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# Proposition of Agent-based Preventive Maintenance Algorithm for Hammer mill Machine Upkeep

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**A B S T R A C T**

**Key words:**
agent, hammer mill, preventive maintenance, watchdog

*Agent-based preventive maintenance algorithm for the upkeep of hammer mill is being proposed. Material wastage has been a major challenge for production enterprises as a result of poor machine maintenance and incessant breakdowns recorded at the production floor. Hammer mill being machine that is meant for material size reduction or whose output serves as material input for other machines meant for production processes needs to be given a special care. In view of this, there is need to place a watchdog that monitors the behavior of the hammer mill and informs plant operator or enterprise managers what needs to be done in order to avoid sudden breakdown. The paper positions agent as a watchdog whose actions are predefined by set of algorithm for carrying out preventive maintenance activities on hammer mill machine using "if" and "then" rules as basis for its preventive and prognosis operations. Successful application of this methodology will reduce wastages and thus increase the machine optimal functionality and efficiency.*

## 1. Introduction

The success of a production firm lies on the optimization of its operational costs. Thus, the need for optimizing the maintenance functions. Moore and Starr (2006) estimated that 18-30% of production operating costs are being wasted due to poor maintenance culture and opined that inadequate maintenance could result in higher levels of unplanned asset failure, which has many inherent costs to the organization.

Lee et al., (2006) and Andrew et al., (2006) opined that the earliest wasteful machine maintenance practice is either reactive (fixing or replacing equipment after it fails, which is called breakdown maintenance) or blindly proactive (assuming a certain level of performance degradation, without input from the machines, and servicing equipment on a routine calendar whether the service is actually needed or not).

Lately, with technological advancement in order to reduce or eliminate waste totally, maintenance technique has multiplied into time-based preventive maintenance (also called planned maintenance), which schedules a periodic interval to perform preventive maintenance regardless of the health status of a physical asset. With the rapid development of modern technology,

products have become more and more complex while better quality and higher reliability are required. This makes the cost of preventive maintenance higher and higher (Andrew et al., 2006).

Therefore, condition-based maintenance (CBM), a subset of preventive maintenance which is the most efficient has become the main maintenance practice of most industries today to handle this scenario.

It is worth noting at this junction to establish what agent system is. The term agent means an entity meant to perform a task continuously and autonomously in the non-determinacy environment where exist other processes and entities. It is an encapsulated computer system that is situated in some environments and capable of being flexible and autonomous in action in order to meet its design objectives (Ming et al., 1998 and Telgen et al., 2012). From this definition, it is evident that agent operates in an environment from which it is clearly separated; has its own knowledge and beliefs about its environment; uses preference in dealing with its environment; initiates and executes actions to change the environment. Based on actual problem and available technology, agent uses searching, reasoning, planning, learning, symbolic methods, classical and quantitative decision theory as well as knowledge-based reasoning and sophisticated belief-desire-intention (BDI) models as tools in solving problems

[Telgen et al., 2012 and Monostori et al., 2006).

Therefore, this research work concept is built on using this encapsulated autonomous computer system or agent system in carrying out preventive maintenance upkeep of the hammer mill machine. Thus, section 2 briefly discusses hammer mill operation, and the preceding section 3 maintains its argument by considering the review of maintenance practices in the industry. Section 4 covers the architecture framework of the proposed agent system for the hammer mill machine maintenance upkeep. The system modular algorithm needed for the watchdog is discussed in section 5. The conclusion is given in section 6 with the suggested future research being captured.

## 2.0    Description of Hammer mill

Hammer mill is a machine whose purpose is to shred or crush aggregate material into smaller pieces by the repeated blows of little hammers. An annotated diagram of a typical hammer mill is shown in Figure 1.
Hammer mills principles are hinged on crushing, shattering or pulverizing upon an impact. Its working operations are:

i.   feeding of material into the mill's chamber by means of gravity;

ii.   strucking of fed in material by ganged hammers (generally rectangular pieces of hardened steel) which are attached to a shaft which rotates at a high speed inside the chamber. The material is crushed or shattered by the repeated hammer impacts, collisions with the walls of the grinding chamber as well as particle on particle impacts;

iii.   retention of coarse materials for further grinding with the aid of the perforated metal screens, or bar grates covering the discharge opening of the mill, thus allowing properly sized materials to pass as finished product; and

iv.   hard, heavy materials such as glass, stone or metals exit the mill via gravity. Pneumatic suction is used to assist in the discharge of lighter materials such as wood, paper or other low bulk density products (Buffalo, 2016).

Varying the screen size, shaft speed or hammer configuration can dramatically alter the finished size of the product being ground. For example, faster speed, a smaller screen, and more hammers result in a finer end product. Each component can be changed individually or in any combination to produce the precise grind required

## 3.0    Brief Review of Maintenance Practices

Lee, (2001); Al-Najjar and Alsyouf, (2003); Dhilon, (2006) and Ashayeri, (2007) posited that machine maintenance is important to ensuring the runing of different subsystems that make up a machine in order to ensure its optimal functionality, usability, reliability and maintainability. To this end, various maintenance

management systems such as corrective breakdown maintenance, which uses a fail and fix maintenance technique (Dhillon and Liu, 2006); preventive maintenance which is elimination or prevention of corrective and breakdown maintenance tasks uses "regular and routine observations" as its techniques (Higgins et al., 2002; Sheu and Kuo, 2006, Mori and Fujishima, 2013); opportunistic maintenance that utilizes "repair opportunity" maintenance techniques (Cui and Li, 2006); predictive maintenance techniques, which utilizes probabilistic, stochastic and adaptive models for machine subsystems failure prediction (Shrotri and Khandagale, 2012); total productive maintenance which uses industrial tools and techniques such as Lean Six Sigma, Failure Mode and Effects Analysis (FMEA) and Failure Modes, Effects and Criticality Analysis (FMECA) for machine maintenance optimization (Chan et al., 2005 and Rajput and Jayaswal, 2012); dynamic maintenance which considers customers product demand in formulating machine maintenance policies (Adeyeri and Kareem, 2012); and computerized/e-maintenance systems which utilizes Information Communication and Technology (ICT) in synthesizing the different maintenance planning and scheduling, diagnosing and prognosing algorithms for optimal machine management have evolved over the years (Zhang et al., 2003, Muller et al., 2008, Holgado and Macchi, 2014).

In view of the literature analysis carried out on maintenance practices, Maalal and Addou (2011) and Mourtzis et al., (2016) posited that advanced maintenance system based on agent-based maintenance system embedded with reactive, communicative, cognitive, autonomous, adaptive and rational intelligent behaviour have not been fully exploited and implemented in the production/manufacturing industries.

Similarly, the works done so far on hammer mill known by the author are majorly on: the design, fabrication and testing of a laboratory size hammer mill (Ajaka and Adesina, 2014); and the design and analysis of rotor shaft assembly of hammer mill crusher (Kumar, 2013). With these literatures, hammer mill design analysis, its fabrication, performance rating, rotor modeling and testing were only covered and discovered.
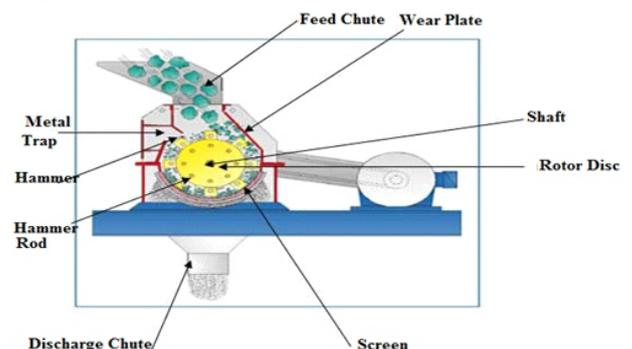


Figure 1: Annotated diagram of Hammer mill (Buffalo, 2016)

The existing manufacturer's manual of this machine only addressed installation procedures and safety tips. The existing manufacturer's manual of this machine only addressed installation procedures and safety tips.

In view of this gap, the present work therefore aimed at providing a preventive maintenance framework for this machine using watchdog agent system as an approach to formulate intelligent diagnosing and prognosing algorithm to ensure optimal functionality, reliability and material waste reduction or elimination if possible.

## 4.0 Architecture Framework for Agent System / hammer mill Machine Maintenance

The architecture framework proposed for the hammer mill upkeep is as shown in Figure 2.

The degradation assessment of the hammer mill hangs on the readings from embedded sensors that measure critical properties of the hammer mill machine components. The agent system watchdog functionalities therefore lie on this degradation assessment. The degradation process changes the sensor readings that are received into the Watchdog Agent system, and thus allowing it to assess, judge and measure the degradation through

quantitatively describing the corresponding change in sensor characteristics or signatures. The mathematical models of the hammer mill as well as expert knowledge of this machine are potent tools harnessed and integrated together to assist the degradation process interpretation. The observed hammer mill performance behavior or engineering model factors is then statistically trended for the purpose of predicting the system immediate and future performance over a period of time. This prognostic duty is majorly performed by the agent system developed.

Other duty performed by the agent system is the diagnostic (causes and effect) function using the signature behavioral pattern of the hammer mill by recognizing conditions that have been established in its sensory module, and from this draw out probable causative factors responsible for the newly observed signature or trended pattern of machine degradation or failure. Thus establishing trouble shooting recommendations using the fuzzy logic functions hanged on "if" and "then" rules for the necessary actions needed to be taken in proffering solutions to the probable developed faults. The decision taken by agent system is made known to the operations manager through the graphic display peripheral put in place in reporting all actions and system decision.
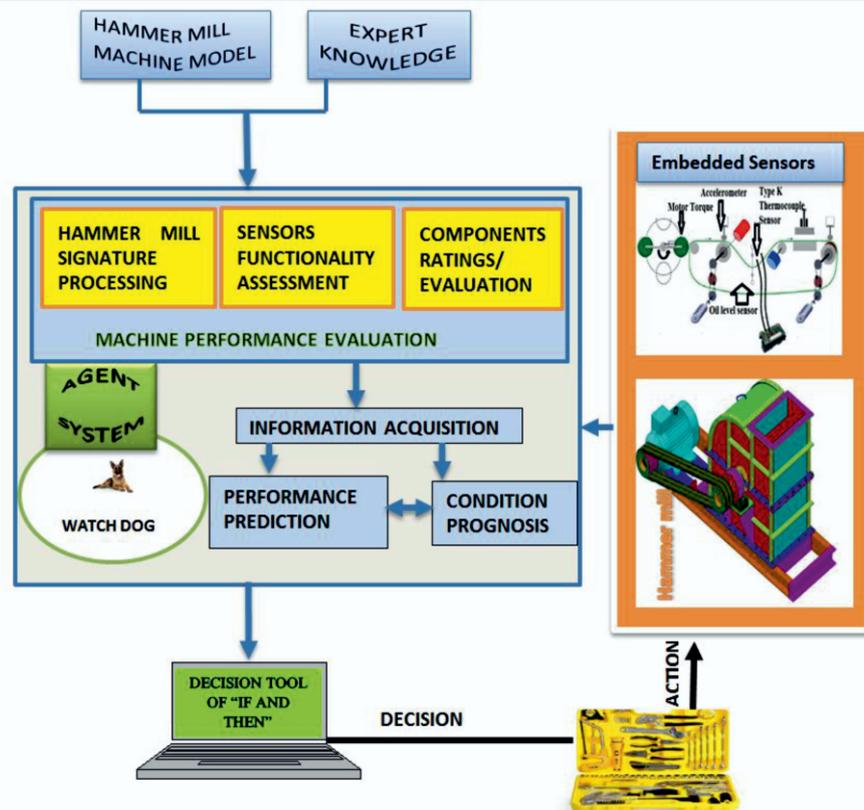


Figure 3: Agent-based Maintenance Platform Model for Hammer mill

**5.0     Agent System Algorithm for Preventive Maintenance of Hammer mill**

The set algorithms are part of the expert experience sourced for over the years in which it interplays with agent system, meant to proffer solutions to the various components that might malfunction at operational level as a result of their degradation processes. Figure 3 shows the simplified platform on how the agent system interacts with the hammer mill environment through the embedded sensors which form part of the transducing elements for machine signature, functionality assessment and evaluation. The algorithms are into modular subroutines as the major critical components such as hammer rod, screen, bearing, shaft, electric motor and the grinding process form the major subroutines created. These are discussed sequentially for better understanding and implementation.

The algorithm used by the agent system in carrying out maintenance activities are as stated in the steps indicated.

A.     Hammer rod module

The major problem with excessive vibration using worn parts and failure to diagnose irregularities in the grinding process can lead to costly repairs and operational inefficiencies. Therefore, the algorithm required to avoid this failure are:

i.    *remove all hammers, hammer rods and spacers*

ii.   *start the hammer mill and run it at operating speed*

iii.  *does vibration disappear? If yes, check hammers for proper fitting*

iv.   *if vibration persist, stop the hammer mill, check the tightness of bars, stabilizer and spanner nuts*

v.    *re-start hammer mill to run at operating speed.*

vi.   *if persists, check rotor for excessive wear, then check for worn hammer rods*

vii.  *then, initialize reverse rotation of the hammer mill rotor weekly*

B.     Screen module

i.    *if perforated hole edges are becoming rounded, then change screens*

ii.   *is screen wear plate thickness reduced by 50%?, then change wear plates*

iii.  *is air volume into the hammer mill adequate to required volume? Then adjust accordingly*

C.     The grinding/crushing process module

i.    *is set mill capacity achievable, if no, check operational characteristics*

ii.   *is product from mill equals the required sizes, if no check hammers and screens*

iii.  *has grinding chamber exceeded the allowable temperature, check grinding chamber*

iv.   *is material fed into the mill uniformly? if not, check the feeding device and possible discharge obstruction*

D.     Electric Motor Module algorithm for implementing preventive maintenance

a.    when motor runs noisily

i.    *are vibration and noise from hammer mill system being transmitted to motor?, if yes, "locate source of noise and isolate motor with belt drive" if no move to (step ii).*

ii.   *if hollow motor foundation acting as a sounding board, if yes, redesign mounting, cast foundation with sound damping materials. If no, then utilize (step iii).*

iii.  *check motor mounting, is it loose, if yes, tighten it and ensure shaft alignment. if no, go to (step iv).*

iv.   *is motor mounting even and shaft properly aligned? If no, align shaft. Else consider (step v).*

v.    *if yes, is fan hitting or rubbing on stationary part or is object caught in fan housing, if yes, repair damaged fan, remove trash from fan housing.*

vi.   *is air gap non uniform or rotor rubbing on stator?. If yes, reset rotor rubbing on worn bearings or relocate pedestal bearings. If no next (step vii)*

vii.  *listen to bearings. Are they noisy? If yes, lubricate bearings. If still noisy, replace. Next step (viii).*

viii. *is voltage between phase unbalanced, if yes balance voltage. Next step (ix).*

ix.   *is three phase motor operating on one phase? If yes, restore power on three phases.*

b.    Maintenance tip for when motor accelerate too slowly

i.    *Check input power to starter. Is there power on all lines, if no, restore power. Else move to (step ii).*

ii.   *Check starter. Is overload protection device opened? Then replace or reset device. Next (step iii).*

iii.  *Is starter opened again when starting? If yes, is there power on all lines to motor? If no, repair starter. If no, next step (iv).*

iv.   *Is voltage to motor more than 10% below voltage required? Then restore proper voltage. If no, next step (v).*

v.    *Check motor terminal connections. Are they loose or broken? If yes, repair connection .Else, go to step (vi)*

vi.   *Is starting load too high? If yes, install larger motor, and go to (step vii).*

vii.  *Is driven hammer mill overloaded or jammed? If yes, remove jam or overload. If no, next (step viii)*

viii. *Are misalignments, bad bearings, damaged components causing excessive friction in hammer mill or power transmission system? Then repair or replace. If no, next (step ix).*

ix.   *Are bad bearings, bent shaft, damaged end belt rubbing*

fan or rotor or other problem causing excessive friction in the motor? If yes, repair or replace motor. If no, go to (step x).

x. Check rotor, are any belt or ring broken? If yes, then replace rotor.

C. Motor overheat

i. Is ambient temperature too high? If yes, reduce ambient or increase ventilation. Else, go to (step ii)

ii. Is motor too small for operating conditions? If yes, install larger motor. If no, next (step iii).

iii. Is motor started too frequently? If yes reduce starting cycle, elso go to (step iv).

iv. Is external frame covered with dirt which acts as insulation and prevents proper cooling? If yes, wipe, scrape or vacuum accumulated dirts from frame. Else move to (step v)

v. Feel output from air exhaust opening. Is flow light or inconsistent indicating poor ventilation? If yes, clean dirt preventing air circulation. Next (step vi)

vi. Check input current while driving load. Is it excessive, indicating an overload? If no go to (step 11). Else, go to (step vii).

vii. Is the driven equipment overloaded? If yes, reduce load or install larger motor. Else, go to (step viii).

viii. Are misalignments, bad bearings or damaged components causing excessive friction in driven hammer mill or power transmission system? Then repair or replace. If no, next (step ix).

ix. Are motor bearings dry? If yes, lubricate. Does motor still draw excessive current, then goto (step x).

x. Are damaged end balls, rubbing fan, bent shaft or rubbing rotor causing internal friction? If yes, repair, or replace motor. Else, next (step xi)

xi. Are bad bearings causing excessive friction? If yes determine cause of bad bearing. Else, next (step xii)

xii. Check phase voltage. Does it vary between phases? If yes, restore equal voltage on all phases. Else, next (step xiii).

xiii. Is voltage more than 10% above or 10% below the manufacturer recommended voltage? If yes, restore proper voltage or install motor built for the voltage. Else, goto (step xiv).

xiv. Check stator. Are any coils grounded or shorted? If yes, repair coils or replace motor.

a. Motor bearings rung hot or noisy

i. Check loading. Is excessive side pressure, end loading, or vibration overloading bearings? If yes, reduce overloading. Else, goto (step ii).

ii. Is sleeve bearing motor mounted on a slant causing thrust? If yes, mount horizontally, or install ball bearing motor. Otherwise, next (step iii).

iii. Is bent or misaligned shaft overloading bearings? If yes, replace bent shaft or align shaft. Else, next (step iv).

iv. Is loosed or damaged end bell overloading shaft? If yes, tighten or replace end bell. Else, next (step v).

v. Are bearings dry? If yes, lubricate, else next (step vi).

vi. Is bearing lubricant dirty, contaminated or of wrong grade? If yes, clean bearings and lubricate with normal grade. Else, next (step vii).

vii. Remove end bells. Are bearings misaligned, worn or damaged? If yes, then replace.

All the algorithms stated are integrated into the microcontroller of the agent system using the machine language program, and then programmed with the agent sensory for its BDI and react sensibly to the hammer mill environment to which it is placed. As shown in Figure 3, the decision belief of the system is communicated through the autonomous computer and communicates to the hammer mill on the action needed to take in order to proactively salvage the machine.

**6.0 Conclusion**

The paper has presented a skeletal framework based on the concept conceived towards hammer mill upkeep. The scope of the proposition has only taken care of hammer mill machine using an A.C. motor, while future work will be able to combine both A.C. and D.C. motors on a similar entity and platform. It is hoped as the framework or blueprint presented is successfully implemented, the hammer mill would be optimally maintained and effectively managed.

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