The Use of Autonomous Maintenance in the Fertilizer Industry in Zimbabwe

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***Abstract* — The paper seeks to give a guideline on the implementation of Autonomous Maintenance in a typical manufacturing facility. It details the chronic and perennial problems besetting typical developing countries maintenance regime scenarios. It then proffers a simple but concise paradigm shift toward the adoption and use of Autonomous Maintenance. A thorough literature exposé is articulated which it is hoped should cement the benefits of Autonomous Maintenance. Autonomous Maintenance is a dynamic, team-based methodology for involving all employees in identifying and eliminating equipment related losses such as equipment failure, lengthy set-up time, inconsistent adjustment procedures, idling and minor stoppages, reduced production yields, processing defects, etc. The importance of teams in goal attainment is highlighted and finally the paper concludes by articulating the World famous 5's due to Nakajima and incorporates these in the implementation of Autonomous Maintenance.**

***Index Terms*— autonomous maintenance; manufacturing; developing countries, maintenance, fertiliser, automation.**

I. INTRODUCTION

The fertilizer industry in Zimbabwe is dogged with profitability problems. For example, in 2010, ZimFert made a loss of US$ 800 000 whilst in 2011 it made a marginal profit of $400 000 (Mutombozana, 2012). The ever-increasing costs of new equipment and spares, perennial foreign currency shortages and the need for improved competitiveness bring about the need for more effective maintenance systems, this results in maximum utilisation of plant-installed capacity through improved reliability, uptime, quality and asset life, all achieved at optimal levels of costs versus benefits (Endrenyi, 2001). Emphasis should be on ensuring that the correct maintenance is being done (doing the right job) rather than merely ensuring that maintenance is being done correctly (doing the job right). For the same company ZimFert, for example, process losses have traditionally been 1.5% of total losses but increased to 10% in 2011 (Mutombozana, 2012). This has raised concern and hence the need to find new emerging maintenance management philosophies such as improving maintenance cost effectiveness as one sure way of increasing the overall profitability. Experience in other parts (Aicheson, 2003), of the world shows that eliminating chronic failures can reduce maintenance costs by between 40% and 60%. This is a typical example where elimination of the chronic failures is doing the right job, as opposed to just ensuring rapid return to operations whenever a failure occurs. As a result, maintenance is necessary to restore the machine to its functional state, preferably for as long a time as possible (Gorelick, 1998). It is often forgotten that these failures are normally a result of human error or omission. The role that effective maintenance plays in cost effective manufacturing has received a greater attention with the concepts like asset management and life cycle costing of the productions asset gaining importance in the recent times. Maintenance has to ensure economical production (Hitomi, 1998), and hence profitability. Thus profitability has to do with both maintenance cost effectiveness and economical production as well; and in turn profitability itself leads to overall company effectiveness (Horner, 1997).

Autonomous Maintenance is one of the latest plant management tools directed at the maximization of equipment effectiveness that results in increased productivity and reduction in costs in any industrial establishment (Zhongwei, 2010). As a facet of maintenance, Autonomous Maintenance is necessary to help restore the machine to its functional state, preferably for as long a time as possible (Gorelick, 1988).

II. AUTONOMOUS MAINTENANCE PRINCIPLES

Within autonomous maintenance, operators maintain their machines in highest standards. These operators are trained to do so through a structured approach of seven steps of Autonomous Maintenance (Nakajima, 1988). Autonomous Maintenance means activities of the operator that uses the machine to personally conduct maintenance activities, including cleaning, oiling, retightening and inspection thereby raising production efficiency to its limit. Such activities will prevent forced deterioration of equipment (Kelly 1991). This is because equipment can revert to systemic failure even after maintenance has been carried out if due regard to maintenance instructions is not adhered to. The major reductions in routine operations and scheduling leads directly to large reductions in operations cost (Kiinigsmann 1996).

Operator based maintenance seeks to empower operators to being full partners with engineering. It is basically the blending of traditional preventive maintenance with quality management (Khanna, 2009). Preventive Maintenance involves the policy of upkeep; replacement and modification rather than repair and incorporates periodical inspection of the plant in order to diagnose the imminent failure (Levitt, 1988). However Autonomous Maintenance seeks to create

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that operator ownership of the plant hence developing that sense in the operators that they are responsible for plant reliability as well as its availability (Khanna, 2009). Secondly, it has the appreciation that the operator has more of the machine and plant inter-phase therefore the operator has more appreciation of the faults and defects that are common and usually encountered during the running of the plant hence is more likely to give a more practical and immediate solution to those problems (Mckone, 2001). Autonomous Maintenance incorporates Condition Based Maintenance which is based around monitoring a parameter or parameters that will indicate the condition of the equipment (Myers, 1988). Thirdly, since the birth of world class manufacturing, it has been noted that there is a competitive advantage in preventing maintenance than to repair broken down equipment; as a result the involvement of all concerned in production, engineering and management is important, and this is well addressed by Autonomous Maintenance (Wheeler, 2007. In addition, Autonomous Maintenance also has an important role in overall system safety management (Rausand, 2008). Overall Equipment Effectiveness (OEE), which is the product of availability, utilisation and quality rate, is increased with the implementation of Autonomous Maintenance (Nakajima, 1988).

III. IMPLEMENTING AUTONOMOUS MAINTENANCE

The purpose of Autonomous Maintenance is to minimize maintenance costs and downtime costs at a given quality of production whilst at the same time fulfilling the requirements of safety (Rausand, 2008). The current maintenance problems in Zimbabwe fertiliser manufacturing sector include:

1 Malfunctioning equipment
2 Process not meeting quality control standards
3 General deterioration of infrastructure
4 Frequent breakdown of equipment

These challenges result in the following consequences

- Failure to meet production targets
- Reduced plant availability
- Low overall equipment effectiveness
- Deterioration of process capability index
- Low plant utilization
- Loss of revenue (Mutombozana, 2012).

With the current economic environment in Zimbabwe, buying new equipment or making drastic process changes is costly due to shortage of foreign currency. This of course could be abated by the use of multi-currency instead of heavily relying on a single currency. This calls for an optimal maintenance strategy that is cost effective. From historical data and records of companies, the consequences listed above can be addressed by utilizing Autonomous Maintenance. However its implementation can be labour intensive if carried out in full. Autonomous Maintenance has been identified as an important solution in having a committed maintenance workforce that is a sufficiently motivated workforce (Kelly, 1998). Some of the typical problems likely to face Autonomous Maintenance implementation are operator resistance and management inertia (Nakajima, 1988). This has also necessitated the need for this paper to analyse these likely problems in coming up with a possible smooth implementation of Autonomous Maintenance that can be accepted by all stakeholders.

The implementation of Autonomous Maintenance was considered for the fertiliser sector because it is a pivotal component in the agro based country’s economy (Mutombozana, 2012). There are similarities in the implementation of Autonomous Maintenance for any plant and the method that will be considered is applicable to any plant with only minor variations needed (Nakajima, 1988).

Unlike predictive/preventive maintenance, Autonomous Maintenance is aimed at failure root causes, not just symptoms. Its central theme is to extend the life of mechanical machinery as opposed to:

- making repairs when often nothing is broken
- pre-empting crisis failure maintenance in favour of scheduled failure maintenance (Hackman, 2002).

Autonomous Maintenance prevents failures as the key to reducing the Maintenance, Repair and Operation (MRO) costs, and to increasing the return on assets. Within Autonomous Maintenance, the optimal reliability threshold is determined by minimizing the cumulative maintenance cost per unit time in the residual life of the system (Xiaojun. 2007). As such, regular Autonomous Maintenance helps keep machines running efficiently and eliminates potential breakdowns (Zhongwei, 2010).

An effective way of implementing Autonomous Maintenance is through the use of small group activities. These are actually achieved by using three main Task Groups.

1. A management task group 1.
2. An engineering task group 2.
3. A production task group 3.

The management task group will be responsible for:

- Formulating the Autonomous Maintenance policy and objectives
- Selling the Autonomous Maintenance philosophy to the whole plant personnel. The information should clearly describe the maintenance policy, Autonomous Maintenance concept and why it is going to be implemented in the factory.
- Staff training.
- Executives and the Managing Director should show enthusiasm in the implementation of the Autonomous Maintenance. Introductory seminars to remove resistance to change are necessary.
- Formulation of master plan is imperative.
- Kick off of Autonomous Maintenance programme, usually in the factory greens, and attended by sister companies, suppliers etc. The other Task Groups, 2 and 3 are responsible for:

- Defining current problems in their areas.
- Analysing the problem areas and bottleneck operations.
- Identification of every condition potentially related to the problem.

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- Evaluation of the equipment, materials and malfunctions.
- Planning and investigating functions and malfunctions.
- Improving plant availability for both task groups 2 and 3.
- Implementation of autonomous maintenance for operators for task group 2.
- Increasing plant utilisation for task group 2.
- Autonomous maintenance can be achieved by using the five S's or 7 Nakajima steps of stage 8 in the 12 step Autonomous Maintenance implementation plan.
- 5S's stand for Seiri (Organisation), Seiton (Tidiness), Seiso (Cleaning) and Seiketsu (Discipline), Shitsuke (Training). The engineering task group shall also handle training and education.
- Preventive maintenance, reduction of breakdowns through continuous improvements, spare part consumption reduction, maintenance for quality and reliability

IV. CONDITION BASED MAINTENANCE

Condition Based Maintenance (CBD) is a management philosophy that posits repair or replacement decisions based on equipment on the current or future condition of assets (Raheja et al, 2006); it recognizes that change in condition and/or performance of an asset is the main reason for executing maintenance (Horner et al, 1997). CBM is a modern procedure which uses the condition of equipment to determine what, if any, testing and maintenance procedures should be performed (DiLeo et al., 1999). CBM is similar to preventive maintenance (PM) program which includes an extensive array of predictive maintenance (PdM) procedures, so that necessarily means CBM is not PdM but a PdM is a subset of CBM.

$PdM + CBM = Holistic\ maintenance$ (This can have intelligence applied in it). The Intelligency can be applied through fuzzy controller. In this research a fuzzy controller has been used. As shown in Fig 1, the CBM approach has proactive and a predictive maintenance. All the problems and failures are analysed and solved systematically. Condition based is a holistic approach to maintenance and is a powerful tool for autonomous maintenance.

V. CONDITION MONITORING

Condition monitoring (CM) is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure, i.e. it uses statistics (Okah-Avae, 1981). It is a major component of predictive maintenance. The use of conditional monitoring allows maintenance to be scheduled, or other actions to be taken to avoid the consequences of failure, before the failure occurs. Nevertheless, a deviation from a reference value (e.g. temperature or vibration behavior) must occur to identify impeding damages (Jardine, Daming and Dragan, 2006). Predictive Maintenance does not predict failure. Machines with defects are more at risk of failure than defect free machines. Once a defect has been identified, the failure process has already commenced and CM systems can only measure the deterioration of the condition. Intervention in the early stages of deterioration is usually much more cost effective than allowing the machinery to fail. Condition monitoring has a unique benefit in that the actual load, and subsequent heat dissipation that represents normal service can be seen and conditions that would shorten normal lifespan can be addressed before repeated failures occur. Serviceable machinery includes rotating equipment and stationary plant such as boilers and heat exchangers (Liu, Jie, Wang and Golnaraghi, 2008).

Condition Based Maintenance on the other hand is to monitor and assess the condition or health of a machinery unit while it is running and stop it for maintenance only (Okah-Avae, 1981). On-load monitoring is done without interruption of the operating unit and off - load monitoring, which would require the unit to be shut down or at least removed from its prime duties. Figure 2 shows the available prognostic methods and its groups. Currently, driven by the demand to reduce maintenance costs, shorten repair time, and maintain high availability of equipment, maintenance strategies have progressed from breakdown maintenance (**fail and fix**) to preventive maintenance (Lee, Ni, Djurdjanovic, Qiu and Liao, 2006), then to condition-based maintenance (CBM), and lately toward a prospect of intelligent predictive maintenance (**predict and prevent**) (Heng, Zhang, Tan and Matthew, 2008), (Tao, Chen, Chan and Wang, 2013). In actual fact the breakdown maintenance and preventive maintenance are labor intensive and also expensive to keep on doing them. For rotating machinery it will be very difficult however to apply PM and breakdown maintenance hence the need to come up with intelligent CBM. Generally this section of literature highlights the other work and case studies that have been carried out in doing maintenance to move away from the general maintenance that is found now to be expensive and time consuming.

The idea underlying conditional maintenance is that a component is not replaced unless it is showing signs of ageing or wear likely to impair its performance (Blanchard and Fabrycky, 1990). The decision is based on physical measurements which are usually:

- Noise and vibration
- Temperatures (thermal monitoring)
- Analysis of oil debris
- Corrosion monitoring
- Acoustic emission monitoring
- Motor and transformer current analysis

The more specialized methods which tend to be associated with particular plant or industry include ultrasonics, shock pulse monitoring, crack detection and some more advancement (Okah-Avae, 1981).

VI. FUZZY LOGIC IN MONITORING PLANT

Most companies are using what is termed smart technologies in reducing machinery breakdown (Innovolt, 2014). The term control is generally defined as a mechanism used to guide or regulates the operation of a machine, apparatus or constellations of machines and apparatus. Often the notion of control is inextricably linked with feedback: a process of returning to the input of a device a fraction of the output signal. Feedback can be negative, whereby feedback opposes and therefore reduces the input, and feedback can be positive whereby feedback reinforces the input signal (Passino K and Yurkovich S, 1998).

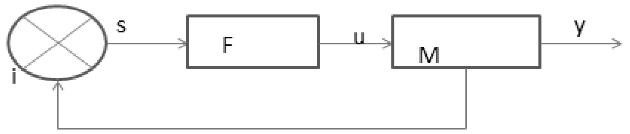

Fig 3: Feedback conventional control mechanism

Where;
M- Machinery, F- Feedback, s- Signal of the error, i- Input, u-control signal or non-linear function, y-output

Fig 3 shows a typical feedback conventional control mechanism and it controls the error if it arises.
The control signal (u) can either be; proportional to the error, proportional to both the magnitude of the error and the duration of the error or lastly can also be proportional to the relative changes in the error values over time. There are also constants in this setup of feedback which are the proportional constant (K_P), derivative constant (K_D) and the integral constant (K_I).
According to (Babuska and Mamdani, 2008); these constants can be linked as follows;

$$u(t) = K_p s(t) + K_I \int_0^t s(\tau)d\tau + K_D \frac{ds(t)}{dt}$$

Equation 1
With equation 1 deductions of the following is carried out and concluded.

TABLE I: WHAT THE PID MEANS

Value (PID)	Determines reaction to the
Proportional (K_P)	Current error
Integral (K_I)	Sum of recent errors
Derivative (K_D)	Rate at which the error has been changing

In the case of classical operations of process control one has to solve the non-linear function u. Furthermore, it is very important that one also finds the proportionality constants (PID). In the case of fuzzy controller, the non-linear function is represented by a fuzzy mapping, typically acquired from human beings (Babuska and Mamdani, 2008). The conventional controller used to work as for the general PID but it will face some challenges in case of robotics section. This is where rules and laws are generated, the IF THEN ELSE rules and put in the fuzzy logic software. Figure 4 shows the arrangement of components in fuzzy logic controller.

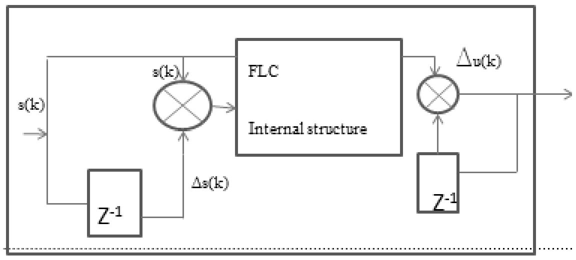

Fig. 4: A fuzzy logic based controller (FLC)

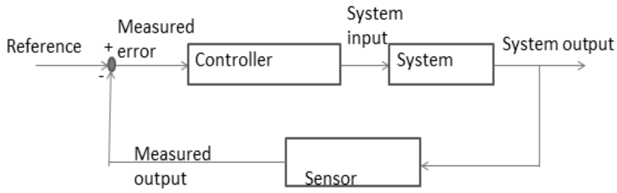

Fig. 5: Fuzzy controller

The fuzzy controller uses intelligent sensors that react faster if any error or fault occurs. Fig 5 shows the fuzzy controller with a sensor and the controller. A fuzzy controller by definition is a device that intends to model some vaguely known or vaguely described processes (Babuska and Mamdani, 2008). Fuzzy logic has basically two types of controllers which are the Mamdani and Takagi-Sugeno (Yager R R and Filev D P, 1994). In this manner the researcher will focus on the Takagi-Sugeno-Kang method which uses (Supervisory Control and Data Acquisition) SCADA for online monitoring.

TABLE II: CONTROLLERS UNDER FUZZY LOGIC

Controller type	Typical operation
Mamdani (linguistic) controller with either fuzzy or singleton consequents.	Direct close-loop controller
Takagi-Sugeno (TS) or Takagi-Sugeno-Kang controller	Supervisory controller – as a self-tuning device

The controller can be used with the process in two modes: Feedback mode when the fuzzy controller will act as a control device; and feed forward mode where the controller can be used as a prediction device (Yager R R and Filev D P, 1994). A controller is implemented using an algorithm. This controller is to be used in this research for maintenance duties in CBM.

VII. Conclusion

It is important to note that the implementation groups are not mutually exclusive but have to interact. This is important especially on the implementation and reviewing of Autonomous Maintenance performance. The benefits achieved will form the basis of a Kaizen path (continuous improvement cycle). The implementation of Autonomous Maintenance is usually done in tandem with an organisation structural change: the new proposed policy would have a deliberate bias towards Autonomous Maintenance to complete the Autonomous Maintenance implementation. The implementation of this policy is sure to improve performance efficiency and effectiveness. The centrality of Autonomous Maintenance and its overarching importance more than ever before in maintenance systems has clearly been brought out.

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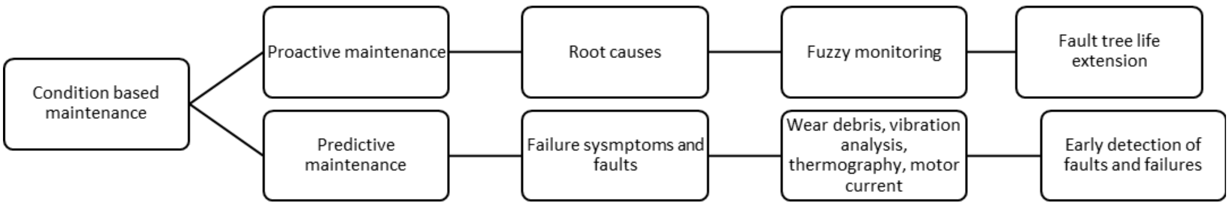

Fig 1: CBM approach has a proactive and predictive maintenance approach.

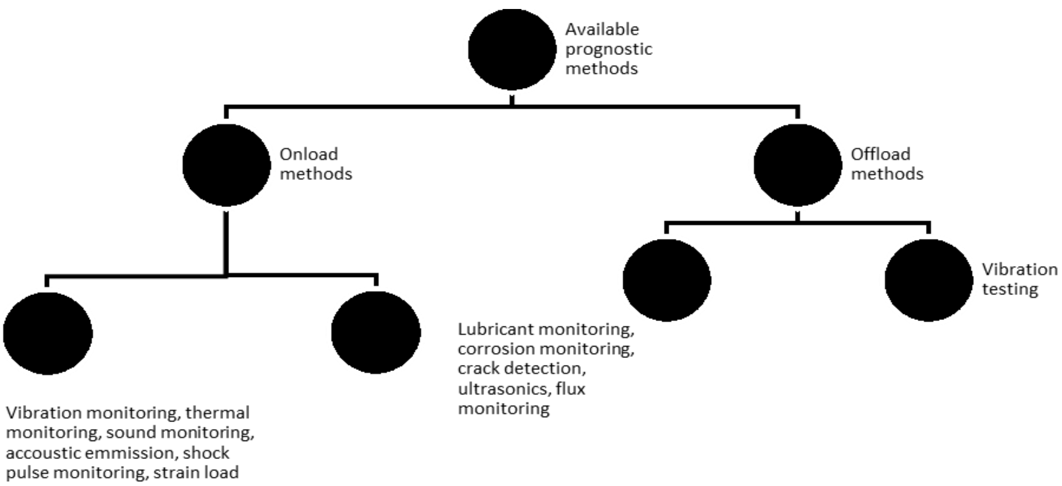

Fig. 2: Condition monitoring methods and their groups

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