

**Wireless condition monitoring to reduce maintenance
resources in the Escravos-Gas-To-Liquids plant,
Nigeria**

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Dissertation submitted in partial fulfillment of the requirements for the degree *Master of Engineering* at the Potchefstroom Campus of the North-West University, South Africa

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Date: November 2011

Keywords

Condition monitoring, wireless sensor networks, availability, Equipment, Cost, Maintenance, Resources, Vibration, Data analysis, Diagnostic, Markovian Technique

Abstract

The purpose of this research is to reduce maintenance resources and improve Escravos-Gas-to-Liquids plant availability (EGTL) in Escravos, Nigeria using wireless condition monitoring. Secondary to the above is to justify the use of this technology over other conventional condition monitoring methods in petrochemical plants with specific reference to cost, reliability and security of the system.

Wireless and continuous condition monitoring provides the means to evaluate current conditions of equipment and detect abnormalities. It allows for corrective measures to be taken to prevent upcoming failures. Continuous monitoring and event recording provides information on the energized equipment's response to normal and emergency conditions.

Wireless/remote monitoring helps to coordinate equipment specifications and ratings, determine the real limits of the monitored equipment and optimize facility operations. *Bentley N, (2005).*

Using wireless techniques eliminate any need for special cables and wires with lower installation costs if compared to other types of condition monitoring systems.

In addition to this, wireless condition monitoring works well under difficult conditions in strategically important locations. The Escravos gas-to-liquid plant in Nigeria, located in a remote and offshore area where accommodation and space for offices is a factor for monitoring plant conditions in every office, is a typical example. Wireless technology for condition monitoring of energized equipment is applicable to both standalone and remote systems.

In the research work of Meyer and Brambley (2002), they characterized the current problem with regards to cost effectiveness and availability of wireless condition

monitoring. Maintenance of rotating equipment provides probability estimates of the total impact of the problem, cost implication of plant equipment maintenance and describes a generic system in which these developing technologies are used to provide real-time wireless/remote condition monitoring for rotating main air compressor (MAC) units and their components as a case study.

Costs with today's technology are provided and future costs are estimated, showing that benefits will greatly exceed costs in many cases, particularly if low-cost wireless monitoring is used.

With management trends such as "re-engineering" and "downsizing" of the available workforce, wireless condition-monitoring of critical machines has been given more importance as a way to ensure quality production with fewer personnel. Wireless condition-monitoring using inexpensive wireless communication technology frees up existing plant maintenance personnel work on machines that are signaling problems and focusing the maintenance efforts away from attempting to work on a large population of machines to only those machines requiring immediate attention.

Lloyd and Buddy (200) suggested that Point-to-point wireless data transmission systems, an excellent example of recent technological advances in communication systems, are now practical and cost-effective for industrial use. While both complex infrastructures and complex protocols are required for cellular communications, non-cellular communication systems, such as the point-to-point wireless data transmission system example, require no elaborate infrastructure.

Limited research was done on the immediate benefits of implementing wireless condition monitoring systems in plants. All papers on the subject have been drawn up by manufacturers of such equipment. This research will thus also deliver a "third-party" perspective on the effectiveness of such devices, justifying their impact on data gathering security, cost and reliability.

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2. Acknowledgement

I would like to thank Chevron Nig. Ltd for hiring me allowing me access to most plant facilities especially the Escravos gas to liquids plant (EGTL) and some offshore production platforms.

To my supervisor, Professor Harry Wichers, who guided me throughout this research and invested a lot of time to read and listen to my ideas and ramblings, and always gave his honest inputs.

To all the Supervisors at work such as Louis Verwey, planners and technicians who have helped me with their knowledge, you all have my gratitude. And most importantly, to my wife Irene who gave her support all through this dissertation.

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3.3 Table 1: List of abbreviations/acronyms

CBM	Condition Based Maintenance
DSP	Digital Signal Processing
DSSS	Direct Sequence Spread Spectrum
DUT	Device under Test
ECM	Equipment Condition Monitoring
EGTL	Escravos gas to liquid
EHM	Equipment Health Monitor
FHSS	Frequency Hopping Spread Spectrum
IEEE	Institute of Electrical and Electronic Engineers
ISM	Industrial Scientific and Medical
ISO	International Standards Organization
JDE	J.D Edwards (A form of CMMS system)
KPI	Key performance indicator
MAC	Medium Access Controller
Mbps	Million bytes per second
MEMS	Micro-Electromechanical Systems
MIS	Management information system
MRVS	Micro Resonant Vibration Sensor
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
MW	Mega Watt
OFDM	Orthogonal Frequency Domain Modulation
OFDM	Orthogonal Frequency Division Multiplexing
PC	Personal Computer
PLCs	Programmable Logic Controllers
PSoC	Programmable system on chip
RAM	Random Access Memory
ROI	Return on Investment
SCADA	Supervisory Control and Data Acquisition
SRAM	Sensor Random Access memory
U-NII	Unlicensed National Information Infrastructure
UWB	Ultra Wide Band
WSN	Wireless Sensor Networks

CHAPTER 1

Overview of Research

1.1 Background

Wireless communication is becoming an acceptable way of communicating various types of information today. When used as designed, wireless technology can significantly reduce the installation cost of asset management systems, permit fast system installation, and provide a long-lasting and reliable communications link. Cost associated to the operations of this method remains a point of argument for professionals. *Bentley N. (2005, p7-17.)*

The maintenance environment has always been a means into which money has been "spent", but this perception is changing rapidly. If the Maintenance section is not properly managed and equipments fail unnecessarily, it is possible that the business will equally fail.

The emphasis therefore has been placed on optimizing the maintenance environment to promote growth and sustained availability through the reduction of maintenance resources as in the case of this dissertation. A plant can no longer afford to have medium terms of average availability followed by periods of intense plant un-availability. These spikes inevitably influence production yields, efficiencies and throughput. All of which influence the bottom line of the company, which is profit. Thus the challenge of maintenance management would be to predict failures 100% accurately.

Cutting down resources by making spares available and operating a maintenance culture where equipments are diagnosed before failure, will go a long way in plant availability and reliability. Such mistakes of scrapping equipment as it fails would have been avoided.

The methodology to adopt in reducing resources would have been to cut costs, streamlining budgets, pooling resources and working smarter (not harder) through employing various tools such as wireless condition monitoring and technologies like Markovian techniques.

In this research work, there are several thematic concerns that must be investigated:

- How is wireless condition monitoring of equipment justified?
- What measurement techniques are really effective?
- Should these parameters be used as protective functions or not?
- Should the measurements be online or periodic?
- What can be done easily to improve the monitoring on existing equipment?

All these are very important questions, but unfortunately there is not one answer to it for all equipment. Based on risk, a main air compressor in a refinery for example, may require a very different condition monitoring approach than a gas lift machine in an oil field application, or a nitrogen compressor in a chemical plant. Addressing the risk, cost and applying the right monitoring approach are the primary objectives of any condition-monitoring project.

Plant performance depends on the performance of major assets, yet research shows that 5% of the world's plant production is lost to downtime every year, and equipment failure is the leading cause. Sharma, (2006)

The result: increased maintenance spending, damaged equipment, and loss of potential revenue. By monitoring equipment health in real time, one can:

1. Predict & prevent process and equipment problems to maximize performance & availability.
2. Detect & diagnose the root causes of poor performance & unplanned downtime.
3. Reduce maintenance costs up to 30% with condition-based maintenance (CBM).
Sharma, (2006)
4. Reduce downtime up to 40% with predictive fault detection. Sharma, (2006)

Most plants use a combination of two common maintenance practices:

- i. Preventative maintenance (service key assets according to a set schedule, whether it is needed or not)

- ii. Reactive maintenance (fix it when it breaks down).

Preventive maintenance is effective, but expensive. Reactive maintenance reduces maintenance costs but runs the risk of serious production losses in the event of major problems. Wireless condition monitoring solutions is very effective. The choice between all techniques is usually made out on financial parameters and risk and would be effective in a terrain like EGTL.

Wireless condition monitoring lets you implement a condition-based maintenance approach, where key assets are serviced based on their actual, current condition and performance. When properly implemented, these solutions can predict serious problems early enough to prevent costly failures, ensure maximum value from your assets, and increase plant availability.

1.1.1 What is Condition Monitoring? (CM)

Condition monitoring as a technique to monitor the performance and condition of equipment in plants is used extensively across many industries, such as, oil and gas, utilities and chemical industries as a critical part of asset management systems. Accelerometers, amongst other techniques, are used to monitor the condition of bearings and rotors in rotating equipment such as motors, fans, pumps and compressors.

Defects in the bearing surfaces and unbalanced or misaligned shafts for instance give rise to vibrations in the machine, ultimately causing machine failure. The frequency of these vibrations is a function of the bearing or shaft construction and its rotational speed, whilst the amplitude is a function of the severity of the problem.

1.1.2 How CM is used in rotating machines

Equipment Vibration Diagnostics:

For successful diagnostics and trouble shooting of rotating machinery, the Vibration analyst must ensure accurate and repeatable quality data collection, and have a detailed and in-depth understanding of the machinery design and operating dynamics to accurately interpret typical fault patterns and symptoms.

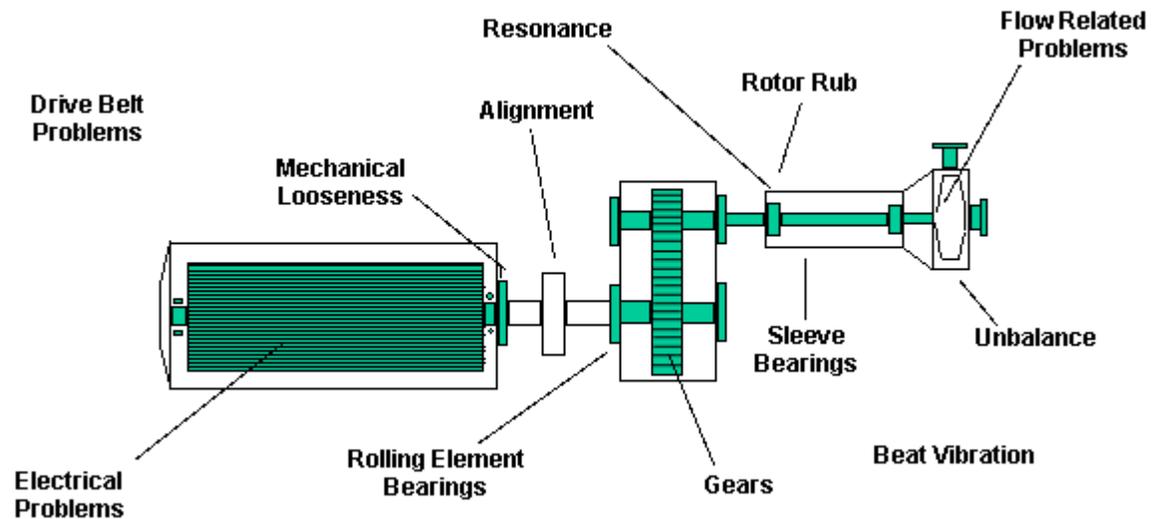


Fig 1 - Typical equipment for monitoring – *Sharma (2006)*

Condition monitoring therefore, is an important technique to use to enable management to make decisions on critical plant equipment to determine when to carry out preventative or corrective maintenance to ensure the required availability of the plant.

1.2 Problem statement

The research as documented in this dissertation was directed towards reducing maintenance resources and increasing EGTL plant availability. There are various ways of doing this; the maintenance strategy currently in use by EGTL is based on Reliability Centered Maintenance (RCM).

Maintenance is a science, based purely on numbers and data. By looking at raw data and making decisions based on tools like Markovian technique, results can be achieved immediately, with little or no capital expenditure. However, no maintenance manager has the time to play with numbers and neither does his research and development team, as they are busy implementing new technologies or improving on the old.

It is possible to implement new technologies which will reduce maintenance resources and increase plant availability in general. One of the focus points of this research will be assessing the efficiency of wireless condition monitoring devices such as the system supplied by "Komatsu". This device reduces the strain on conventional physical condition monitoring resources. By using the internet as a portal to transfer information, it is possible to have managers and outside company monitor the condition of equipment from more than 500km away.

The problem therefore is:

Which tool can be used to implement, interpret figures and simulate systems in complex environment using wireless condition monitoring?

How can new technologies be launched out to achieve maximum results and how viable are they?

These questions are somehow paradox and plant specific. For the purpose of this research, the efficiency of wireless condition monitoring as well as the use of Markovian techniques in reducing maintenance resources and increasing plant availability will be investigated.

The cost of running and implementing wireless condition monitoring in remote areas has been a problem since its inception. This is so because of the needed network infrastructure in such areas, the choice of technique to adopt and the security procedure to adopt (*Reliability.com*).

1.3 Aims and Objectives

The aim with this research is to reduce maintenance resources in the EGTL plant by deploying wireless condition monitoring.

Managers and employees no longer launch investigations into their own business on a higher level in order to identify major inefficiencies. They have become too multi-skilled and monotonously driven towards a certain school of thought.

By using wireless condition monitoring systems it is possible to indicate that wireless diagnostic/early-warning systems have their place in petrochemical plants. The EGTL plant needs to adopt a wireless condition monitoring system considering that her head office is hundreds of kilometers (km's) away from the field.

By incorporating a wireless based system that indicates plant abuse, early failure warnings and preventative measures; it is possible to initiate a preventative maintenance philosophy.

The specific objectives with this research will therefore be:

- i. To prove that wireless diagnostic/early-warning systems can reduce maintenance resources.
- ii. To utilize failure rates, repair rates and define certain states that systems can be found in.

- iii. To demonstrate the effectiveness of this proposed technique over the conventional condition monitoring techniques.

The Escravos Gas-To-Liquids plant in Nigeria is the perfect pilot project to suggest the use of this technique. It is extremely flexible not only on the process side, but also has a maintenance environment that readily accepts change. The maintenance team should be willing to try new techniques and experiment with newly introduced maintenance methods and procedures that would go a long way in possibly reducing cost.

1.4 Deliverables

The specific deliverables with this research will be:

- i. To demonstrate the effectiveness of this proposed technique over the conventional monitoring technique.
- ii. To proffer an improved security configuration for wireless networks that would guarantee the classification and availability of the system.

This research work, will also justify the use of wireless condition monitoring over other existing techniques and will also answer the following questions:

- How is wireless condition monitoring of equipments justified?
- What measurement techniques are really effective?
- Should the measurements be wireless or periodic?
- Is it really worth it in terms of cost?

In the next chapter, a literature review on wireless condition monitoring systems would be discussed. Evolving wireless technologies and related benefits would also be looked into. In chapter 5, Operator (employee' comments will be gathered to confirm the effectiveness of the diagnostic system and to enable also improvements were necessary.

CHAPTER 2

Literature review: Wireless Condition Monitoring

2.1 Wireless Monitoring

Wireless equipment condition monitoring configurations in general, complement data collectors and other monitoring methods, by expanding coverage into areas where traditional methods would be cost prohibitive or hazardous. This method collects data efficiently and reliably with wireless sensors, so that time is spent fixing problems instead of finding problems. *Christophe. M, Dave. W (2002)*

2.1.1 The Techkor instrumentation perspective

Eliminating cables from online systems is a natural progression for condition based maintenance (CBM). If the cost of integrating the CBM system online can be justified, a wireless implementation with much lower installation costs should apply to even more applications. *Christopher et al (2002)*

Online systems include hard-wired sensors connected to multiplexers, which are networked to a main data base computer. Most industrial facilities cannot fully implement a surveillance system because of the initial high capital costs, installation difficulties, and overall complexity of the system. Online systems are most often used on the most critical pieces of equipment. *Christopher et al (2002)*

After up-front data collection hardware, software, and training costs, labor remains a continuing expense of running routes for data collection. The critical question is how often to monitor a piece of equipment. By monitoring critical equipment daily, one can detect most problems while labour costs are prohibitive.

The cost consequence of machine failure and how rapidly the machine will degrade after a fault is detected usually determines frequency, the average collection interval is 30 days, and this is sufficient to detect most faults. *Teknor (2003)*

With well-designed and well-managed programs, data collectors are cost-effective CBM tools; however, the frequency of the readings is subject to the time constraints of technicians, budget cuts, and human error.

According to McLean et al (2002), wireless systems are more cost-effective than data collectors when the machinery it is monitoring is critical to the process, has a rapid failure history, operates with a known fault and operates beyond its original design. Frequent condition monitoring can change the way maintenance and production decisions are made.

According to Brad. L (2000), after a fault is discovered, a typical next question is, can the machine continue to run and operate or would it be unable to make it to the next outage? A system of thousands of sensors monitoring a facility's equipment (including some with developing faults) provide plant management with a clear, up-to-date picture of its infrastructure's condition. With analysis software that can predict the life expectancy of a failing component, plant maintenance and production can schedule downtime when it is least disruptive, which maximizes process throughput and minimizes costs.

Although data collectors have lower installed costs than online systems, their operating costs are proportional to the number of points covered and the number of times per day the points are measured. Surveillance systems will have higher installed costs, but their operating costs are fairly flat, regardless of the number of points and the frequency of monitoring. (Refer to figure 3 below).

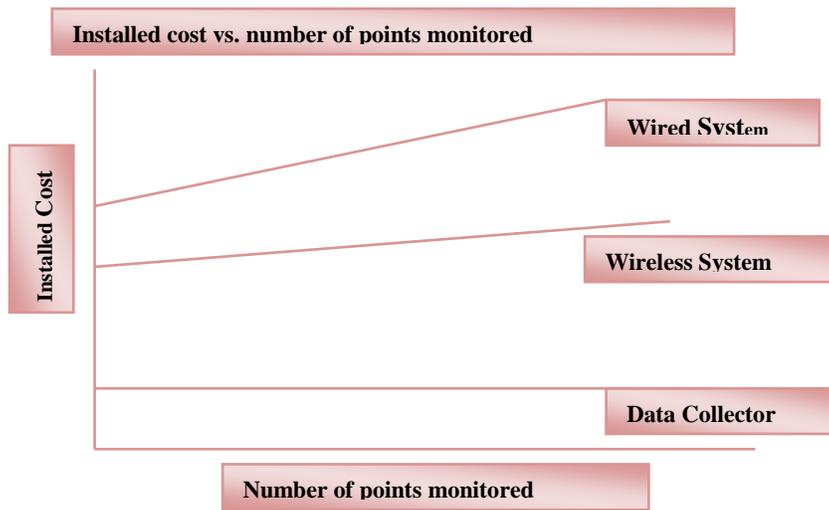


Fig 2 Installed cost vs. number of points monitored. McLean et al (2002)

A wireless system provides the lowest overall cost for large-scale condition-based maintenance monitoring, while the up-front investment of handheld data collectors is less than other systems, the continual cost of labor, especially when frequent readings are required, makes this approach more expensive. *McLean et al (2002)*.

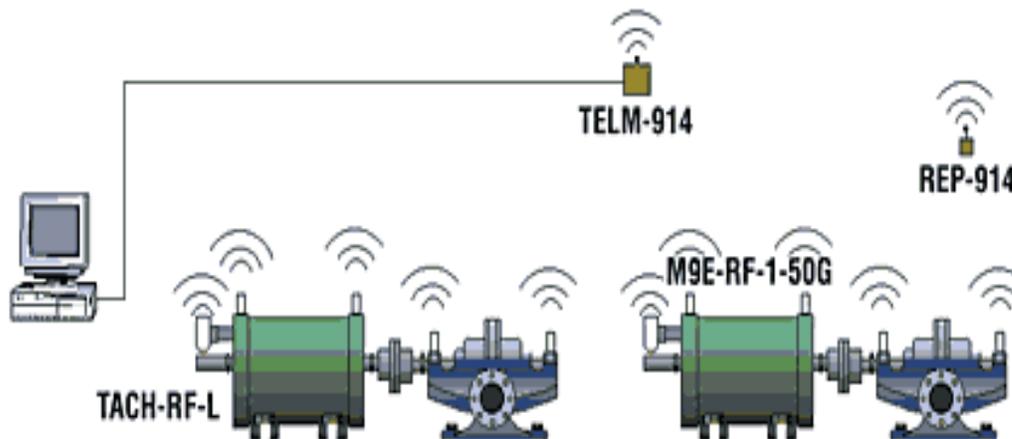


Fig 4 Using the “M9E-RF-1_50G”. McLean et al (2002)

The system configuration shown in the figure above (“M9E-RF-1-50G” accelerometers) and (“TACH-RF-L” laser tachometer), record information and transmit the data

wirelessly to the “TELM-914” access point. The computer communicates with the access point via a standard Ethernet connection and stores data in Open Database Connectivity-compliant databases. The REP-914 wireless repeater is used when required. The description of the systems used above is specific and differs for other manufacturers of similar systems because it communicates via standard Ethernet connection. The choice will therefore depend on advice based on its functionality. *Mclean et al (2002)*

Condition monitoring for rotating equipment is a well-established field that is decades old. The most basic practice is to take vibration measurements of machine shafts or bearing casings. The magnitude and phase relationships of this vibration are compared with historical baseline values to infer changes in equipment condition. In addition, practitioners examine the component frequencies present in the signal from the sensor.

These may correspond to particular mechanical components of the machine. The objective of this application is to identify the signatures of impending problems (and perhaps their root cause) in time to enable preventative maintenance action rather than running the equipment to failure.

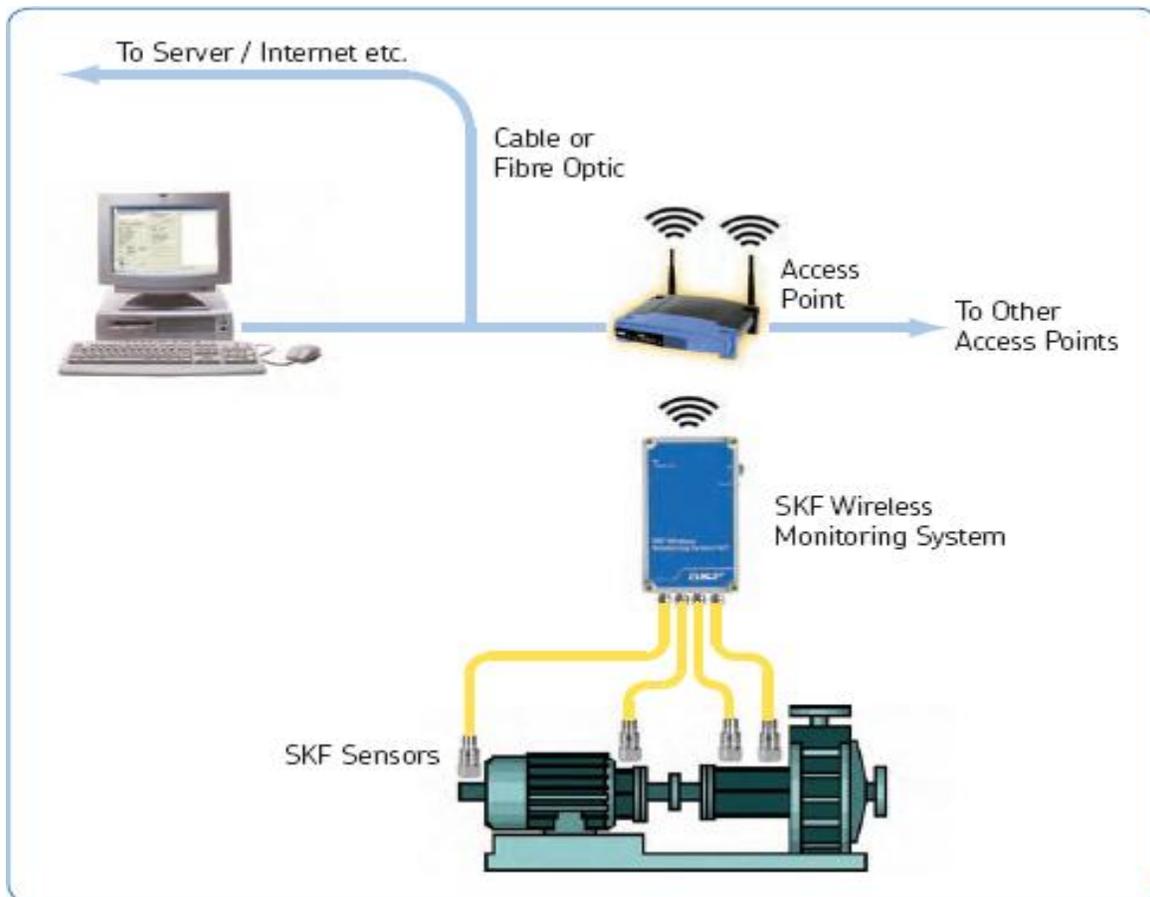


Fig 3 Typical wireless configuration system for equipment monitoring
 – SKF.com (2005)

Other sensor inputs besides vibration are also used to determine equipment condition. The other major data inputs are lube oil analysis, motor electric current, infrared thermograph and ultrasonic measurements. SKF (2005)

From an economic standpoint, continuous equipment condition monitoring (ECM) has penetrated only a small fraction of the rotating shafts found in plants. The high cost of permanently mounted sensors and a continuous monitoring system has limited its penetration to only the most critical 1% to 5% of installed rotating equipment. SKF (2005)

Discrete manufacturing operations, which usually have many more (though smaller) rotating shafts, are even less likely to have installed continuous monitoring. Instead, common practice is to use hand-held systems to capture periodic vibration signatures, which (hopefully) are quickly analyzed for problem indications. *Harry F, (2008)*

2.1.2 Wireless Equipment Condition Monitoring (ECM) Systems

Several manufacturers and suppliers of wireless systems have recently introduced new products intended to improve this situation. This was instigated by the introduction of a wireless vibration transmitter by ‘Emerson Exchange user event’. Emerson had been working on small-footprint condition monitoring solutions for some time with its CSI products and wireless sensing was a natural extension in that direction. *Bob C (2002)*

‘General Electric (GE)’ Energy introduced wireless condition monitoring (the Bentley Nevada WSIM system) at the 2007 ISA Expo. *Peter F, Wayne M, Gideon V, (2002).*

GE added the extra twist that sensors could be powered either by batteries or alternatively by vibration energy harvesters built into the sensor package. The use of vibration energy harvesting had been mentioned as one of GE’s visions for its wireless sensor research (which received partial sponsorship from the U.S. Department of Energy). *Peter F et al (2002)*

At the same time, GE also announced that these new wireless vibration sensors had been tested and deployed at the ‘Ormen Lange gas project in Norway’, work done in partnership with Shell Global Solutions. Most companies’ objective is to use wireless sensors to expand the coverage of condition monitoring far beyond what could be economically justified using wired sensors and systems. *Peter F et al (2002)*

The deployment of micro-generator energy harvesting for the first time in a wireless sensing application is an important development for condition monitoring. *Peter F et al (2002)*

Besides being a natural fit, this combination enables simplified retrofit of new ECM

applications on existing machines. GE's line featured a magnetic sensor mount so that sensor installation would not involve any drilling. The battery-free design was likely a big plus in the view of Global Solutions.

Honeywell later introduced a wireless Equipment Health Monitor (EHM) for its One Wireless product portfolio. This offering used sets of wireless sensors, which are networked to a Honeywell One Wireless mesh network. The analytical capability is provided by a partnership between Honeywell and SKF, a renowned ECM supplier. Honeywell also assembled a "starter kit" for its solution, consisting of the sensors, gateways and software needed to monitor four machines.

Besides adding wireless sensing, the EHM package enabled Honeywell to promote the IEEE 802.11 compatibility of its wireless infrastructure and the incremental value of that infrastructure once installed. ABB, showed a new line of wireless condition monitoring sensors. These sensors were developed for the offshore oil and gas industry as part of an R&D program that included major offshore oil producers BP and Statoil Hydro as sponsors. *Manges W, Allgood G. (2002).*

Each wireless sensor has an accelerometer, a temperature sensor and a radio transmitter. These combination temperature and vibration sensors are quite compact, being packaged in a unit 10 centimeters long which is mounted directly on the motor. They use a battery along with some local digital signal processing to conserve battery power. The device will use the Wireless HART protocol and its block data transfer capability to provide data to a centralized ECM application. *Manges et al (2002)*

2.1.3 Analytics – Data deluge

Aside from getting data from sensors, effective condition monitoring requires analytics. When data sets arrive once a month from manual data collection, the processes required to manage the data and analytics can afford to be less than fully automated. However, with a much larger number of machines providing several equipment data sets each day,

a deluge of data is created. This data deluge must be managed and maintained in order to extract the potentially valuable information it contains.

The most valuable ECM solutions will enable utilities to spend less time analyzing and managing data and more time focusing on exceptions and important findings that automated analytics uncover. In addition, collaboration and data sharing among plant personnel, in-house ECM experts, equipment suppliers and service firms will likely become an important future activity.

The expansion of ECM brought about by wireless may enable structural changes in the business as well, since it may become possible and economical for many more people to collaborate and deliver value in this domain. *Manges et al (2002)*

2.1.4 Condition monitoring in the Future Power Industry as a review

The low-cost base load generation of future power markets will include far greater amounts of wind power. In the future, engineers will have to monitor the condition of a far larger number of machines, and the machines will not all be located within a few minutes walking distance from their desks. *Peter F et al (2002)*

Following the lead of Europe and with steady financial incentives in place, North American utilities are now building wind generation on a much larger scale. According to Harry, in 2007 over 5,500 MW of new wind generating capacity was installed in North America, nearly twice the amount installed just one year earlier. New wind farms are being developed as quickly as possible, stretching the ability of wind turbine suppliers to deliver equipment and of power grids to accommodate them.

As regional markets for power generation develop, the financial opportunities for wind power improve. Since these units often provide power on a “spot” basis, they can take advantage of the higher spot prices—provided they can operate at capacity. Today’s

higher fuel prices for all types of fossil-fired power generation improve the attractiveness of wind power even further.

2.1.4.1 Burden for future Engineers

Future engineers will be burdened by wired CM configurations and there is need to have a reliable wireless configuration for real time and online maintenance monitoring. The size of today's utility wind turbine is 3 MW to 5 MW, less than 1 percent the size of a base load fossil unit. Utility-sized wind farms, then, consist of dozens or even hundreds of units. These units are located in remote areas that optimize high prevailing wind rather than easy access for engineers and maintenance crews. While many of these units will be of identical design, European experience indicates that over time large wind farms will expand to include several different turbine models and also different turbine suppliers.

Large wind farm operators will face the challenge of dealing with multiple generating equipment suppliers, which can create barriers to globally accessing real-time equipment condition information. Especially in a wind farm, this information is essential for improving operational performance. To succeed, utilities must be able to manage wide-area production networks. They will use these networks to connect their own experts and their partners with the large numbers of remote generating units.

They must detect equipment condition degradation and perform the required analysis remotely. Increased low-cost generation will be the most important benefit of this effort, but not the only one. The same data and infrastructure can be used to monitor other unit performance metrics in the petrochemical industry such as the Escravos-Gas-To-Liquid project in Nigeria. The remoteness of this plant is strategic to the implantation of wireless system.

This can lead to better understanding of unit performance, and to better decisions about future equipment selection and location. Operating and maintaining wind farms efficiently will be done best by larger operators who can exploit their operational and maintenance know-how and technology on a sufficiently large scale. The global trend in

wind power is toward this model. *Peter Fuhr et al (2002)*

Cost, flexibility and other advantages of new wireless sensing technologies will expand the coverage of equipment condition monitoring to a far higher fraction of critical equipment in the power generation industry. At the same time, the power grid will be developing into a much more complex system that includes many thousands of new and much smaller units along with traditional large generating units.

2.1.5 Evolving Wireless Technology

To gain a competitive advantage, many industrial companies are demanding greater amounts of information, faster methods of processing it, and the means to distribute it to more locations. More devices are sought after to collect better information on the physical world, assess its meaning, and communicate it often over longer distances. Increasingly, industry is turning to systems composed of distributed intelligent devices that communicate via digitized data streams.

These systems can move the human-machine interface, monitoring, and control functions closer to the production process, enhancing performance while reducing wiring and cable costs. *Peter F et al (2002)*.

Wireless sensor technology is now moving rapidly into niche applications in plants and other industrial environments where it can deliver cost advantages and increase flexibility. The cost factor is critical; industry will invest in these systems only if the resulting performance improvements exceed the cost to communicate. Wiring and cable have traditionally dominated the cost of industrial communications, but a new dynamic is now in effect, high-speed, license-free, low-cost wireless devices have dramatically altered the equation. *Peter F et al (2002)*

Industrial wireless systems must transmit information over distances that can range from seven inches to 60km, depending upon the application. Not surprisingly, distance exerts a

strong influence on the choice of communications technology. Key industrial wireless markets can be grouped into the following three areas according to their typical distance requirements (from shortest to longest): factory automation, process automation, and supervisory control and data acquisition (SCADA) or telemetry.

Most of the industrial applications currently in use perform monitoring rather than control due to remaining security and performance issues. Peter F et al (2002)

Hurdles to the wider use of wireless systems currently include a range of limitations imposed by both the industrial environment and the state of the technology. Industrial end-users must feel confident in the solutions to these issues before they will entrust control functionality to a wireless system supporting mission-critical industrial system requirements. Peter F et al (2002)

2.1.6 Interoperability

In my opinion, a key issue currently limiting wireless deployment in industry involves compatibility among wireless components from different suppliers, generally referred to as interoperability.

Some industrial end-users are wary of becoming locked into a proprietary system that might later hinder system upgrades as technology advances. Full compatibility among components would also provide end users with the flexibility to connect highly specialized, high-end sensors with best-in-class wireless interface devices.

The issue becomes how to guide the development of interoperability in the least restrictive manner to encourage creative and unbound solutions. As a framework, the International Standards Organization (ISO) has developed a network model composed of seven different levels or layers.

By standardizing these layers and the interfaces between them, portions of communications protocols can be adjusted as needed to accommodate new technologies or altered system requirements.

Attainment of the long-sought goal of interoperability will depend upon how wireless suppliers implement interfaces among the seven layers of the ISO model. Numerous standards now exist or are under development to promote the compatibility of these interfaces.

2.1.6 Wireless Standards

The move toward networking of industrial wireless applications is relatively recent. Most of the millions of wireless devices currently used in industrial applications are neither networked nor standards-based. Instead, they pass digitized data transparently and are either FCC-licensed solutions or solutions using the license-free bands. Wayne M et al (2002)

Today's networking standards typically address the physical layer and the lower portion of the data link layer (also known as the medium access controller, or MAC, sub layer). The physical layer addresses modulation (encoding data onto an electromagnetic waveform), frequency use, and transmission. The MAC layer refers to access points and maintains the order of signal flow to avoid signal collision and cancellation. Peter F et al (2002)

Two of the most widely used standards today were originally designed for office or in-building wireless systems. They are known as 802.11b, issued by the Institute of Electrical and Electronics Engineers (IEEE), and Bluetooth, which was developed by a group of commercial companies (www.bluetooth.org).

Both of these standards use the unlicensed 2.4 gigahertz (GHz or billions of cycles per second) band, the same band used for microwave ovens and industrial heating and the Federal Communications Commission (FCC) has classified it as an Industrial, Scientific,

and Medical (ISM) band. Other popular ISM bands include 5.8 GHz and 900 megahertz (MHz) (see table of ISM Bands). The 60 GHz unlicensed band has also recently become available and holds promise for reducing interference in short-range applications. Peter F et al (2002)

The FCC set aside these ISM bands for license-free, low power radio transmission over short to medium distances. In these bands, the FCC requires that the signal be distributed over a wide range of bandwidth using a spread spectrum technology. Wireless devices that operate in these license-free bands can allow immediate, real-time commissioning of a network, avoiding the delays associated with installing wiring or cables.

By spreading data transmissions across the available frequency band in a prearranged scheme, spread spectrum encoding technology makes the signal less vulnerable to noise, interference, and snooping.

The significant amount of metal often found in industrial settings can cause signals sent over a single frequency to bounce and cancel other signals arriving at the same time. Spread spectrum technology helps overcome this problem and allows multiple users to share a frequency band with minimal interference from other users. Although there are three spread-spectrum schemes suitable for industrial wireless systems, the two most common is frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS).

ISM Bands

Frequency Band	Characteristics	Compatible Products
900MHz (902 – 928MHz)	Lower throughput, better wall penetration.	Proprietary protocols
2.4GHz (2.4 – 2.4835GHz)	Slots of this frequency are available in most part of the world	Bluetooth 802.11b industrial heating equipment
5.8 GHz (5.725 – 5.850GHz)	Highest available throughput, better noise immunity, stricter line-of-sight constraints, smaller antennas possible.	None developed yet because of greater technical challenges

Table 2 ISM Bands. Peter F et al (2002)

	IEEE 802.11b	Bluetooth
Effective Distance	500metres	10 meters
Spread Spectrum Technique	Direct Sequence (DHSS)	Frequency Hopping (FHSS)
Data Rate	11 Mbps	721 Kbps

Table 3 IEEE wireless Standards

Bluetooth uses FHSS, in which the transmission hops in pre-defined patterns from channel to channel across the entire 83.5 MHz spectrum. 802.11b uses DSSS, which divides the spectrum into overlapping 22-MHz channels and sends all the information through those swaths. The popularity of both of these standards has increased interoperability among wireless products from different vendors, but the two standards have the potential for spectrum conflict. (www.bluetooth.com)

The third spread-spectrum technique, Ultra-Wideband (UWB), broadcasts on many frequencies simultaneously, distributing its signal across a vast bandwidth. The idea is

that the signal is spread so thinly that interference will be negligible in any one frequency, but many have expressed concern about potential interference. (www.bluetooth.com)

The newer 802.11a and 802.11g standards support speeds as high as 54 Mbps (million bits per second). Instead of spread spectrum, both of these recently ratified standards employ the relatively power-intensive, wideband orthogonal frequency division multiplexing (OFDM) signaling technique. Wayne M et al (2002)

OFDM, which was not originally designed for industrial applications, offers higher throughput in areas without intervening walls or other obstructions, but is less power efficient than most other data-transmission schemes due to its requirement for high radio frequency linearity. Unlike FHSS, it uses all channels at once, boosting throughput but increasing the likelihood of interference with other wireless devices in the area.

Both standards also use the unlicensed ISM and national information infrastructure (U-NII) frequency bands (802.11a at 5 GHz and 802.11g at 2.4 GHz). The U-NII bands are just beginning to be exploited by wireless networking applications. If these standards achieve widespread commercial acceptance that results in lower costs, they are likely to find numerous niche applications in industrial operations. Peter *F et al* (2002).

Also, other bands now available in the U-NII category include 100-MHz bands beginning at about 5.1 and 5.2 GHz. Although some commercial, off-the-shelf products are now available for use in these bands, few have been implemented in industrial applications to date.

Technique	Approach	Characteristics
Frequency hopping Spread spectrum(FHSS)	Transmission jumps from frequency to frequency at a predefined rate and pseudorandom sequence	Reduces interference
Direct Sequence Spread spectrum(DSSS)	Signal is sent over a range of frequencies by sub-sampling each bit in the data stream with high-rate pseudo-random spreading code	Implementation with a 63-bit spreading code provide a robust interface and process gain (power savings)
Ultra-Wideband(UWB)	Spreads signal over a very large frequency range at low power	High throughput; good in areas with physical obstacles' used for live video feeds

Table 4 Spread Spectrum Encoding Techniques

As the speed of data transmission (throughput) increases, radio frequency signals supply less energy per bit, adversely affecting reliability. Suppliers to the commercial market for personal communications devices tend to value throughput over reliability (generally higher frequencies), and they exert a strong influence on emerging standards. (Wayne M et al (2002)

Developers of wireless industrial sensor systems, on the other hand, tend to value reliability over throughput (generally lower frequencies). Greater flexibility is needed in making these tradeoffs as appropriate to the application. (Peter F *et al* 2002).

2.1.7 Bandwidth Availability/Regulation

Data throughput is adversely affected by distance and the amount of noise or interference in the area.

If too many wireless devices are operating in the same vicinity, they can interfere with each other, restricting network capacity.

If insufficient spectrum is available for interfaces among the wireless devices, communication can become difficult or impossible. Many of today's wireless systems contain provisions for collision avoidance and packet retransmission in the event a signal is blocked by interference.

Peter. F (2002), asserted that users can also block out frequencies that experience continuous interference, thereby sidestepping offending signals. These techniques, combined with the use of maximum permissible transmit power and highly sensitive receivers can yield a reliable transmission even over longer distances. On the down side, these solutions are energy-intensive and can generate interference for other systems.

In terms of protection from interference, users of FCC-licensed, narrow-band systems have a regulatory edge and an avenue of redress if interference does occur. Spread-spectrum technology is based on interference avoidance techniques, but if outside transmission does disrupt communications, users can only switch to another frequency⁸ or block out channels occupied by the interferer. Rapid growth of wireless devices has generated increasing concern about future overcrowding of the ISM bandwidth. Wayne M et al (2002)

2.1.8 Power

Since industrial applications increasingly employ miniaturization and require longer intervals between scheduled maintenance, the power source and power conservation strategies are key issues for wireless sensor systems. Some of today's wireless systems rely on solar panels, but many require batteries that require periodic replacement. Although this is an important power source issue, maintenance requirements have been greatly reduced by more power-efficient wireless devices and recent gains in battery performance. Peter *F et al* (2002).

Also, many current wireless systems require regular attention to the power source, necessitating a scheduled outage every 3 to 18 months. Techniques such as exception reporting and power management can extend battery life for multiple years. Even when maintenance is required, shutting down a networked wireless site need not cause disruption to the remainder of the network. Auto-discovery techniques will recognize the site when it is brought back online, and operation will continue.

Frequency hopping (FHSS) provides greater range by transmitting short signal bursts, but this uses higher peak power. In contrast, direct sequencing (DSSS) uses available power to spread the signal thinly over multiple channels, resulting in a wider signal with less peak power. Transmitting over longer distances and overcoming interference increase the power demand. Bi-directionality and the need to transmit waveforms similarly drive up power requirements. Wayne M et al (2002)

One power conservation strategy is to minimize the duty cycle and the interval between measurements. This strategy can be applied only when the measured process parameter changes relatively slowly. In applications where power consumption must be kept to a minimum, many of today's networks report by exception rather than by the traditional polling scheme used in multiple address systems.

Also, rather than requiring the wireless device to transmit at regular intervals (whether it has new data to report or not), transmissions are made only when a user-definable condition is met. One potential problem with this approach is that the network may be flooded with reports if the process suddenly goes bad.

Another power conservation strategy is to use process gain, an encoding technique that involves spreading the signal over a wider bandwidth than is strictly necessary to recover the signal from background noise or interference. DSSS, for example, can sample every bit 63 times, which has the same effect as amplifying the signal without actually using power to do so. Peter F et al (2009)

Process gain can increase the reliability of transmission and avoid the need for retransmission or use of higher power to overcome interference (in effect, reducing power demands without sacrificing reliability). Wayne M et al (2002)

2.1.9 Manageability

When a network experiences drop-outs, outages, or reduced throughput, end-users need tools that can help locate the problem and prevent recurrences. Some of the systems include tools that allow early detection of problems before they pose a threat to network operations. Managing several networks linked with connectors can lead to additional power requirements. In figure 6 below, more devices and transmissions will demand increased power demand which would lead to cost.

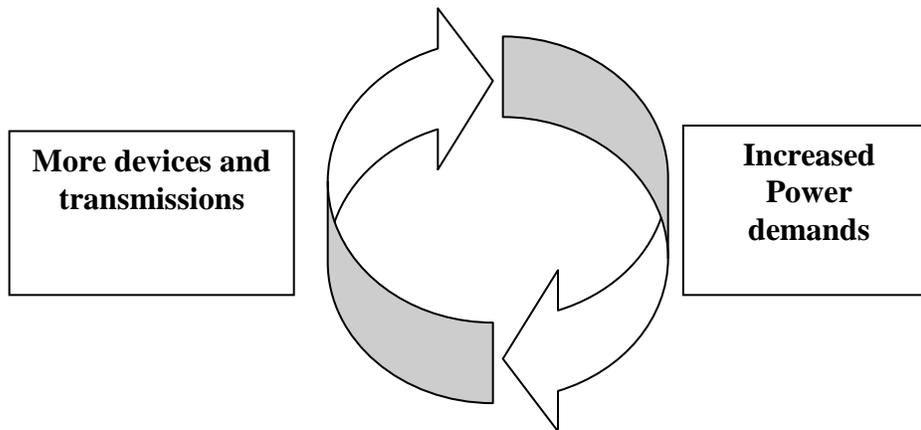


Fig 4. System tool- devices and power demands.

2.1.10 Reliability

In chapter 3, more detailed information on reliability would be outlined. However, many of today's standards-based solutions offer a –grade mean time between failures (MTBF), which may not be adequate for industrial applications. Severe industrial environments, in particular, can adversely affect reliability. Some of today's systems can operate within some industrial environments.

Reliability also includes avoidance of interference or noise from other devices and the ability to receive weak signals reliably in the presence of such interference. Consequences of failure are not trivial. Industrial applications entail the risk of substantial losses through equipment damage, personnel injuries, loss of raw materials, and environmental pollution.

2.1.11 Wireless condition monitoring benefits

2.1.11.1 Reduced Connector Failure

Most failures in networks occur at the connectors; wireless sensors eliminate this problem. When connectors are not properly fixed or are experiencing rusts, there are possibilities of failure. The age of the cable points also play a significant role in this.

2.1.11.2 Improved Flexibility

Without the constraint of wires, plant managers can better track materials and more easily reconfigure assembly lines to meet changing customer demands. Freedom from wires also allows greater flexibility in sensor placement, particularly in the case of mobile equipment (e.g., cranes and ladles).

2.1.11.3 MEMS Exploitation

Micro-electromechanical systems (MEMS) offer a rapidly expanding wealth of sensing capabilities. Integrated wireless sensors with built-in communications capabilities can

avoid the failure modes introduced by attaching bulky wires to these miniature devices. This advantage will increase in significance as sensors continue to shrink.

Fuhr et al (2009)

2.1.11.4 Rapid Commissioning

Simple wireless sensor systems can rapidly organize and configure themselves into an effective communications network. Self calibration and verification are on the horizon, opening the possibility of deploying ad hoc systems to explore a range of production scenarios.

2.1.11.5 Wireless Systems Create Value

Significant technological advances exist at bench-scale in labs across the country. These technologies need to be brought forward and integrated with other emerging technologies to realize the full potential of wireless systems. As these systems move into wider use, industrial end-users will gain greater flexibility and discover new possibilities. Low-cost, high-performance, easily deployed wireless devices will change the way end-users view sensors and sensor systems. Peter F et al (2009)

2.1.11.6 Dynamic adaptation

Integrated wireless sensor systems with distributed intelligence can enable operator-independent control of industrial processes. Sensor nodes can dynamically adapt to and compensate for device failure or degradation, manage movement of sensor nodes, and react to changes in task and network requirements. Wanye M et al (2002)

It can be located in 3-D space and correlate their positions with on-line plant maps to assure correct placement. Continuous, high-resolution, ubiquitous sensing systems have the potential to autonomously monitor and control industrial processes. Based on the application, such systems will be capable of maximizing product quality and yield while minimizing waste, emissions, and cost.

2.1.11.7 Adaptable Design

Recent advances in materials technology should enable integrated wireless sensor systems to meet durability and reliability requirements in harsh industrial environments. Integrated sensor nodes encased in advanced materials should be able to endure repeated exposure to caustic gases and high temperatures. Some applications may require components designed to withstand highly specific environmental challenges. Adam G. (2004)

2.1.11.8 Open Architecture

With the wide range of potential applications and broad diversity of physical devices, the software components will need to be highly modular and efficient. Generic development architecture should allow specialized applications from a wide spectrum of devices without requiring cumbersome interfaces. This will also enable connection to existing sensors and easy upgrades to incorporate more advanced modules in the future. Adam. G (2004)

2.1.11.9 Advancement in technology

Advances in a number of technologies at the beginning of the 21st century, is collectively paving the way for the growth of wireless industrial sensor systems. The phenomenal explosion of the personal communications market has dramatically reduced costs and increased the quality of the underlying radio components and technologies. Peter F et al (2002).

Continued reductions in the costs of computational capabilities also support a distributed architecture for these systems. Embedded intelligence reduces the bandwidth requirements for communications and lowers power requirements both. The technology will also benefit from continuing progress in sophisticated modulation techniques, emerging standards, miniaturization of sensors, and enhanced system reliability and robustness. Adam G (2004)

Integrated wireless sensor systems promise exciting prospects for manufacturing and industrial competitiveness. In line with the increasingly interdisciplinary nature of

technology, many of the advances described in this dissertation both build on and apply toward the development of sensors, controls, and communications systems in other application areas, such as automobile assembly, building management, power generation, and transportation systems. Adam G. (2004)

Continued technology development and the use of a collaborative, multidisciplinary approach to solving common challenges in a cooperative environment can signal a new era in productivity. Before this wireless evolution, the wired or conventional system has been in existence.

It was found that the major practice in the past depended on wired several connectors and the reliability of the CM configurations was a suspect. A wireless health diagnostic configuration for the EGTL plant will seek to eliminate the delays in reporting defects and also provide solutions on cost effectiveness and reliability. This in general will reduce maintenance resources required to carry out maintenance on various equipments in the plant.

In chapter 3, this research covers methods and procedures for wireless condition monitoring in the reduction of maintenance resources as well as the application of Markovian technique in data gathering. This chapter will try to justify the application and effectiveness of the wireless condition monitoring system for the EGTL plant.

CHAPTER 3

Reducing maintenance resources in EGTL plant

3.1 Method and Procedure

Wireless equipment condition monitoring is the process of monitoring the condition of a machine, gathering the data and ensuring that the information is transmitted wirelessly. The proper monitoring of a machine ensures the maximum performance and productivity of that machine.

Vibration, noise, and temperature measurements are often used as key indicators of the state of the machine. Machine condition monitoring is important because it provides information about the health of a machine. This information can be used to detect warning signs early and can help an organization to stop unscheduled outages, optimize machine performance and reduce repair time and maintenance costs.

Industrial machinery test, portable machine diagnostics, wireless machine monitoring and wireless machine protection are different types of machine condition monitoring. In modern machine condition monitoring systems, various types of sensors and transducers are used to measure machine health parameters such as force sensors, pressure sensors and accelerometers. Muhammad. A, Othman. S (2009)

Micro electromechanical system (MEMS) accelerometers are the most popular general purpose vibration sensors and transducers. The MEMS accelerometers, which include both the signal conditioning circuitry and the sensor, are fabricated together on a single monolithic chip at a very low cost but with high reliability, high-performance and high accuracy.

MEMS accelerometers use various techniques for measuring forces such as silicon piezoresistive, silicon capacitive, strain gauge, force balance and micro machined resonators. From among a number of sensing methods, the capacitive sensing technique

has recently become the most attractive because it provides high sensitivity, low noise performance, good DC response, low temperature sensitivity, low power dissipation and a simple structure.

Because of these advantages, silicon capacitive accelerometers have been applied to numerous applications ranging from low-cost, large-volume automotive accelerometers to high precision, and inertia-grade microgravity devices. Muhammad. A and Othman. S (2009)

3.1.1 Reduction of maintenance resources through Vibration monitoring

Vibration analysis in particular has become increasingly popular as a predictive maintenance procedure and as a support for machinery maintenance decisions. The EGTL plant has various critical rotating equipments and would require constant vibration monitoring. Monitoring of these equipments wirelessly will be an advantage in the early detection of failures.

By measuring and analyzing the vibration of a machine, it is possible to determine both the nature and severity of the defect and hence predict the machine's failure. Thus, vibration analysis is a vital part of predictive and preventive maintenance programs that seek to reduce costs and unplanned down-time. Marin M (2004).

Holger F (1997) developed a micromechanical resonant vibration sensor (MRVS) to detect vibrations in the low-frequency range for wear monitoring. It was found that the sensors showed significant improvement in the signal-to-noise ratio, had good resolution and was simple to construct.

Odin and John (1998) developed a novel self-improving architecture for data fusion, novelty detection and dynamic learning which was applied in condition monitoring. It was found that the local fusion system can identify novel conditions from the normal operating state and that it can build up network of diagnostic networks over time for faults that it encountered.

Adam G. et al. (2004) used a printed circuit board (PCB) piezotronics model 352C68 piezoelectric accelerometer to measure the vibrations and investigate the fault and failure of the spindle positioning drive (Z axis) on a Proteo D/94 precision machining center. This type of accelerometer can measure up to 50g acceleration and a frequency range of up to 12 kHz.

Marin M et al (2004) used a MEMS accelerometer ADXL250 from Analog Devices as a sensor to measure vibrations. It was found that Micro machined accelerometers offer a low-cost alternative to piezoelectric vibration sensors, particularly for sophisticated on-line diagnostic systems requiring a large number of transducers.

Li Wang et al. (2007) developed an embedded intelligent local set for machine condition monitoring and fundamental diagnosis. It was designed to support the adoption of ICP type low-impedance voltage output acceleration sensors at industrial sites.

Paul Wright et al. (2008) used a MEMS accelerometer ADXL320 from Analog Devices for the monitoring of machine tool vibration wirelessly. It was found that the accelerometer-based WSN was easy to deploy for machine tool vibration monitoring hence providing a useful tool for the predictive maintenance and condition-based monitoring of factory machinery.

Andreas Vogl et al. (2009) developed a MEMS accelerometer for wireless vibration measurements on AC motors for condition monitoring. It achieved an acceleration of up to 30g, sensitivity at about 0.19 mV/g and a noise floor equivalent to 5mg RMS.

The commercial MEMS accelerometer ADXL150 from Analog Devices was selected as a detection sensor. The ADXL150 is a single axis, low noise and low power MEMS accelerometer with signal conditioning on a single monolithic integrated circuit (IC). This work is a continuation in the development of an intelligent vibration-based machine condition monitoring system for the production industry.

3.1.2 Design of Circuit

The complete electronic circuit design consisted of a single accelerometer, an ac coupling circuit, an rms-to-dc converter and an alarming circuit. It was built with a single printed circuit board (PCB). The overall circuit was designed for 0-10g rms acceleration sensing. The output of the accelerometer was an input to an ac coupling. It was then connected to a rms-to-dc converter that finally triggered the alarming circuit.

The circuit level design is based on work done by Jagadeesh P et al. (2006). *Figures 5 and 6* shows an AC coupling circuit and a rms-to-dc converter circuit respectively. In this design, the corner frequency considered is 3 Hz. The value of the resistor (R2) is 249k Ω and the capacitor (C3) is 0.22 μ F which corresponds to this frequency. The other values are C1=0.1 μ F, C2=0.1 μ F, C4=0.1 μ F and R1=1M Ω . The output voltage V1 is applied to the rms-to-dc circuit.

The values for the capacitors and the resistors are C6=0.1 μ F, C7=1 μ F (electrolyte), C8=0.1 μ F, C9=0.1 μ F and R6+R7=R8=10k Ω , R3+R4+R5=20k Ω . The output voltage V2 is fed as input to the alarming circuit. The output V2 from the rms-to-dc converter circuit is also fed to the alarming circuit. The circuit consists of a Programmable System on Chip (PSoC) microcontroller and a display panel.

The PSoC is a small computer on a single integrated circuit consisting of a relatively simple CPU combined with support functions such as a crystal oscillator, a program memory, timers, a watchdog, an analog to digital Development of a Vibration Measuring Unit Using a Microelectromechanical System Accelerometer for Machine Condition Monitoring 153 converter, and a serial and analog I/O.

A PSoC Designer is used to write the program and is downloaded into the microcontroller. The V2 needs to be converted into a digital number using Equation (1). The output is displayed on a display panel attached to the microcontroller.

$$\text{digital number} = \frac{V_2 \times 2^N}{V_s}$$

where $N = 8$ bits and $V_s = 5V$

Equation 1 – Converting output voltage to digital number

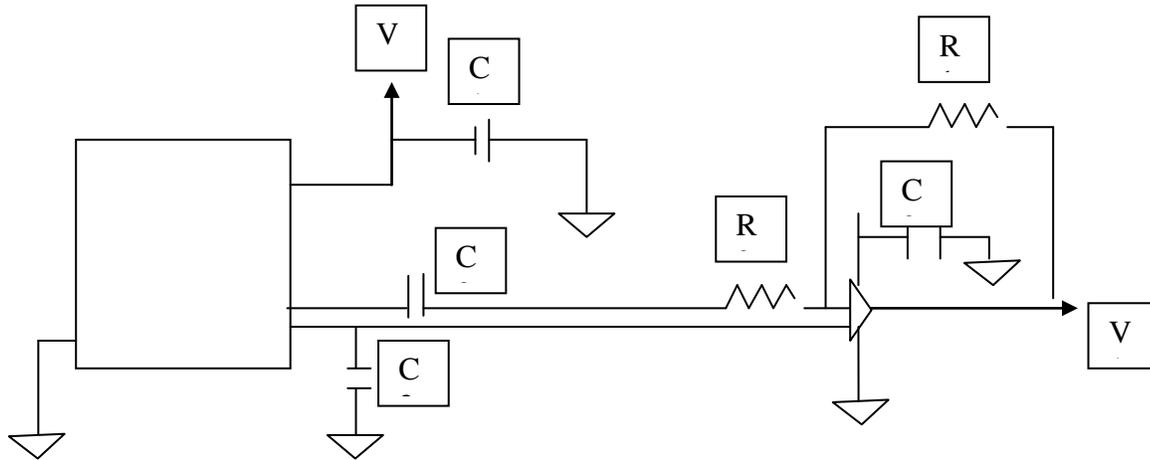


Fig 5 Electronic circuit for the AC coupling

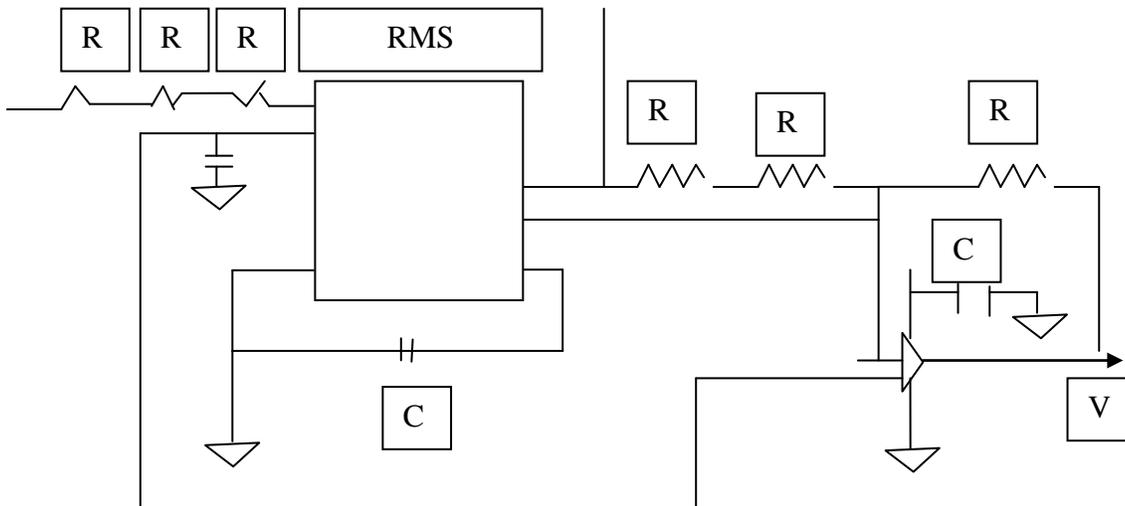


Fig 6 Circuit for rms-dc converter

3.1.3 Characterization and testing

The MEMS accelerometer ADXL150 is characterized through its output voltage. A simple circuit as shown in Figure 8 is configured on a breadboard. The vibration measurement setup is shown in Figure 9. The device under test (DUT) is mounted onto a

dynamic shaker (TIRA Shaker TV50101) and the input and output of the accelerometer are connected to the power supply and a multimeter respectively.

A commercial accelerometer is attached to the breadboard to ensure it vibrates with the same amplitude as the input acceleration to the accelerometer. Input acceleration is applied from 1g to 5g. According to the ADXL150 datasheet from Analog Devices, the range of supply voltage is 4 to 6 volts. Hence, the Development of a Vibration Measuring Unit Using a Microelectromechanical System Accelerometer for Machine Condition Monitoring.

155 output voltage of the accelerometer for each supply voltage is measured and discussed through the graph of output voltage (V_{out}) versus acceleration (g) to determine the optimum supply voltage for the accelerometer. In addition, the sensitivity of the accelerometer for each supply voltage is also calculated.

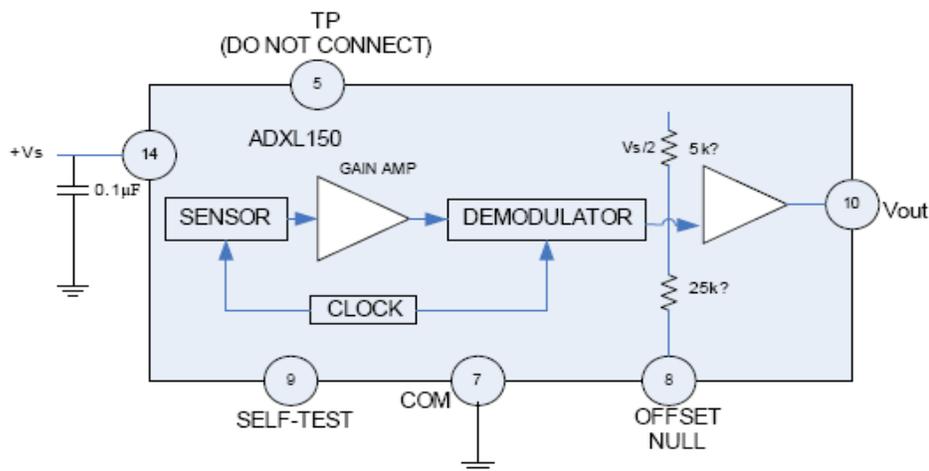


Fig 7 Circuit connection using ADXL 150

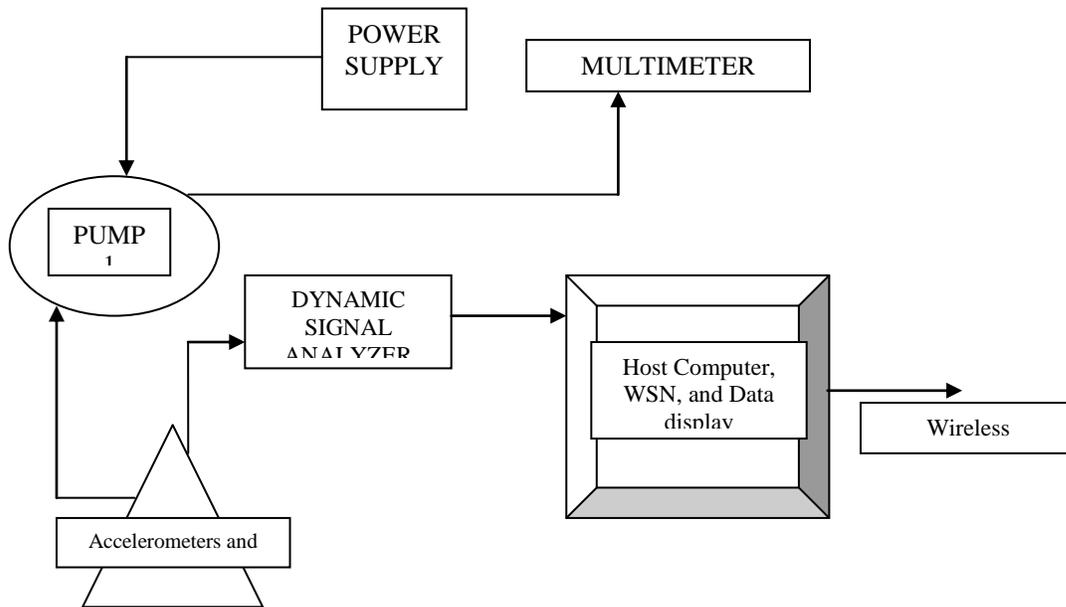


Fig 8 PUMP1 - Vibration measurement set up to EGTL pump1

To determine the output voltage of the rms-to-dc converter, the DUT that was mounted on the shaker machine was tested in the acceleration range between 1g to 5g. The output voltage of the circuit was measured by using a multimeter and the values were used for designing the alarming circuit. Theoretically, the output voltage can be calculated by using Equation (2) with the sensitivity of 38mV/g.

$$V_{out} = \frac{V_s}{2} - \text{sensitivity} \times g \times \frac{V_s}{5}$$

Equation 2 - Output voltage calculation

Where V_{out} is the output voltage, V_s is the supply voltage and g is the input acceleration.

To ensure the functionality of the developed vibration sensing unit, the DUT is characterized by connecting it to the microcontroller for monitoring purposes.

3.2 Wireless condition monitoring of vibration

From the data display PC above, it was connected to an internet gateway and networked via techknor NAP914P network access point instrument. The figure below shows the line up for this connection.

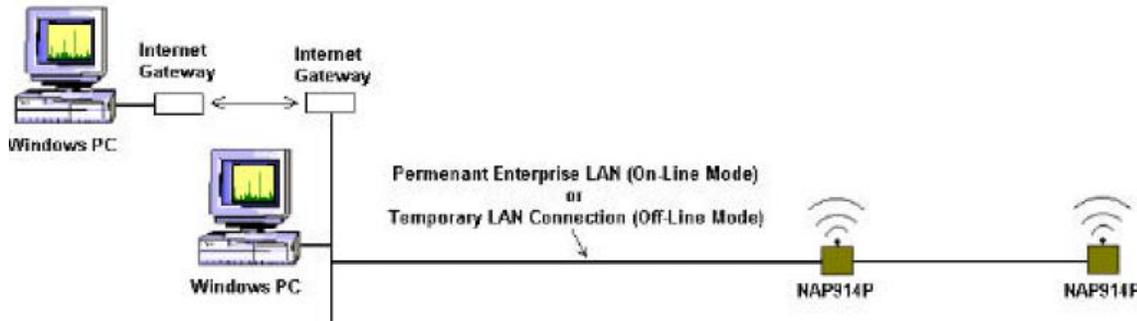


Fig 9 NAP914P Access point

The NAP914P Network Access Point bridges the gap between the wireless sensor network and the enterprise LAN constituted. Up to 128 Network Access Points may be used together to achieve the desired coverage.

To configure Network Access points, items to note are:

- Overlapping coverage permitted among NAP914P units
- Stores over 6800 data records (400 line FFT) in off-line mode
- Encrypted, error corrected, license free wireless transmission
- Software programmable IP addresses, subnet masks, and gateways
- 10 base-T Ethernet, TCP, FTP, and UDP accessibility
- Novell NE2000 compatible, full 16-bit Ethernet chipset
- NEMA 4X radio pod for harsh environments

This set up was used in obtaining results and conditions for the pump 1 at the EGTL plant and the data used in the following chapters were derived from the MIS (management information system). In the following chapter, the procedure for gathering the data used

will be discussed and the resulting data would be analyzed. Interpretation of this result will be based on the analysis obtained.

3.3 Capturing data via Management Information System

The data utilized in the following chapter originates from the MIS (Management Information System - JDE), incorporated into the plant. It is a very powerful tool that helps management track and monitor movement of product through the plant. Moreover it tracks quality, input material and almost any other KPI in a real time mode. Analysis can be drawn from the application and up-to-date decisions made regarding various process variables.

Not only are the many variables associated with the process diesel making tracked, but delays are too. Every time the pump does not have sufficient delivery of product, the system acknowledges this and a delay pops up on the operator's panel. A dropdown menu is then initialized. This dropdown allows the operator to choose one of the many reasons why the pump may have insufficient pressure for delivery. The delays are grouped into the following major categories:

Production Delays

Maintenance Delays

Refractory Delays

External Delays – Air Products delays, power dips, etc.

The importance of the MIS is that it forces the operator to account for all the lost time on the pump. It is also a very powerful management tool in the sense that it allows critical plant performance parameters to be measured, tracked and assessed in reports that are easily accessible and understandable.

The biggest advantage of the MIS is that it allows easy access to all delays on pump1. On the other side of the scale there is the JDE notifications system. Although much more detail than the MIS system the JDE system has drawbacks which will be explained in detail later.

The JDE system allows the user to log various data attributed to a specific delay. Equipment function location, start and end time, long text relating to the incident and RCA (Root Cause Analysis) functionality is some of the information that can be captured in the M3 Malfunction Report feature available in the JDE system.

The problem is that the K2 (Equipment breakdown not associated with delay) and K3 (Equipment breakdown associated with a delay) are only completed by the Mechanical planning department. The flow diagram is as follows:

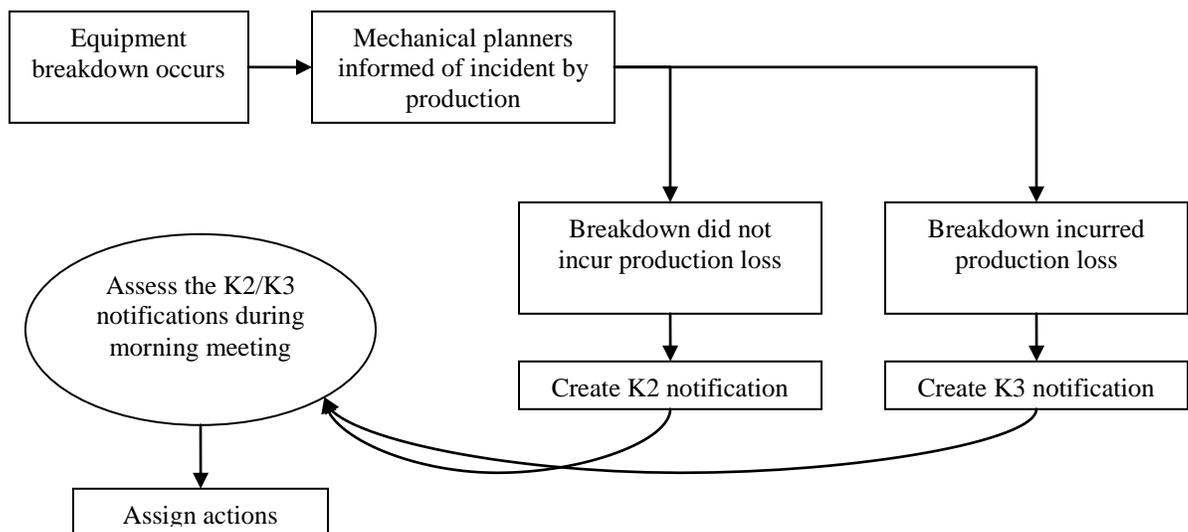


Figure 10: Schematic presentation behind rationale of K2/K3 creation

Thus the mechanical department is the only group that creates K2/K3 notifications as their main function is delay management. However they do not log the following in their shift report:

- Incidents where faulty equipment was rectified by the production employee of which they were not aware.
- Faults that go unreported.

This is the reason why it was decided that these delays would be used for the purpose of this research in line with real time indication of what is happening with the pump. The other advantage is that the data is more accessible as it is extracted in an Excel spreadsheet. The JDE notifications can be drawn into an Excel spreadsheet directly.

The data was extracted from the JDE environment and subsequently analyzed. In the following chapter, results obtained from the delays would be analyzed and interpreted. The procedure for gathering further data would equally be discussed.

CHAPTER 4

Wireless condition monitoring results

4.1 Data gathering

Gathering data for wireless condition monitoring of plant equipment such as in the case of the pump used in this research, is discussed in this chapter.

The data utilized the MIS (Management Information System) incorporated into the plant. It helps management track and monitor movement of product through the plant especially critical pumps such as pump1. It tracks quality, input material and almost any other KPI in a real time mode. Analysis can be drawn from the application and up-to-date decisions made regarding various process variables.

Not only are the many variables associated with the process of pump reliability tracked, but imminent failures and delays are too. Every time there is a vibration for instance, it pops up on the screen and gives the various delays inconsistent with the normal, a dropdown menu is then initialized. This dropdown allows the operator to choose one of the many reasons why the pump may be delayed from performing at optimum. The delays are grouped into the following major categories:

Maintenance Delays – Soft foot, bearing failure, broken impeller etc

External Delays – Products delays, power dips, etc.

This forces the operator to account for all the lost time on the pump. It is also a very powerful management tool in the sense that it allows critical plant performance parameters to be measured, tracked and assessed in reports that are easily accessible and understandable.

The JDE system allows the user to log various data attributed to a specific delay. Equipment function location, start and end time, long text relating to the incident and

RCA (Root Cause Analysis) functionality is some of the information that can be captured in the Fault coding of the JDE environment.

The data is more accessible as it is extracted in an Excel spreadsheet through a JDE system.

The data was extracted from the MIS and subsequently analyzed.

The goal of the predictive condition monitoring of pumps in industrial plants is to indicate deterioration in the condition of the pump before the actual failure occurs. In many cases, the defect does not cause an immediate interruption of the process. If this is the case, the defective part can be replaced or repaired during normal and scheduled maintenance breaks, provided that the defect has been found in its sufficiently early stage. The most common causes to failure of pumps are faults in bearings, the impellers, seals and the shafts. *Lindh et al (2005)*

Wireless diagnostics can be used to determine the failure of these common faults in the plant. The data transmission in this scheme can be achieved over the Internet or mobile telephone network.

Since no analyses are done on the field level, the system can be relatively simple; sensor units and collector units can be based on simple microcontrollers. A DSP-based system, in which the data analysis is done on the field level, has been researched and developed in the laboratory by Spatenka.

The main advantage of higher-level analysis over field level analysis is the simplicity of hardware; great processing capacity is not needed. On the other hand, higher data transmission capacity is required, since all the measured data need to be transferred, instead of transferring the mere results of analysis. *Lindh et al (2005)*

All transmission between the sensors and the collector unit is digital in order to avoid problems caused by interference from surrounding equipment in the industrial environment. The data transmission capacity required between the sensors and the collector varies between different measurements. Since the collector unit needs to be versatile, it has to be designed to fulfill the needs of the most demanding measurement, which in practice is vibration. *Lindh et al (2005)*

The system needs to be **inexpensive** in order to extend condition monitoring to targets where it currently is not economically feasible. Sensors with an analogue output are often cheaper than those with a digital output, so they should be used if possible.

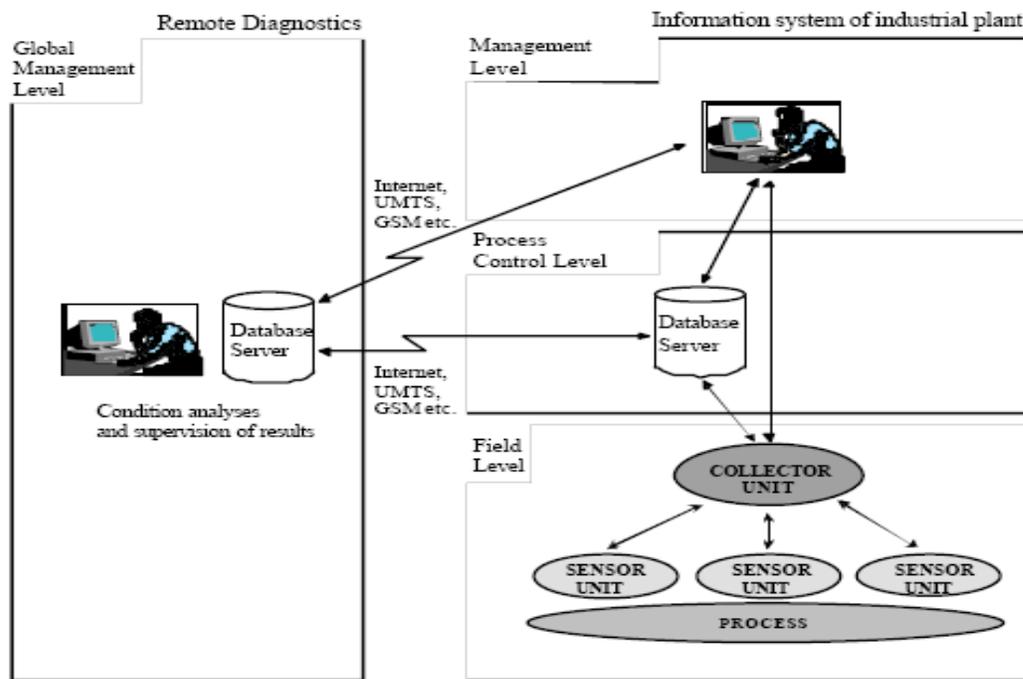


Fig 11 Typical plant information infrastructure *Lindh et al (2005)*

This system is a part of the model of the industrial information infrastructure. For this model, motors, actuators etc are located on the field level. The process control level consists of PLCs and process computers usually interconnected by field buses. The management level includes PC workstations connected to local area networks. The global management level is located outside the industrial plant and is connected to it by, for example, internet. *Lindh et al (2005)*

4.1.2 Comparison of possible system topologies

The data collection system for the pump consists of several sensor units attached to data-collecting units. There can be one or more collector units all having one or more sensor units connected. In order to keep the sensors inexpensive, they are based on a simple microcontroller with no external memory.

Therefore, the collector units provide a temporary storage for the measurement data. If a particular measurement generates data more than the internal RAM of the microcontroller can store, the data transmission between the sensor unit and the collector unit has to be real-time. However, the data transmission from the collector unit onward can be slower and can be packet-based.

As mentioned, it must be possible to connect several sensor units to one collector unit. Two options to accomplish this were considered: a multi-channel collector unit and a bus based solution. *Lindh et al (2005)*

4.2 Results and data analysis from wireless condition monitoring

4.2.1 Results

The EGTL plant consists of several pumps; the test was applied on EGTL pump 1

Pump 1 is the most critical pump at oil work-up platform. The reason being that it is the only pump in that specific arrangement that is mostly depended on to deliver pressure. If the pump breaks down, it would affect the delivery of product to the tank farm.

Pump 1, major delays			
<i>Notification number</i>	<i>Date</i>	<i>Duration (h)</i>	<i>Description</i>
830993467	2008.10.12	6.79	Impeller Damaged (Vibration)

830567450	2008.10.27	3.28	Noise from bearing (Vibration)
830573998	2008.11.01	5.18	Leakage from bearing housing (Vibration)
830567345	2008.11.13	5.53	Coupling guard broke (Vibration)
830217453	2008.12.23	5.12	Motor earthed (Currents)
830275788	2009.01.11	2.21	Base bolt broking (Vibration)
830567389	2009.01.27	2.26	Base bolts loose + coupling worn (Vibration)
830456772	2009.02.16	31.3	Motor base bolt wobbling (Vibration)
830456773	2009.03.15	20.45	Pump Base bolt broking (Vibration)
-	-	7.3	Various (Vibration + Temperature)

Table 5 Pump 1 Delays that could have been prevented using health diagnostic wireless condition monitoring (CNL- RCM)

It can be seen from **Table 5** that there have been three major incidents on the pump prior to the installation of the wireless condition monitoring system.

The combined net loss (at an average margin for the period 2008 – end 2009) is in excess of R 13 million*. (Planning department – EGTL) This was calculated using an average pumping rate of 25,000 liters per hour

** The estimation of these costs is based on sensitive information regarding the company's profit margin. Failure of equipment is based on historical information.*

When the diagnostic system was developed and installed in pump 1, the pump was offline for annual preventative maintenance checks. Only a small window of opportunity existed to test the diagnostic system. The SCADA team assisted with the testing.

From the interviews (See appendix A) held with various employees at various levels of the organization the following was evident:

- All employees could explain the basic principles according to which the wireless health diagnostic based condition monitoring system works.
- All employees see the monthly reports produced by diagnostic system
- All employees feel that the system contributes positively towards the availability of the pump.
- All employees feel that there are other areas where the system can be applied successfully.

One example of an incident that was prevented occurred on the 8th of November 2009. The technicians realized that the vibration of pump I reached a high level and analyzed the vibration. It was concluded that the high vibration was caused by loose base bolts (soft foot). A corrective maintenance task was planned to tighten the base bolts.

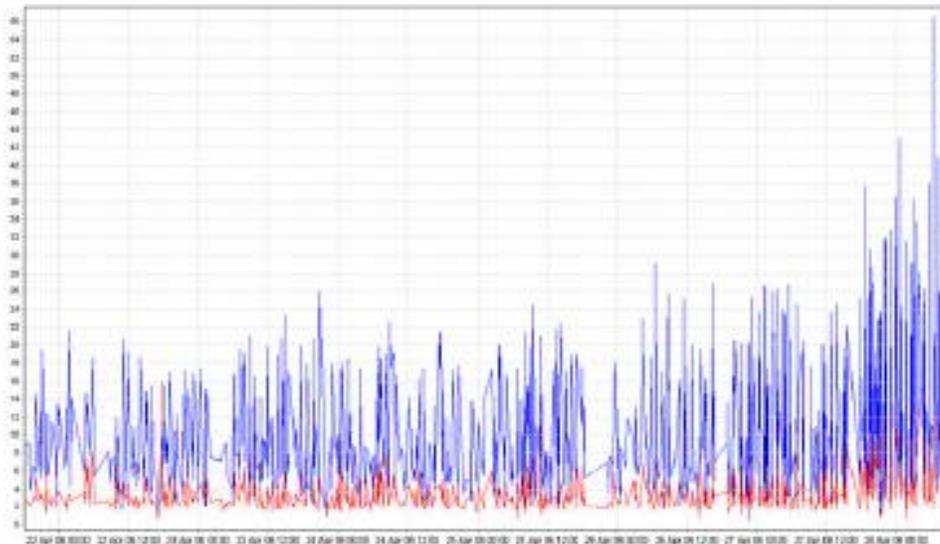


Figure 12: Upward trend in pump vibration (CNL-RCM 2010)

After tightening the base bolts and putting the pump back into operation the results were astounding.

The vibration spectra indicates a steady and upward trend in vibration and in fig 13, when the pump was fixed and brought back to operation, the operation could be seen to be ok and normal. This was picked up by the wireless arrangement and fixed on time to eliminate loss in production due to pump unavailability.

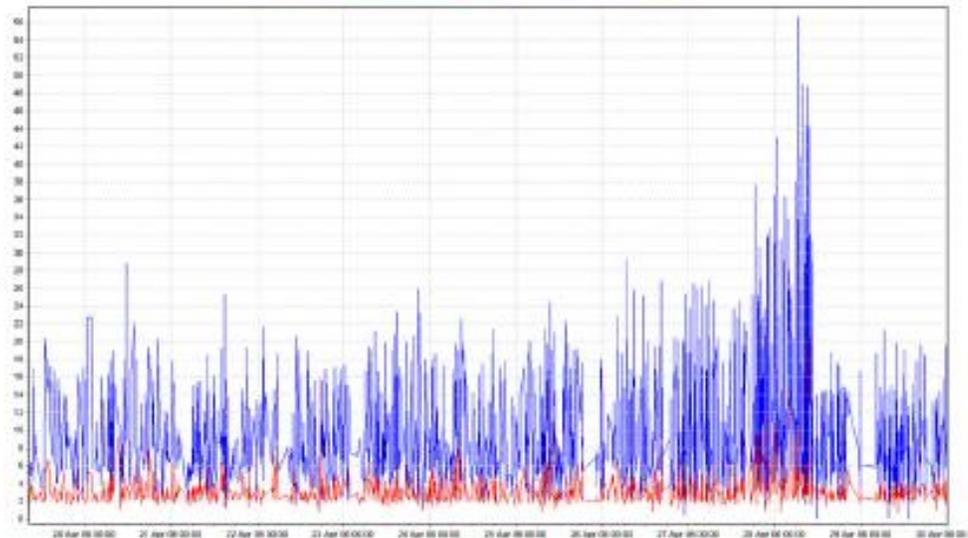


Figure 13: Vibration after putting pump back in operation (CNL-RCM 2010)

4.2.2 Data Analysis

The data stored in the MIS can be extracted to Excel by calling up and dumping a tag. The period for which the data can be extracted is determined by the user. For the purpose of this research, 12 months was chosen as an exemplary set of data. This is because:

- i. Sampling size is adequate (2000 incidents)
- ii. Time between first and n^{th} sample is sufficient to eliminate any unwanted noise in the data (1 Year)

The challenge when manipulating this data was the fact that the tag does not dump the date and time into a single cell. Thus all date differences and durations between two times had to be calculated. The Internet provided better information to this. By subtracting days and multiplying the difference with 1440 minutes (24 hour a day equals 1440 minutes), the amount of minutes could be calculated.

The answer to this problem was fairly simple. If the 2^{nd} time is smaller than the 1^{st} time, which is subtracted from the 2^{nd} , simply add the integer 1 to the 2^{nd} time.

The descriptive statistics were derived from the data and can be reported as follows:

MTBF	Incident1	Incident 2	Incident 3
Mean	28.91	37.38	33.35
Median	10.15	16.34	13.00
Standard Deviation	57.06	68.16	81.28
Range	483.49	1110.24	1394.02
Sum	29290.74	30280.51	23443.86
Count	1013.00	810	703.00

Table 6: MTTR Descriptive statistics (EGTL-RCM)

MTBF	Incident1	Incident 2	Incident 3
Mean	282.26	375.19	409.19
Median	128.00	199.00	237.50
Standard Deviation	354.21	409.83	428.60
Range	1439.00	1438.00	1436.00
Sum	281692.00	296402.00	279065.00
Count	998.00	790.00	682.00

Table 7: MTBF Descriptive statistics (EGTL-RCM)

The following graphs were generated to depict the frequency at which MTTRs and MTBFs of a certain magnitude are represented in the data per EAF. The MTTR and MTBF were calculated according to the following guidelines:

- The first incident recorded for the year has a MTTR but no MTBF.
- The MTBF for incident one cannot be calculated as it is the 1st data point in a series of n data points. With n data points one will only have $n - 1$ MTBFs.
- For this set of data there are refractory rebuilds built into the failure campaign. Thus the first incident after a rebuild will have a MTTR but not a MTBF as it is the first incident.

The graphs were recorded as follows:

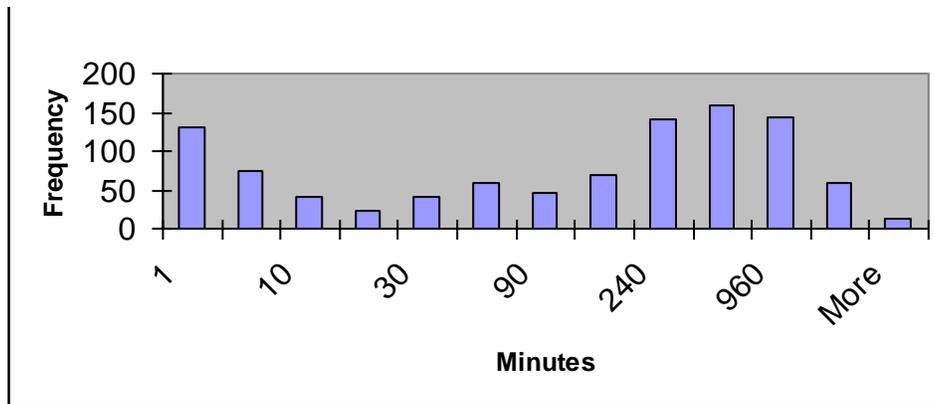


Figure 14: MTBF Histogram EAF1

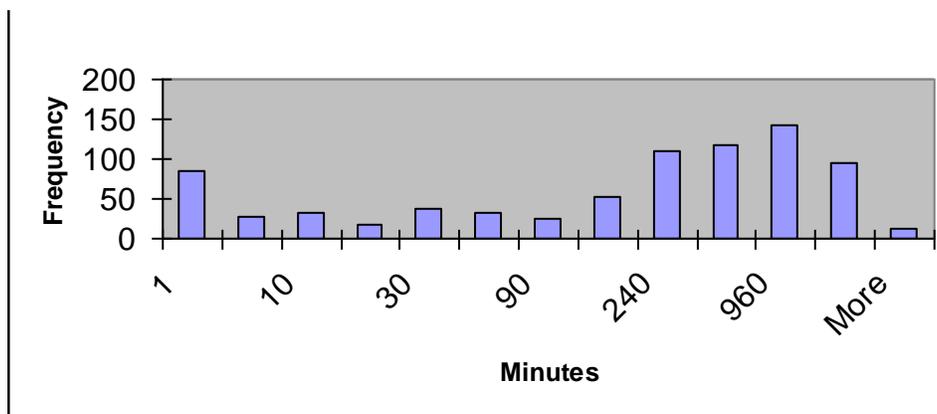


Figure 15: MTBF Histogram EAF2

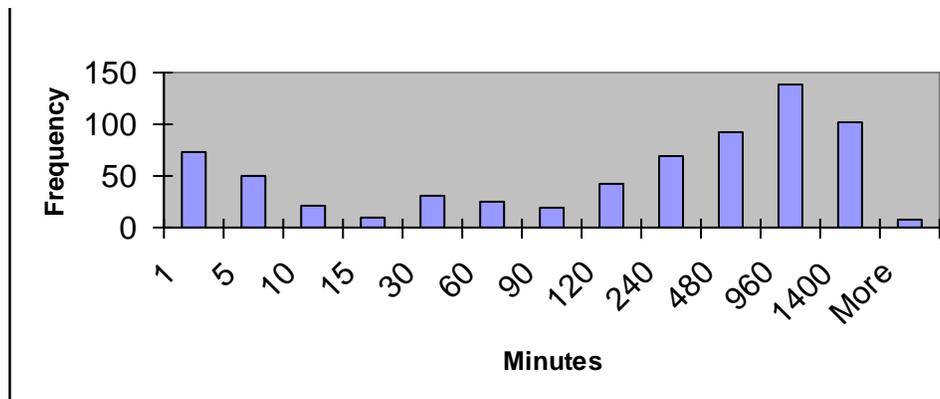


Figure 16: MTBF Histogram EAF3

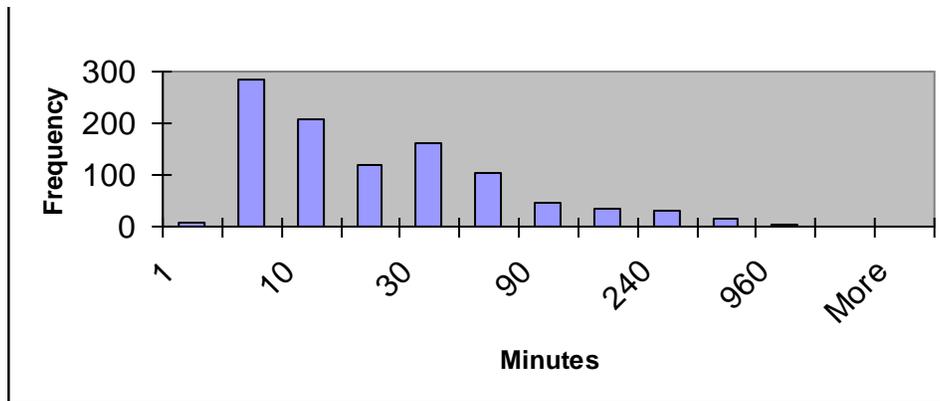


Figure 17: MTTR Histogram EAF1

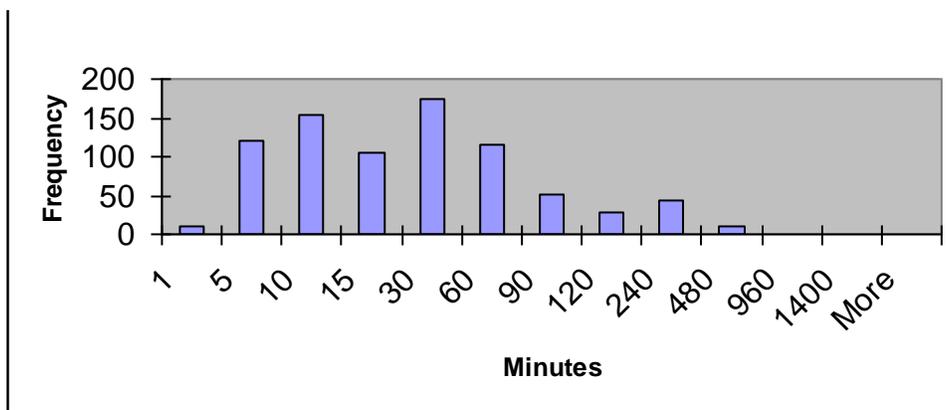


Figure 18: MTTR Histogram EAF2

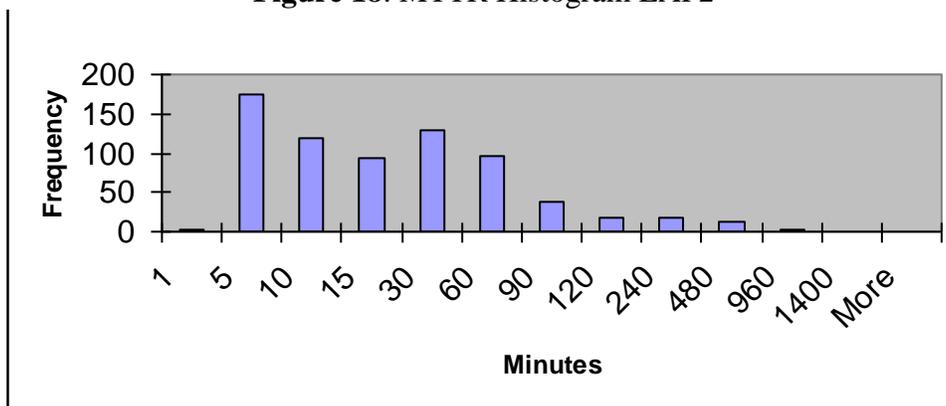


Figure 19: MTTR Histogram EAF 3

Inherent availability (A_i) can be described as the probability that a system will perform satisfactory at any point in time and can be given by:

$$A = \frac{MTTF}{MTTF + MTTR}$$

Equation 3

Utilizing equation 3 in conjunction with the data listed in tables 6 and 7 the following results were obtained:

Parameter	MTBF	MTTR	Availability
A(i1)	282.26	28.91	0.91
A(i2)	375.19	37.38	0.91
A(i3)	409.19	33.35	0.92
A(iAvg)	355.55	33.22	0.91

Table 8 Inherent availability for each failure mode

To study the impact of the delays on availability and to develop the scenario further, it was important to establish the average MTBF and MTTR for pump 1 and 2 other similar pumps, as well as their averages per delay type. This was done by grouping delays (frequency over time) and then calculating MTBF and MTTR between specific incidents.

4.3 Interpretation of results from wireless condition monitoring of pump1

The results obtained from the wireless set up were challenging. It is quite evident that the system could still be improved. For instance, the frequency at which MTTRs and MTBFs of a certain magnitude for conventional results could be higher given the same circumstance.

It was interesting to establish that the general workforce had knowledge of the operations and function of the wireless condition monitoring installation and its performance. This could be to the fact that all functional units were involved with the inception of this project, and subsequently took an interest in the overall success of the vibration monitoring.

The initial installation was done for a fee less than thought; the service fee seemed substantial at the time.

It is estimated that the loose base bolts alone could have been a delay costing in excess of R 50 000 potential income. This is indicative of a payback in less than 4 months since pump1 is a critical pump. It is however important to note that condition monitoring

devices are always seen as an “unnecessary” cost, until failure occurs. In recent months more and more instances of failure prevention have occurred.

It was evident that the mode which delivered the highest degree of value is vibration Knowledge of the vibration tendencies and history is now also known for this specific pump. The use of wireless condition monitoring based preventative maintenance tool cannot be emphasized enough.

CHAPTER 5

Cost analysis, Reliability and security of wireless condition monitoring

5.1 Cost analysis and justification

The cost of networking conventional/remote condition monitoring systems for vibration analysis in a remote area like the EGTL plant is very high. To reduce maintenance resources in this plant, care must be taken to have a quality installation for a long run balancing cost and reliability of the system. Industrial wireless technologies offer an alternative that can lower costs and improve reliability. Choosing the best technology and wireless hardware is critical to installing a successful system. Jim R, (2007)

Mechanical failure of motors, drives and other vital electromechanical equipment are among the most common reasons for production stoppages. Fortunately, recent advancements in condition monitoring such as; vibration monitoring and data analysis have lead to condition monitoring systems that can accurately detect a problem before failure, thus reducing costly machine shutdowns and maximizing production output.

These systems are installed on the monitored equipment and are typically networked back to a central computer for data analysis and alarm annunciation. Because the machines may be in remote locations such as the case of the ‘Escravos Gas-to-Liquids Project in Nigeria where network infrastructure is not readily available, or on moving platforms where hardwired network connectivity is not practical, wireless communications is a networking alternative that offers installation cost savings, quicker deployment and even improved reliability in certain situations.

5.1.2 Wireless Technologies used in industries

The most common approach to wireless Ethernet is RF transmission in the spread spectrum bands. Globally, the 2.4-GHz and 5.8-GHz bands are available for license-free use in most countries. Jim R (2007)

Spread spectrum literally means spreading the RF energy across the entire (or wide portion of the) spectrum. This technique permits relatively high speed communications while being designed to operate in noisy environments where multiple RF systems are present. There are two major methods of spreading spectrum bands; RF energy: Direct Sequence and Frequency Hopping. Both methods have advantages and disadvantages for industrial wireless communications.

Direct sequence uses a wide channel within the band to simultaneously modulate a highly encoded bit pattern (see Figure 13).

Direct sequence offers the fastest spread spectrum data rates as the wide channel permits transmission of complex modulation schemes. Jim R (2007)

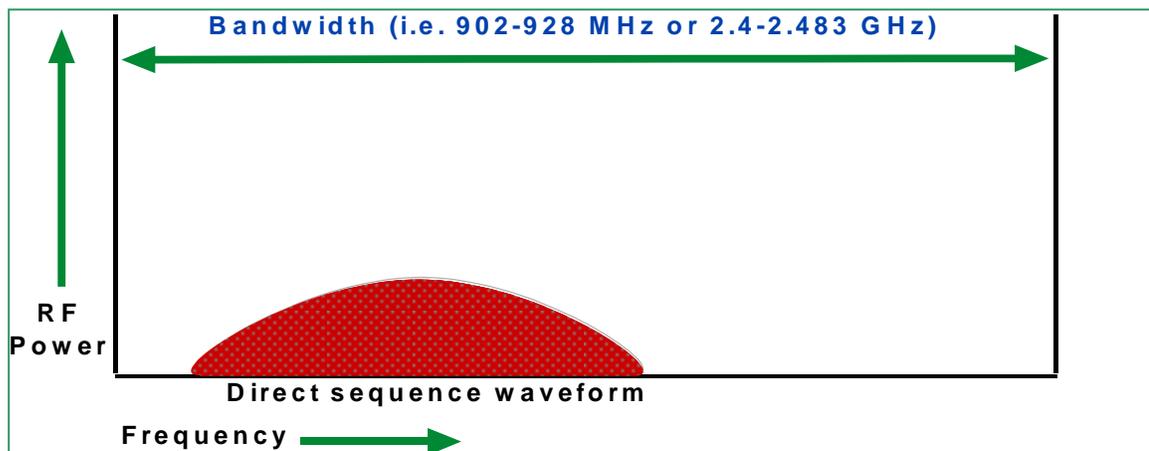


Fig 20 Direct Sequence Waveform - *Curl'd from prosoft.com*

Direct Sequence offers the fastest spread spectrum data rates as the wide channel permits transmission of complex modulation schemes. Jim R, (2007)

5.1.3 Wireless Condition Monitoring Integration

Most condition monitoring systems have an Ethernet communication option for network connectivity. Ethernet is the most easily adaptable interface for wireless if two

considerations are observed: Data rate (bandwidth) and data latency. These considerations especially come into play when multiple remote machines are monitored. Jim R (2007)

It is important to design an RF network that effectively reaches all remote sites while maintaining adequate data rates. If the number of remote machines is high, then it may be best to install separate RF systems to maximize the performance of each system.

Machine locations and building structures will determine antenna placement and may be another reason to consider multiple RF systems. Many industrial systems also support packet repeating to aid in RF signal propagation while also creating self-healing meshes. It is very important for the wireless equipment to be designed specifically for industrial installations. Key specifications to examine are RF power output (higher is usually better), operating temperature, built-in diagnostics and hazardous certifications. Jim Ralston (2007)

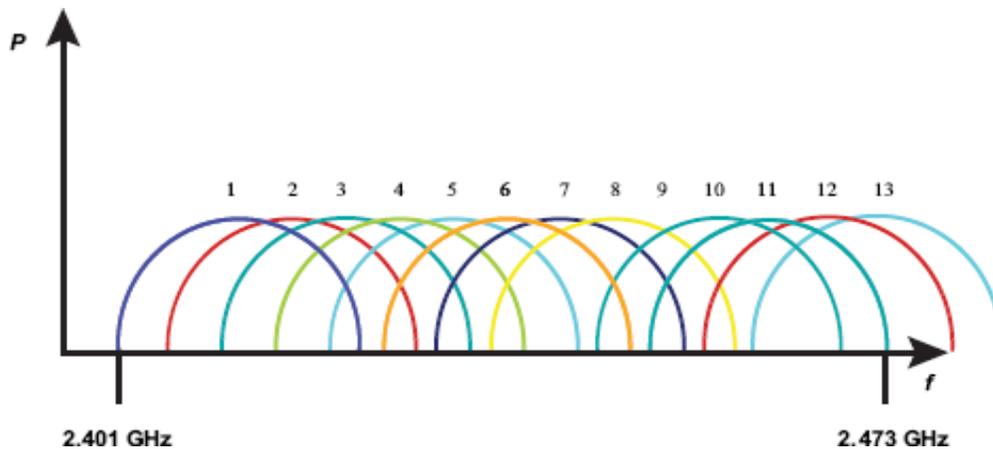


Fig 21 802.11b Direct Sequence Channels

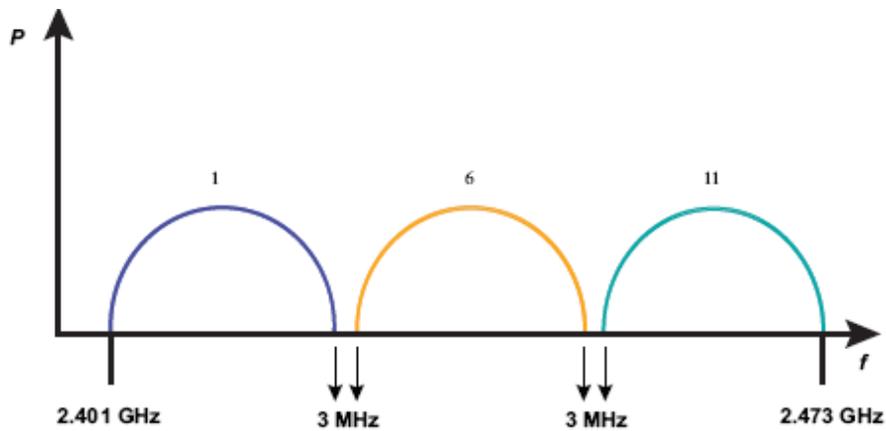


Fig 22 Non Over-lapping 802.11b Channels

5.1.4 Application Examples

Remote condition monitoring can benefit just about every industry where electromechanical machines are vital to production. Several applications where this developed wireless condition monitoring is particularly effective include monitoring of pumps in wastewater treatment plants, drives used on oil/gas drilling rigs, drives on assembly lines in automotive plants and overhead cranes in hot metal mills.

One particularly interesting application is power plant cooling fan monitoring. A coal fired power generation plant wanted to monitor their cooling fans located at the base of their cooling towers. The cooling fans are mounted in very harsh areas where hot steam is always present. Jim R (2007)

When a fan would fail, the tower had to be shut down to allow a technician to repair, thus reducing the power output of the plant, sometimes during peak demand periods. By installing the condition monitoring system, the plant would be able to schedule fan repair during non-peak shutdowns.

The condition monitoring system was relatively easy to install, except that it lacked Ethernet network infrastructure. The cost of pulling a complete fiber optic cable is

estimated at over R800, 000 on a broader base and would take more than six months to install.

The EGTL plant was investigated using wireless Ethernet and discovered that it would only cost a smaller fraction of fiber, and could be installed within three months.

5.1.4.1 Summary

Advances in vibration analysis have lead to other modern condition monitoring systems that can significantly improve plant production.

Unfortunately, the cost of networking these devices can be very high. Industrial wireless technologies offer an alternative to hardwired networking and can result in lower costs and better reliability. Care must be taken, though, to choose a suitable technology and wireless hardware to ensure a successful system.

Fig 16 Frequency Hopping Channels showing time over frequency

5.1.5 Cost analysis of wireless condition monitoring.

Wireless sensing should not only be relegated to locations where access is difficult or where cabling is not practical. Wireless condition monitoring (CM) systems can be cost effectively implemented in extensive applications that were historically handled by running routes with data collectors.

The result would be a lower cost surveillance program with more frequent data collection, increased safety, and lower spare parts inventories. Facilities would be able to run leaner because they will have more confidence in their ability to avoid downtime.

The key to widespread CM sensors is low cost: both installation and operating costs. Data collectors are considered by many to be the lowest cost method for monitoring vibration. With monthly or quarterly route running, companies can prevent many failures and provide an acceptable cost justification to management.

The EGTL plant would benefit from implementing this strategy. While the installed costs of data collectors are typically the lowest, this is because typical wired connectors will be cost effective considering the location of the EGTL project. Operating costs are higher due to continuing labour expense. When analyzed over a period of time, the overall cost of a data collector system will be comparable to a low cost surveillance system, such as wireless CM sensors.

In addition to comparable costs, wireless systems provide more frequent readings for better identification of short time-to-failure situations. Cost justifications for many predictive maintenance practices tend to be complex and rely on some intuition, fudge factors, and an experienced practitioner/consultant. Christopher and Dave (2002).

A traditional method for vibration analysis is to assess the speed degradation to failure and the cost consequence of the machine's failure. This method is well proven, but as technology changes, the justification chart also changes. On-line surveillance systems have become more cost effective, so they have migrated down to the data collector area where there is more overlap of appropriate systems.

The costs to analyze the pump include hard-wired accelerometers, cables, and a switch box (totaling several thousands of rands). Companies are electing to install on-line surveillance systems on the more difficult applications, because these areas are expensive to analyze with data collectors, a low cost wireless accelerometer allows more of these applications to be monitored. Christopher and Dave (2002).

Christopher et al suggested that these traditional cost justifications only touch upon a portion of the benefits of widespread CM sensors. Much like cellular phones, low-cost wireless CM sensors can change the way manufacturing facilities are run. Many companies understand the importance of vibration analysis, but only apply it to critical applications. The most expensive or rapidly declining components are monitored, but these companies still experience unplanned stoppages because the entire facility is not

being monitored; a R800 motor, for example, can shut down an R80,000 / hour production line.

Many facilities account for unplanned downtime with excess production capacity. In petrochemical and petroleum refining plants, up to 15% of production capacity is required to account for unplanned maintenance.

For typical heavy process industries, unplanned downtime costs can also represent 1- 3% of revenue, potentially 33-50% of profits, annually Christopher et al (2002). Widespread usage of condition monitoring sensors can provide up-to-date machine condition so that unscheduled downtime can be significantly reduced.

5.1.5.1 Ease of implementation

Very few companies can afford to implement any type of widespread system. Capital investment is not the only consideration, but also installation costs, training, documentation, spare parts, and cost of production losses. The key for widespread implementation is ease of installation and ease of maintenance of the system. For example, a wireless system would be easier to maintain and implement than a wired system due to the network of wires channeled not only to the host computer but also to other systems.

Wireless sensors have:

- Plug-and-play connectivity
- Intelligence to assist with start-up and maintenance
- Ease of expansion
- Long life

Plug-and-play connectivity means physically installing the sensor, turning it on, and configuring.

Intelligent sensors and software that assist with start-up and maintenance are also important for ease of use. A wireless sensor should be able to determine a path back to the main computer database without configuration by an operator. System components such as repeaters should work seamlessly with no operator interface required. Sensors mounted within range of several transceivers should allow overlapping and be error tolerant. Christopher and Dave (2002).

As network conditions change the system should also adjust and adapt so that data collection remains reliable without operator interface. The next step in widespread implementation is an easy-to-expand system with no discrete input limitations. Companies can purchase and install a handful of sensors on a monthly basis. Installation doesn't require extensive planning or extended shutdown periods. Sensors can also be relocated very easily.

Battery life becomes very important when dealing with large quantities of sensors. Power management is critical to battery life because frequently replacing batteries on hundreds of sensors would be unmanageable.

5.1.5.2 Typical installation

A possible installation scenario might be a production plant that has considered an on-line system for 50 points on critical components. While not being able to justify the R8,000 per point installed costs of a wired system, a R5,600 per point wireless system is more manageable. Included with the 50 wireless sensors are transceivers and software that can be used for additional sensors, so future wireless sensors are only R4,000 per point or less. Christopher and Dave (2002).

Due to infant mortality rates during wear-in periods, 100 wireless sensors are installed to monitor the refurbished production line for several months. By documenting savings during the wear-in period, cost justifications can be determined in that short period of time. After a sufficient wear-in period, the 100 sensors can either remain where they are or be redistributed to other areas of the plant.

A reasonable plan would be to start with the most critical locations and work towards the less critical. By simply installing a number of sensors every month on fairly critical applications or installing on overhauled equipment, a plant can slowly work towards complete coverage. Over several years, a plant could install hundreds of sensors that will eventually provide a complete picture of the plant equipments' health.

Overall plant health data can be included with production information so that facilities will run more efficiently. Process control parameters are already present and provide valuable production data. By incorporating this data with predictive maintenance data, plant managers will have access to not only the existing condition of the factory, but also how degrading equipment is affecting production. A motor might still have a couple months of useful life, but if the motor begins lowering product quality or increasing scrap rates, managers can make the best decision for plant performance.

With complete coverage of condition monitoring sensors, unscheduled downtime due to maintenance failures can be greatly reduced. In addition to traditional cost savings, widespread usage of CM sensors will have additional benefits, particularly a reduction in excess production capacity. The key to widespread usage of CM sensors is the ease of installation and low cost of ownership. (Christopher, Dave- 2002).

5.1.5.3 Cost

Over the next decade, technological advances and economic drivers will move wireless sensor systems onto a track of steadily increasing performance and declining costs. Inexpensive, disposable, peel and stick sensors with .plug and play compatibility will lead the way for sensor networks to operate on 'Moore's Law' for the first time. (*An observation made by Intel co-founder Gordon Moore in 1965. He noticed that the number of transistors per square inch on integrated circuits had doubled every year since their invention. Moore's law predicts that this trend will continue into the foreseeable future as seen in figure 23*).

Continued advances will gradually open the door for sensors further up the complexity continuum to migrate toward this model. Competitive pressures continue to force

industrial end-users to seek new strategies for streamlining operations. Integrated wireless sensor systems represent a promising tool as their costs continue to drop.

The installed cost of a wireless system should be only one-tenth of today's installed cost in the future. In the long term, many sensors will be integral components of the production equipment, and their costs will be incorporated into equipment costs. Sensors at either end of the complexity spectrum, however, will continue to be offered separately on the market. Christopher et al (2002)

Integration costs provide a convenient measure of progress in compatibility. In the near future the addition of individual sensors to a system should increase the cost in a linear rather than compounded fashion as is now the case. Linear cost escalation is far easier to justify in an industrial environment than the current exponential (or worse) cost increases associated with network expansion. Manges W, and Allgood, G (2002)

The true cost of wireless sensors includes the cost of the devices, calibration, integration, maintenance, operation, information abstraction, and security. By 2010, these life-cycle costs should be only half of current costs. As in any business, the key to the cost issue is return on investment. As wireless sensor systems improve resource productivity on the plant floor, industrial companies will readily invest in wireless sensor networks.



Fig 23 Cost of wiring versus Wireless solution

5.1.5.4 Functionality

Wireless system components of the future should be able to recognize each other and organize themselves to carry out effective, efficient, and secure communications, even on

an ad hoc basis. These smart, distributed, heterogeneous computing devices should be nearly self-sustaining.

Demands on the user will be minimal as the systems become self-configuring, self-calibrating, self-identifying, and self-reorganizing for optimal network performance and fault recovery. Sensor nodes will also be designed to be self locating to ease bookkeeping requirements and associated costs. Wayne M et al (2002).

Individual components will be capable of performing different functions as required in response to dynamic industrial environments and system conditions. Multi-functional devices may redistribute tasks to assume the functions of a node temporarily blocked from performing.

In Manges research, the primary metric for gauging progress in functionality is ease of use. The 2012 goal is to provide wireless sensor networks that are self-configuring. For the long term, the goal is to create self-commissioning systems with advanced, embedded computing and communications solutions. These advanced systems will increase ease of use to the point that they perform autonomously.

5.2 Reliability and Security

5.2.1 Challenges in Wireless Security

Organizations see many advantages in deploying wireless LANs (WLANs), a technology that in the past few years has witnessed considerable market penetration. Compared to wired networks, WLANs incur lower installation costs per user given the reduced cabling and manual labour required. Connectivity is provided to mobile users at no extra cost, improving efficiency and productivity. According to Infonetics Research, the worldwide revenue from wireless LAN equipment reached \$2.4 (R16.8) billion in 2005.

One major challenge regarding the deployment of wireless networks is dealing with the unpredictable nature of signal propagation. While signal strength decreases with distance, the rate of decay inside a building depends on the construction materials used, door layouts, the placement of furniture and other obstacles, as well as the number of people and their moving patterns.

The resulting reflection, distraction, and scattering of waves create environment-dependent oscillations in received signal strength, which challenge not only services such as network planning but also all others that rely on signal strength statistics.

Regarding security, one major disadvantage of wireless networks is that they violate the physical security model that is so effective in wired LANs, requiring additional mechanisms to implement proper access control and accountability. Unlike the wired scenario, there is no inherent access control: wireless links extend connectivity beyond physical boundaries, making networks available in parking lots, across the street, and in nearby buildings, adjacent locations where coverage was not intended.

When left unprotected, these wireless links make networks vulnerable to misuse and attacks. It is also more difficult to make clients accountable for their acts, as misbehaving devices can move freely and be 50 meters from the access points they use.

As a result of this trade-off between security and management costs, a large percentage of wireless networks still operate with insecure configurations and many of them are commonly victims of network abuse. A world-wide driving effort performed in June 2004 detected over 200,000 access points, with more than 60% of them running without cryptographic protection.

Wireless LAN technology is compelling for many reasons; on the other they introduce a new security paradigm that creates challenges for access control and accountability. It is clear that security problems will continue to exist unless cheaper yet effective solutions become available.

5.3 Limitations of model

For many petrochemical plants and industries, the purchase of a condition monitoring system is easily justified with a simple return-on-investment (ROI) calculation. For a relatively nominal cost, vital machines may be retrofitted with condition monitoring to reduce operating failures.

However, there are additional costs to consider when network infrastructure is not available or practical. This extra expense can include fibre optic cable installation, conduit engineering/installation, trenching between buildings, leasing phone lines for remote sites where applicable and installation of festooning or slip rings for moving equipment.

These additional costs may push the ROI out beyond what management will accept. If the monitored machine is in a remote location within the factory where network infrastructure is not available, cable installation is necessary. The installation costs of cable in an industrial plant can vary greatly based upon the type of plant and physical configurations. For example, studies have shown that average cable installation in a chemical plant is far much less than the same cable installation in a nuclear plant.

The actual cable cost depends on the location of the machine relative to existing network infrastructure, type of cable needed (e.g. fibre optic), conduit engineering (if needed), labour cost rates and trenching (if required). *Christopher M, Dave W (2007)*

If the machine is in a remote location several miles (kilometers) or more away, as the case of Escravos Gas-To-Liquid plant in Nigeria, then leasing phone lines for communications is required. Leased phone line costs usually include an initial activation/installation fee and then a monthly fee based upon speed of service. Since vibration monitoring is continuous and typically data intensive, the phone line service must support a high enough speed for continuous monitoring.

Phone line service to remote sites such as pump stations is also prone to communication failures due to poor line quality and occasional unreliability. Wireless cellular services are sometimes an option for remote sites, but are subject to service availability and limited in speed. Cellular data subscription costs may also be expensive.

If the machine is on a moving platform (such as pump 1 at the CNL oil platform), then connecting the wireless condition monitoring system to the plant network, is a particular challenge. Depending on the speed and distance that the platform travels, traditional cabling methods such as festooning may be possible.

For spinning platforms, slip rings with Ethernet support are available but are expensive and require periodic maintenance. Some machines may move so fast that the only practical communication method is wireless RF.

Given the challenges of networking condition monitoring systems, wireless communications offer lower installation costs (shorten ROI time), eliminate phone lines and remotely monitor machines that were not practical before. But wireless technologies and equipment vary widely in performance and reliability in industrial installation. Designing a successful wireless network requires an examination of existing wireless usage, RF paths and environmental challenges of the industrial plant.

CHAPTER 6

Findings, Recommendations and Conclusions

6.1 Findings

Preliminary tests proved that the wireless condition monitoring device is capable of measuring pump vibrations for machine condition monitoring where the sensor has several advantages in terms of its compact size, low cost and high sensitivity.

The screen displayed the desired output corresponding to the applied vibration. The application of a wireless monitoring device will act as the fundamental monitoring study for a future design; wireless sensor network (WSN) monitoring system for continuous data monitoring.

The system will be based on wireless RF technology that can measure more accurately in real time.

It is estimated that the loose base bolts alone could have been a delay costing in excess of R 210,000 potential income. This is indicative of a payback in less than 10 months. It is however important to note that condition monitoring devices are always seen as an “unnecessary” cost, until failure occurs. In recent months more and more instances of failure prevention have occurred. This is a clear indication that maintenance resources can be reduced with a good application of wireless condition monitoring in the EGTL plant, Nigeria.

It was evident that the modes which deliver the highest degree of value are vibration followed by temperature measurements.

The amount of details elaborated on in the report is also helpful. Knowledge of the vibration tendencies and history is now also known for this specific pump. The use of this preventative wireless maintenance tool cannot be emphasized enough.

From the wireless health diagnostic system process applied above, good deductions could be made that supports the reduction maintenance resources. Even though the system could not be applied in full, formerly unknown data pertaining to failure modes was exposed because the system continuously monitors the health of pump1.

Upon further investigation it was found that the problem was related to the fact that multiple drivers (strange attractors) grouped the data into distributions which were seemingly random.

Upon investigation of this phenomenon it was found that the grouping could be explained by multiple drivers (sub-failure modes) acting on the system.

It is now known that 94% of all failure modes have more than one driver behind each failure. This deduction will enable management to plan for effective maintenance culture aimed at the reduction of maintenance resources in the plant.

The pre-requisite of breaking the system up into states and defining each by using attributes such as failure and repair rate has confirmed many beliefs and eliminated many wrong perceptions.

The design and implementation of a wireless smart sensor platform targeted for mechanical rotating systems and predictive maintenance was discussed and presented. Tests were carried out to determine system performance for maintenance applications, and as the results suggest were quite satisfactory.

The experimental results show that a sustained near-real-time system can be set up with smart sensor nodes, and the versatility of the smart sensor interface allows implementing diverse applications.

6.2 Recommendations

Future work entails development of multi-hop networking capability among the heterogeneous-radio-equipped smart sensor nodes. A hierarchical network with gateway nodes, network aggregators and end-sensor-nodes is envisaged.

The success of the wireless equipment condition monitoring installation on Pump 1 has opened the doors for further improvement on the real time maintenance strategy to reduce maintenance resources. It is estimated that the savings on pump 1, which can be attributed to production loss, are in the region of R6 million.

This concept should be adopted by the EGTL project in Nigeria.

6.3 Conclusion

This research has proven that there is scope for applying wireless condition monitoring to the EGTL plant in Nigeria for the reduction of maintenance resources. The payback received from the trial conducted during this research is proof to management that this technology is most efficient for a typical remote plant such as the EGTL plant.

For a successful implementation, further studies should be carried out on a suitable technique to adopt considering that this technology is fast becoming acceptable to other organizations and as such recent technologies could affect the present practice.

However, there is still place for improvement. The ever increasing pressures placed on resources have necessitated the introduction of wireless condition monitoring techniques. Owing to the remarkable success of the technology application in this research, it is clear that maintenance strategies can be complimented by the application of a wireless equipment condition monitoring technique aimed at the reduction of maintenance resources.

To meet new energy efficiency standards, many facilities will need to adopt and implement new and existing wireless technologies. To propel energy efficiency, it is

critical to provide support, education, and training for plant operators, engineers, and production workers.

Consequently, the increased demand for remote monitoring, advanced control methods, condition monitoring, and predictive diagnostics is not surprising. Customers are increasingly seeking devices that save energy, optimize their maintenance schedules, and provide greater system protection to reduce overall costs and downtime. Remote monitoring devices allow customers to monitor conditions in hard-to-access areas such as the EGTL plant, trend in real-time motor conditions that could otherwise go unnoticed, and dispatch maintenance personnel before a problem occurs. Remote monitoring of asset conditions allows for optimal and timely predictive maintenance actions to prevent equipment failure and inefficient operation.

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Appendix A: Interview held with employee involved with pump1 maintenance

1. Please state your name and function within Chevron Nig Ltd.
My name is Isaac Omoloso and I'm a Technician at the Terminal Maintenance section.
2. What do you know about the diagnostic Equipment fitted on Pump 1 and how it operates?
It senses vibration from the probes; It's connected to a wireless signal from pump 1 and was seen by the SCADA group.
3. Have you ever seen the report published by the system concerning the results of the data measured on the pump? If you have, how do you perceive them?
I've seen the reports and it's good for the pump. But not fully deployed.
4. Do you feel that the system can prevent any major failures on the pump?
Yes I do. For example there was a vibration, the base bolts came loose and they picked it up using the system.
5. What do you think would have been the extent of the damage, had this early warning system not been in place?
That pump would have come loose and could have broken the coupling. This would have caused serious damage.
5 a) How long do you think the pump would have stood if that happened?
If we had to replace the pump and depending on the damage on the coupling, easily five days would have been expended.
6. Do you think in your opinion that this system has been successful as a trial?
Well, we will see how the system helps with respect to other existing systems.
6 a) Do you think we can use the system on other critical equipments?
Yes, but still needs improvement.
7. Do you think there are other applications except that of the pump for the system?
Yes I think so.
7 a) What do you think you can use it on?
Any place where there are a lot of vibrations, temperature difference and so on.