CORPUS PUBLISHERS

Journal of Mineral and Material Science (JMMS)

ISSN: 2833-3616

Volume 5 Issue 3, 2024

Article Information

Received date : June 14, 2024

Published date: July 03, 2024

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DOI: 10.54026/JMMS/1087

Key Words

Maintenance Transformation Roadmap (MTR); Time Based & Condition Based to Predictive; SMART Sensor

Abbreviations

IoT: Internet of things; MTR: Maintenance Transformation Roadmap; MTBS: Mean Time between Shutdown; MTTR: Mean Time to Repair; FMEA: Failure Mode Effect Analysis; RPN: Risk Priority Matrix; WTI: Winding Temperature Indicator; UT: Ultrasonic Testing; FTP: File Transfer Protocol; OEM: Original Equipment Manufacturer; FFT: Fast Fourier Transformation; SSID: Service Set Identifier

Mini Review

IoT Enabled Condition Monitoring Under Predictive Maintenance Framework of Mines and Steel Plant

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Abstract

This case is about a century-old integrated steel plant combined with mines, having more than 0.42 million capital-intensive assets, ages ranging from 0 to 100 years and spreads across 700+ hectares as shown in Figure 1. Assets having varied levels of automation maturity with different maintenance methodologies. It's about shifting the whole maintenance paradigm from Time-based & Condition-based to Predictive. Through digital initiatives & optimum maintenance cost, we are trying to develop a Maintenance Transformation Roadmap (MTR) to ensure maximum machine availability/ reliability. For this paradigm shift from conventional to predictive maintenance, critical assets were identified through a systematic approach. Under this MTR Journey, to bridge the sensor gap, SMART Sensor (3 axis vibration & Temperature) was identified as the appropriate solution. Customizable In-house SMART Sensor applicable in Mining & Steel industry application and low-cost solution helped in cross locational horizontal. Presently early warning alerts saved 1000+ potential breakdowns on 1200nos critical assets. The Predictive Maintenance Framework has both tangible and intangible benefits. While safety is the most important intangible benefit of this technology, tangible benefits include approved savings of $20 Million. Further, we expect to save $12.5 Million by deploying our Sensor and $35 Million via prevention of breakdowns in the next 5 years.

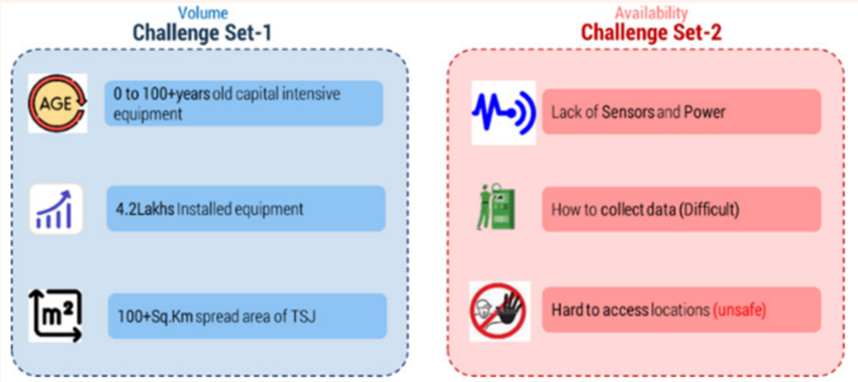

Figure 1: Data collection challenges in steel industry.

Introduction

The rapidly evolving technological landscape, coupled with the increasing complexity of machinery and the ever-present demand for higher efficiency, has made it clear that traditional maintenance methodologies are no longer sufficient. Predictive maintenance is the subject of extensive research and application across various industries. Early works, such as [1-3], emphasized the importance of predicting failures before they occur, thereby reducing downtime and maintenance costs. Analyzing the existing issue, which asset needs more maintenance and contributes to low MTBS, MTTR is very high and causing huge production losses and incurring high costs. Failure Mode Effect Analysis (FMEA) on this type of asset to improve the Risk Priority Matrix (RPN) score, [4-6] Refer Table 1. To improve the RPN Score we can improve the detectability part (i.e. we can detect the upcoming fault in advance and avoid unplanned outages), hence identifying the sensor gap. The evolution of predictive maintenance with a background of Industry 4.0, focuses on the integration of IoT based [7] sensors with advanced analytics to transform maintenance strategies. The use of these sensors and interconnected devices for real-time monitoring of assets generates an early warning to the domain experts. This integration approach enables proactive, data-driven maintenance strategies aimed at preventing issues rather than just fixing them. According to [8,9], IoT provides the foundation for a truly integrated maintenance strategy, where data from various sources can be aggregated and analyzed in a centralized manner (Figure 2). Furthermore, IoT enables the remote monitoring of assets, allowing for timely interventions even in hard-to-reach or hazardous locations [10].

Table 1: Failure mode effect analysis and risk priority number.

		From			To			RPN Before	RPN After			
Equipment Type	**Failure Mode**	**O**	**S**	**D**	**O**	**S**	**D**	**R1**	**R2**	**Alarm or Analytics**	**Possible Solution**	**Types of Sensors Needed**
Gear Box	Bearing failure	5	5	5	5	5	1	125	25	Analytics	Vibration FFT	IoT based Smart sensor
	Teeth failure	2	5	3	2	5	1	30	10	Analytics	Vibration FFT	IoT based Smart sensor
	Coupling failure	2	5	3	2	5	3	30	30	Analytics	Motion amplification	Camera
	Shaft failure	3	5	3	3	5	3	45	45	Analytics	Offline UT	Offline solution
Motor	Bearing failure	5	3	3	5	3	1	45	15	Analytics	Vibration FFT	IoT based Smart Sensor
	Winding failure	3	5	4	3	5	1	60	15	Analytics	WTI Monitoring	WTI Sensor
	Motor Termination failure	5	2	3	5	2	1	30	10	Alarm	Temperature Sensor	IoT based Temperature Sensor
	Shaft failure	2	5	4	2	5	3	40	30	Analytics	Offline UT	Offline Solution
	Foundation failure	4	3	3	4	1	1	36	4	Analytics	Motion amplification	Camera
	Coupling failure	5	2	4	5	2	4	40	40	Analytics	Motion amplification	Camera

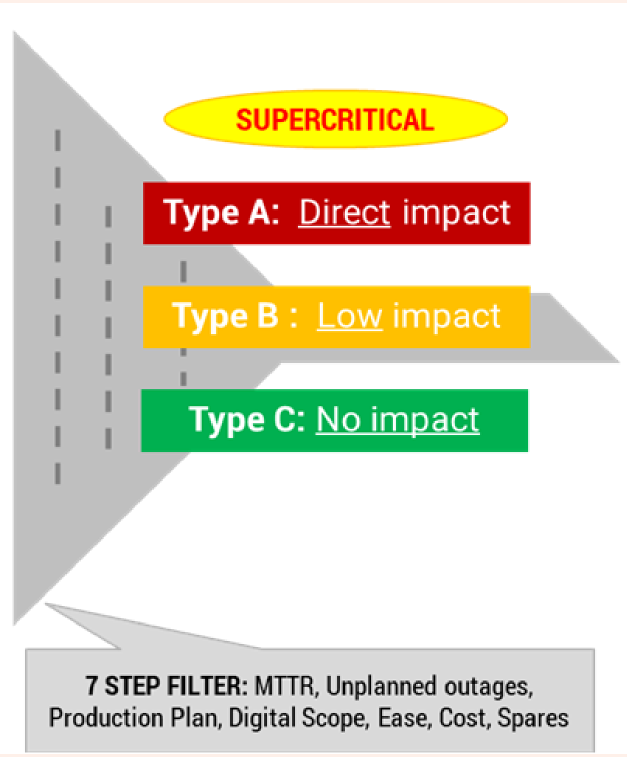

Figure 2: Identification of critical assets.

IoT based SMART Sensors

Analysis depicts the massive numbers of this sensor requirement across the value chain of Mines & Steel plants. Recognizing the limitations of external OEM sensors, especially in terms of customization and turnaround time, there was a clear need for a more tailored solution. To bridge the existing gaps, an in-house vibration monitoring SMART sensor system was developed as shown in Figure 3. The data generated from these sensors is integral to our predictive maintenance practices, playing a pivotal role in averting critical breakdowns. In essence, our methodology, influenced by cross-industry learnings and driven by the need to stay competitive, is a blend of strategic planning, technological innovation, and data-driven decision-making. This holistic approach ensures that our assets, both old and new, are monitored, maintained, and managed with the highest standards of efficiency and reliability.

Figure 3: Inhouse developed smart sensor.

This sensor, designed with capabilities to measure 3-axis vibrations and temperature, was not just another monitoring device. It is a solution meticulously tailored to cater to the unique requirements and challenges of the Mining & steel industry. The journey from its conceptualization to deployment involved several critical stages as shown in the Figure 4. We can observe in Figure 5. that the peak-to-peak vibration of the sensor is around 3g close to the expected value, hence validating that 1g rms (1.414g peak or ~3g peak to peak) is obtained when a mass is loaded on the shaker. We collected data of 1024 sample length by mounting vibration sensor on shaker in vertical position. The known frequency for shaker is 159.2 Hz for determining the accuracy of frequency determination. We obtained the following Figure 6. pulse width for sending data of 1024 samples. For the next step, we have to find the number of samples taken in one cycle. From the above plot, we find the number of points or samples taken between two peaks. We can see that the number of samples taken for one cycle (N) is 63. Therefore, by multiplying the number of samples taken in one cycle(N) with the time taken to calculate one data (T) and by taking the inverse of the product we get shaker frequency. Shaker frequency (F) = 1/(63 x T), F = 159.88715 Hz. The frequency of the shaker obtained is 159.88715 +, which is approximately equal to the desired frequency. error = (known freq. – actual freq.)/known freq. = (159.2 -159.887)/159.2 = 0.004315% error = 0.43% or 4300 ppm

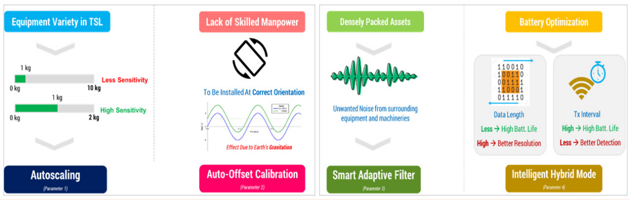

Figure 4: Salient design features of Inhouse developed smart sensor.

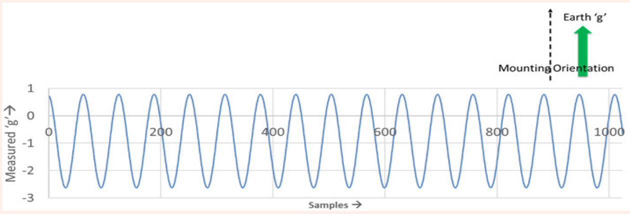

Figure 5: Measured time series vibration.

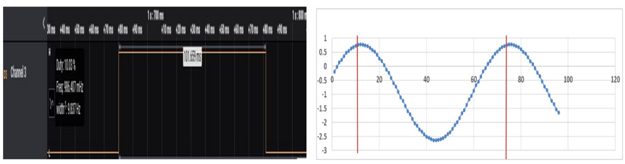
Figure 6: Measured time for 1024 data collection and numbers of samples between peaks.

From the above experiments, we can conclude that the in-house developed vibration sensor is capturing and sending correct data from the shaker. The data obtained is in line with the expected result from the shaker. The in-house developed sensor is deployed at various field sites. The location selected Crusher, fan Bearing application. The data obtained from the sensor was further analyzed and Fast Fourier Transform was performed on the same. The in-house sensor is battery-powered and is mounted on ¼-28 UNCF screw mount. It connects to the Wi-Fi SSID [11] and sends the data to an FTP server [12]. The device is programmed to send data every 4 hours for all the 3 axes. The data is sent in.txt format. Quality analysis data can be seen in Figure 7.

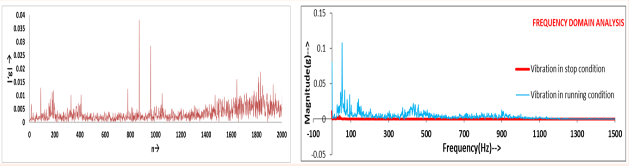

Figure 7: Time domain vibration data and FFT data.

Conclusion

The journey of integrating an IoT-enabled condition monitoring under predictive maintenance framework within the operations of the Mining & steel behemoth has been both enlightening and transformative. This initiative has not only reshaped the way maintenance is perceived but has also set new benchmarks in operational efficiency and asset management. By harnessing real-time data, advanced analytics, and the power of the Internet of Things, the company has transitioned from a reactive maintenance approach to one that is proactive and predictive. The results achieved thus far are just the tip of the iceberg. As the framework continues to evolve and expand its reach, the potential for further savings and enhancements in machine availability and reliability is immense. The development of tools like the SMART Sensor, coupled with the strategic vision of MTR, ensures that the company is well-poised to harness the full potential of this initiative. In wrapping up, the journey of the Mining and steel giant stands as a testament to the power of innovation, strategic vision, and relentless pursuit of excellence. It serves as a beacon for other industries, highlighting the transformative potential of technology when aligned with a clear vision and purpose.

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