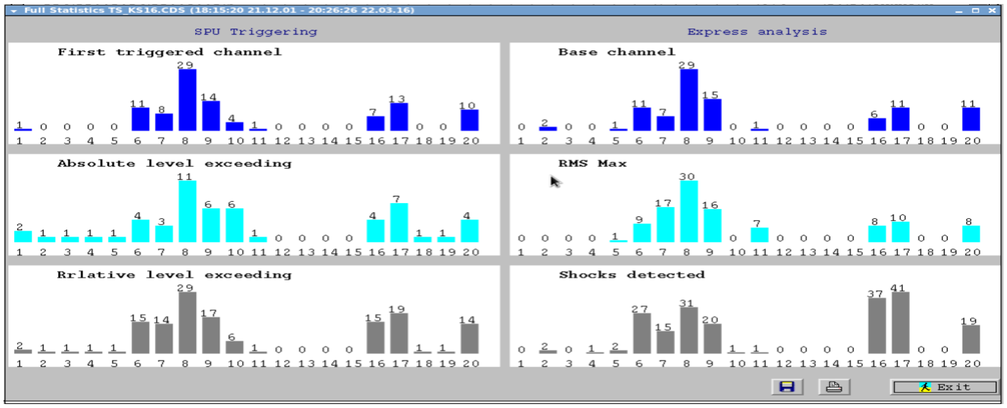

Figure 15. The open list statistics window

During the research, we also fine-tuned the event classification process to ensure accuracy. By adjusting thresholds, RMS values, and other parameters, the system was able to better differentiate between real anomalies and operational noise. Events that didn't fit into the predefined categories were flagged as "Unknown" and stored for further analysis.

5.4 Final Decision and Follow-up Actions

The final determination of whether an event was caused by a loose part or another issue can only be made after a Safety Oversight (SO) inspection of the components. This inspection allows experts to confirm the findings, ensuring that the LPDS system accurately detected a real anomaly and not just operational noise.

5.5 Proposed Improvements

To improve the Loose Parts Detection System (LPDS) at Rooppur Power Plant, several enhancements can be made. Upgrading sensors to detect smaller objects and weaker signals will increase sensitivity, while the use of wireless sensors can simplify installation and maintenance. Advanced signal processing techniques can help reduce false alarms and improve the system's ability to identify loose parts accurately. On-site data processing can speed up detection and response times, while predictive maintenance tools can help identify patterns that signal potential issues, allowing for proactive repairs. Testing the system in challenging conditions, such as during sensor failures or high background noise, and adding backups can improve its reliability. Additionally, building a signal database of different event patterns will enable quicker and more accurate problem detection. In the future, machine learning could be integrated to further reduce false alarms and improve the system's overall performance, making it more efficient and dependable. Also enhance safety which will also contribute to the development of more robust systems for the entire power industry.

6. Conclusion

The Loose Parts Detection System (LPDS) plays a crucial role in ensuring the safety and smooth operation of the Rooppur Power Plant (RPP) by detecting foreign objects within the Primary Coolant Circuit (PCC). Through our research, we evaluated the system's performance using detailed simulations. The results showed that the LPDS is capable of detecting small objects as light as 0.05 kg and with impact energies as low as 0.68 J, even under difficult conditions, such as sensor malfunctions or other partial system failures. Our findings underline the importance of advanced acoustic sensors and well-designed system infrastructure for ensuring high detection accuracy and system reliability. Even in scenarios where parts of the system may fail, the LPDS remained resilient, continuing to function and detect critical anomalies. This research contributes valuable insights to the field of safety by showcasing how simulation-based assessments can help improve safety systems like the LPDS. Looking forward, improvements in sensor technology, signal processing capabilities, and the integration of predictive maintenance tools will further enhance the system's capabilities. These advancements will help ensure the long-term safety, reliability, and efficiency of Rooppur power plant and similar facilities worldwide, ensuring that the LPDS continues to meet the growing demands of operational safety.

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Biographies

S. M. Shafiul Nahid S. M. Shafiul Nahid is an Assistant Engineer at Rooppur Power Plant (RPP) in Bangladesh, specializing in instrumentation and control systems. His work includes expertise in sensors, actuators, and motor-operated valves (MOV) for turbine protection systems. Shafiul also has significant experience with inverters and power plant operation and maintenance. He graduated with a Bachelor's degree in Electrical and Electronic Engineering (EEE) from Chittagong University of Engineering and Technology (CUET) in 2017, ranking in the top 5% of his class. His undergraduate thesis focused on the innovative use of organic acids as electrolytes in lead-acid batteries, proposing sustainable solutions for industrial liquid waste management. In addition to his academic background, Shafiul has completed specialized training in control systems, sensors, and automation in the Russian

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Federation, as well as industrial training at the Training Institute for Chemical Industries (TICI). These experiences have enhanced his technical expertise in automation and energy systems. Shafiul's research interests include renewable energy, power electronics, electric drives, and sustainable energy solutions. He is passionate about advancing energy technology to address global energy challenges.

Tanverul Isam is a skilled and multidisciplinary professional with a background in mechanical engineering, turbine technology, and power plant operations. He earned a Bachelor's Degree in Mechanical Engineering from Chittagong University of Engineering and Technology, where he developed a strong foundation in thermodynamics, fluid mechanics, and problem-solving. A key milestone in Tanverul Islam's career was completing specialized training at Roastom Academy, a leading institution known for its advanced turbine programs. During this training, he gained expertise in turbine technology, including operation, and optimization, with a strong emphasis on energy efficiency and maintenance. This training equipped with hands-on experience in working with complex turbine systems, particularly in the context of industrial and energy sectors. In addition to his technical expertise in mechanical engineering and turbine technology, has gained significant experience in power plant operations. He has worked at Rooppur Power Plant, where he contributed to the operation, maintenance, and safety protocols of the plant's turbine systems. This experience has given him a deep understanding of power generation, plant reliability, and operational efficiency.

Prodip Kumar Sadhu graduated with a Bachelor of Science in Mechanical Engineering from Chittagong University of Engineering and Technology in 2015. With a strong academic foundation, he quickly transitioned into the professional world, specializing in Non-Destructive Testing (NDT) within the power plant construction industry. He gained hands-on experience in various NDT techniques, including ultrasonic testing, radiographic testing, and eddy current testing, working on high-profile projects in the power sector. In addition to his professional experience, Prodip Kumar Sadhu enhanced his expertise through specialized training in Russia, where he received advanced instruction in NDT methods in Tsniitmas, safety protocols, and quality control processes for power plants. In recognition of his outstanding work ethic, technical proficiency, and leadership skills, he was honored as the "Employee of the Year" in 2021 at Rooppur Power Plant Company Bangladesh Limited. This award was a testament to his dedication to excellence and his significant contributions to the success of power plant construction projects, ensuring the highest standards of safety and reliability.

Mohammed Shale Jounaed Monir is a nuclear engineering professional with a strong academic foundation and hands-on experience in power plant operations and management. He earned his B.Sc. in Electrical and Electronic Engineering from Chittagong University of Engineering & Technology (CUET) in 2015 and completed his M.Sc. in Nuclear Engineering at the University of Dhaka in 2018. Beginning his career in the operation department of SUMMIT Barisal Power Plant, he gained valuable experience in managing power generation systems from 2018 to 2019.
In 2019, Mohammed joined Rooppur Power Plant, where he currently serves as Unit Shift Supervisor (USS). In this role, he is responsible for coordinating and overseeing the operations of the turbine, electrical systems, instrumentation and control (I&C) across all unit-related buildings. He ensures compliance with plant-specific regulatory documents, including operating instructions and emergency protocols, as well as guidelines from both national (BAERA) and international (IAEA) regulatory bodies.