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Failure Mode Identification And Prioritization Using FMEA- A Case Study Of Corn Milling Industry

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Abstract: *Failure Modes and Effect Analysis (FMEA) is a fundamental reliability analysis tool used in industrial systems with many interacting components for failure modes identification and prioritization with the ultimate goal of eliminating the failure modes causal factors. It entails identifying equipment failure modes using a structured approach. The ability to perform effective failure modes identification and accurate procedure for failure elimination is critical for effective maintenance management. This paper aims to identify and prioritise critical recurrent and potential failures in corn milling plants using selected control parameters through the application of FMEA for purposes of improving critical milling plant sub systems reliability.*
Past research on corn milling plant case studies show that these industries experience frequent shutdowns and lack of equipment optimization resulting to high operations and maintenance costs. This research evaluated a corn milling plant's critical sub-systems failure modes and established that corn milling plants have priority sub-systems with critical failure modes whose failure consequence caused prolonged downtime and high downtime cost. Moreover, it was established that 'run to failure' (RTF) was critical and required close condition monitoring. This condition forced the milling plant maintenance team to apply failure based maintenance policy, a reactive corrective measure which was applied after sub-system failure to solve the failure occurrence. This crisis maintenance approach did not optimize maintenance function but instead led to failure effect characterized by unplanned prolonged downtime and hence correspondingly high down time cost. This paper presents a frame work for corn milling plant failure modes identification and prioritization for purposes of failure elimination to enhance milling plant equipment availability.

Keywords *- Equipment Optimization, Failure Identification, Failure Mode and Effect Analysis, Failure Prioritization, Maintenance Management, Run to Failure*

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I. Introduction

The role of maintenance as an effective tool to improve plant reliability, increase profit margin and reduce safety and environmental hazards has become increasingly important. The perception about maintenance has shifted from being a "necessary evil" to being an effective tool to improve processing efficiency and ultimately larger profits [1]. The trend is part of the new approach to processing named Smart Plants, which advances the concept that such plants anticipate problems instead of reacting to them [2]. One of the effective approaches to solving industrial system failures is through proper mechanisms for failure modes identification and prioritization through application of failure mode and effect analysis (FMEA) as a tool for reliability analysis.

Outcome of past research case study shows that plant reliability analysis for milling plants is highly affected by lack of accurate data or no data leading to sub-optimal parameter estimates and inaccurate decisions about replacement intervals, repair times and maintenance activities that need to be performed on the plant sub-system or equipment before failure or as most often done, after failure occurrence. The economic loss caused by equipment failure leads to reduced production rate or downtime and this is the economic indicator for maintenance performance, i.e. the better the maintenance plan, the smaller the economic loss [3, 4]. Thus by minimizing the maintenance cost, one simultaneously optimizes the cost and the performance of maintenance [5].

Studies conducted in the cereal milling industry are mostly on the challenges facing the sector. These researches are basically on strategy implementation challenges facing the milling industry and continuous improvement strategies in the milling industry. There is need for current and future studies to seek to find out how firms in the milling sector can use lessons learned from previous experiences to improve on their operations.

Milling plants maintenance function has been regarded by many players in the market as a duty that should be left solely to the millers to give advice and where possible deal with. There are no key performance indicators set by the organization that can act as the standard milling plant equipment performance measure so that in the event of any deviation from the norm, necessary maintenance interventions can be applied.

II. Literature review

Every asset is put into service because there is a need for a specific function or functions, and this asset is expected to fulfill this need [6]. Reliability focuses on asset ability to perform this function under certain specified conditions during a stated period of time [7]. Failure risk analysis is critical since it reveals possible potential failures (evaluate the inherent reliability) and predict the effect which the failures will have on the system as a whole. This is useful in order to pin point potential areas for reliability improvement [8, 9] or if not possible, identify possible failures and take action to mitigate the effects before the failure occurs [10]. There are several techniques and tools that can be used to improve the reliability of equipment [11]. This research considered FMEA as an appropriate reliability analysis tool for failure modes identification and failure risk prioritization. This was due to its capability to identify, prioritize and rank the sub-system failure modes together with application of the Pareto chart. Failure risk was regarded as the sub-system failure criticality in terms of down time and the corresponding downtime cost or the production loss caused by sub-system unavailability.

For purposes of failure risk analysis, failure cost was considered as having three cost elements; materials cost (spare parts cost), labour cost (Man Hour Cost, MHC) and downtime time production loss or cost, DTPC (Milling equipment unavailable time, quantified in monetary value due to lost production for 28TPD production line) which was an 'hidden cost' but very critical in this research. All these costs were evaluated and their values tabulated to assess each equipment failure risk. In the calculations, labour cost was regarded as the service cost per failed equipment, materials cost was taken as the cost of spare parts based on the prevailing market rates whereas the production down time cost was taken as the equivalence of unavailable production time cost for 28TPD milling plant production line and the total down time cost was the sum aggregate for all the sub-system failure costs. Pareto analysis was done to quantitatively prioritise the failure modes and present the results.

Various researchers have used FMEA in the analysis of industrial systems with many interacting components either in process, design applications or else. Pantazopoulos and Tsinopoulos [12], found that FMEA is one potential tool with extended use in reliability engineering for the electrical and electronic components production field as well as in complicated assemblies (aerospace and automotive industries). The main purpose for their study was to reveal system weaknesses and thereby minimize the risk of failure occurrence.

Hoseynabadi et. al [13], used the Failure Modes and Effects Analysis (FMEA) method to study the reliability of a wind turbine (WT) system, using a proprietary software reliability analysis tool. They compared the quantitative results of an FMEA and reliability field data from real wind turbine systems and their assemblies. Segismundo and Miguel [14], proposed a systematization of technical risk management through the use of FMEA to optimize the decision making process in new product development (NPD) as case study in an Automotive industry.

From the afore mentioned literature review, no research studies have been done on milling plants or else in maintenance management function efficiency on failure identification, failure analysis and failure risks prioritization in the milling industry and that's why this research finds its usefulness in the manufacturing industry.

III. Methodology

3.1 Research Design

A case study research design was used in this research. This research prioritised six milling plant sub-systems which were considered to be the most critical along the milling plant production line. These included; Roller mill, Degermer, Elevator, Drive Motors, Plansifter and Screens. FMEA, a reliability analysis tool identified all the failure modes of the prioritised critical sub-systems and their effects on the production process. All the failure modes for each sub-system where further analysed quantitatively using Pareto chart for failure mode risk prioritization. Failure risk criticality in terms failure frequency, down time and down time cost was accomplished through application of histogram and Pareto charts.

3.2 Failure Risk Calculations

Failure data collected from primary and secondary sources (maintenance records/ maintenance logbooks, maintenance team, millers and management officials) was used for the different calculations for every parameter in question in this research. The maintenance management records examined were for January to December 2014 and the same period for 2015 for 20TPD and 28TPD production lines, however for consistency, the data for 28TPD production line was considered for analysis. Failure risk levels were considered as the criticality of failure or consequence of the failure mode on the production process. Failure was prioritised according to three parameters; Sub- system failure downtime or Unavailability (DT), failure occurrence or frequency of failure or failure count, (FF) and the failure cost or Failure Down Time Cost, (FDTC or DTC).

3.3 Failure Risk Cost Elements

i. Downtime production cost, C_{PDTC} or PDTC

In this research, this was regarded as the cost associated with loss of production or loss of value creation due to Sub-system failure occurrence; this was calculated by the equation;

$C_{PDTC} = P_U + C_F$ ……………………………………………………….(1)

ii. Failure down time cost/ potential failure down time cost, C_{DTC}

For each failure mode, the total cost of failure was calculated. Total failure cost included downtime production loss due to equipment failure, spare parts cost and labour or Mh costs. It was given by the equation;

$C_{DTC}=C_{DTPC}+C_M+C_S$……………………………………………………(2)

iii. Failure occurrence

For each of the subsystem or equipment, frequency of failures was calculated. This was interpreted as the number of times a certain failure mode occurred within the study period. Example; The elevator mechanism experienced twelve failures in 2014, two resulting from worn sprocket failure mode, four as a result of worn drive chain and pins and six failures as a result of drive motor defects/ faults.

iv. Man hour cost or Labour cost, C_{MHC}

This is the cost incurred in failure repair or cost associated with rectifying a sub-system failure mode. This cost is based on industrial plant labour rate as stipulated in the industrial labour Act. It was calculated as;

$C_{MHC}= L_R \times TTR$………………………………………………………….(3)

TTR- In this research, TTR was considered as the time taken during faults diagnosis and repair of failed equipment. It was calculated as the difference between the time failure repair work ended and time failure repair work started.

v. Materials cost and or spares parts cost, C_S

In this research, material cost was considered to be the cost of replacement kit or spare part as a result of failure occurrence for the sub-system failure modes. It was obtained by the equation;

$C_S= F_N \times N_C \times C_C$…………………………………………………………(4)

C_S refers to material or spare parts cost per failure mode of a failed subsystem or equipment

Sub-Systems Failure Risk Prioritization

Milling plant subsystem or equipment prioritization in this research considered failure risk or consequence based on failure mode criticality in terms of failure effect and or failure consequence to the production process and considered three failure effect parameters; failure occurrence rate/ frequency, duration of downtime and failure DTC which considered DT, repair or service cost, spares cost and MHC.

i. Failure occurrence rate, %

In this research, this failure parameter was calculated as the ratio of the total failure frequency of a subsystem to the total failure frequency of the milling plant prioritised sub-systems during the period of study.

ii. Subsystem downtime, %

This was calculated as the ratio of total downtime in hours of a subsystem to the total downtime of the milling plant in the period of study.

iii. Subsystem failure cost, %

This was calculated as the ratio of the total failure cost of a subsystem to the total failure cost of the plant prioritised equipment for period of study.

All the six (6) prioritised MP sub-systems were subjected to Pareto analysis to establish the sub-systems with the highest risk of failure in terms of failure occurrence, downtime and failure cost or failure DT cost. The sub-systems with the highest risk of failure were then recommended for further analysis of failure root cause evaluation.

3.4 Sub-Systems Failure Mode Prioritization

The research considered the sub-systems with the highest failure risk for failure modes prioritization. Sub-systems have different failure modes and each failure mode has its distinct failure effect on the plant production process. Prioritization of each failure mode was done on the selected critical subsystem or equipment.

i. Failure mode occurrence rate, %

In this research, this was calculated as the ratio of frequency of a failure mode of a subsystem to the total failure frequencies of the subsystem during the period of study.

Failure mode downtime, %

This was calculated as the total downtime in hours of the failure mode of a subsystem to the total failure modes downtime of the subsystem in a milling plant for the period of study.

ii. Failure mode cost, %

This was calculated as the ratio of the total failure mode cost in a subsystem to the total failure cost of all failure modes in a subsystem of the milling plant for the period under study.

IV. RESULTS AND DISCUSSIONS

4.1 Critical Milling Plant Sub-Systems Pareto failure risk analysis- FMEA

The critical sub-systems were subjected to FMEA for failure modes evaluation by considering the failure modes occurrence frequencies and their corresponding failure mode costs for each sub- system failure modes. Pareto analysis was further performed on each sub-system failure mode to quantitatively prioritise the failure modes. This was based on sub-system failure modes occurrence counts, DT and failure down time cost. This was done to identify the sub-system with the highest failure criticality. FMEA results for milling plant critical sub-systems were evaluated and results presented.

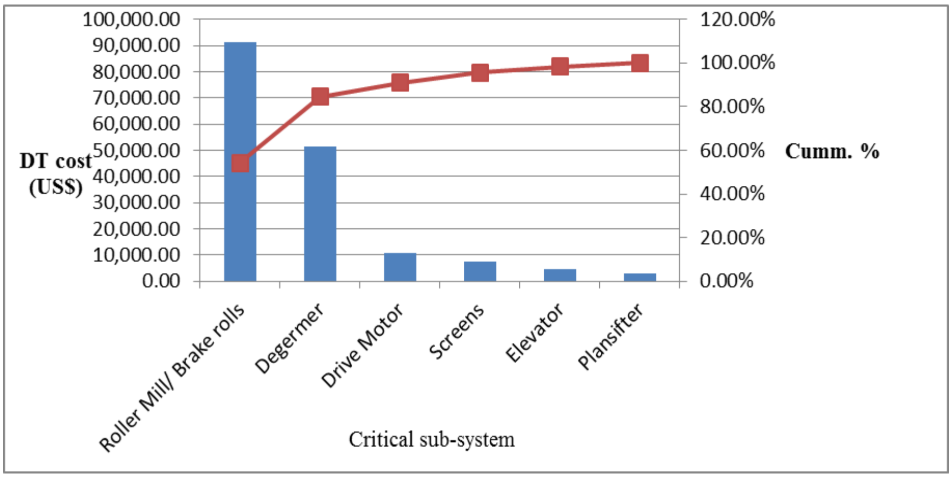

Figure 1: Critical milling plant sub-system FMEA failure risk prioritization

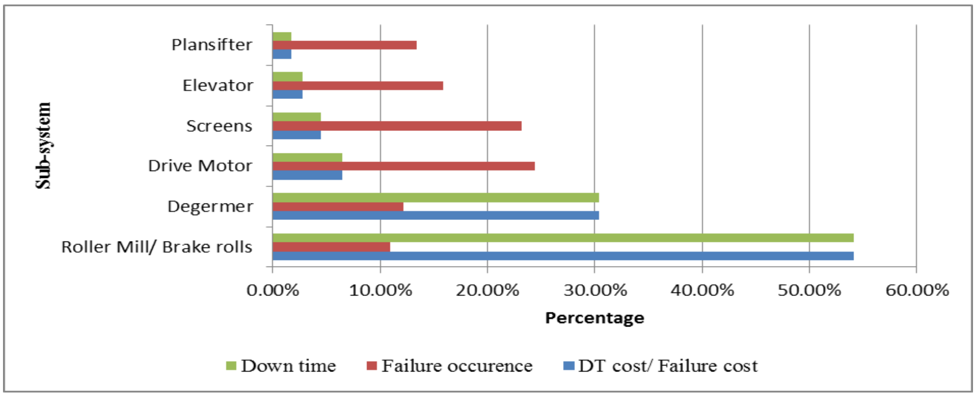

Figure 2: Milling plant critical sub-system % failure occurrence, DT and DTC (Cost of Failure)

From the FMEA, Figure 1 and Figure 2 and considering failure criticality in terms of failure occurrence frequency, DT and the DT cost, research results identified the roller mill as the most critical sub-system in terms of failure risk criticality. This was followed by degermer unit and drive motor. The results again showed that the roller mill had the highest % DT cost of 54.11% of the total milling plant sub-system failure costs. This was followed by the Degermer unit with % DT cost of 30.41%, drive motor with % DT of 6.46%, screens at 4.50%, elevator at 2.78% and the least was plansifter with % DT of 1.74%. The cost of failure for the roller mills and degermer was more than 91,000 and 50,000 USD respectively during the period under study.

4.2 Critical Sub-Systems identified for Failures Modes Pareto Analysis

4.2.1 Roller Mill Sub-System Pareto FMEA

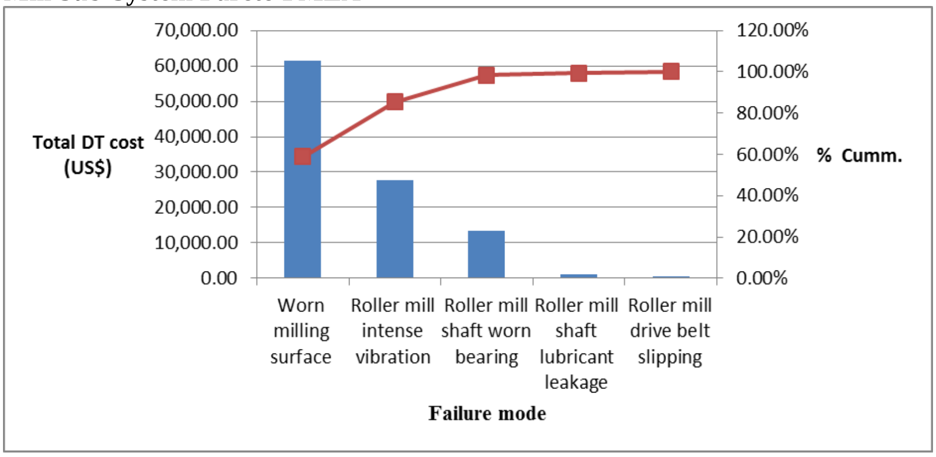

Figure 3: Pareto analysis for Roller mill subsystem failure modes DT cost

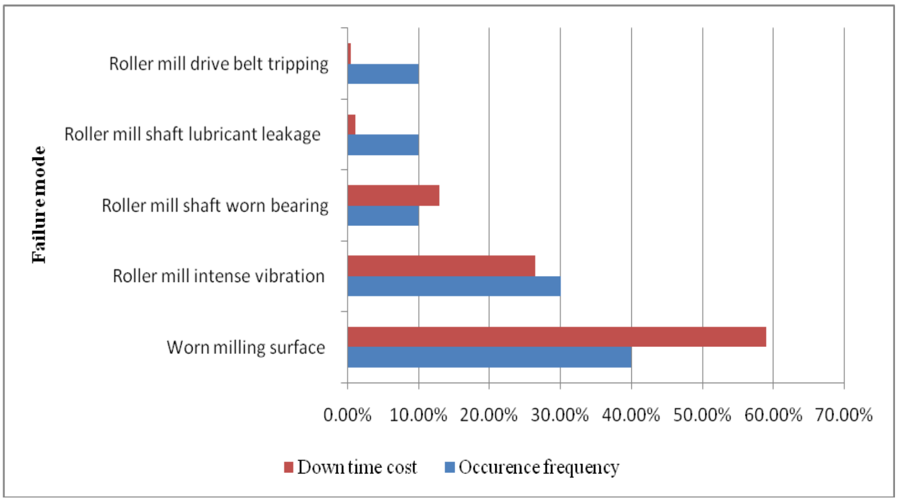

Figure 4: % Failure occurrence rate and % down time for roller mill sub-system failure modes

FMEA for roller mill, Figure 3 and Figure 4, it was identified that wearing of roller mill milling surface was the main cause of roller mill DT with failure occurrence rate of 40% and DT cost or DT failure cost of 58.90% of the total sub-system failures. This was followed by roller mill vibration due to worn bearing or bush with occurrence rate of 30% of the total sub-system failures and DT cost or DT failure cost of 26.48%. Roller mill shaft bearing failure, roller mill shaft lubricant leakage and drive belt tripping had the least contribution to the sub-system DT with almost equal occurrence rate of 10% of the total failures but had different DT costs of 12.95%, 1.14% and 0.52% respectively of the total sub-system DT costs.

4.2.2 Degermer sub-system Pareto FMEA

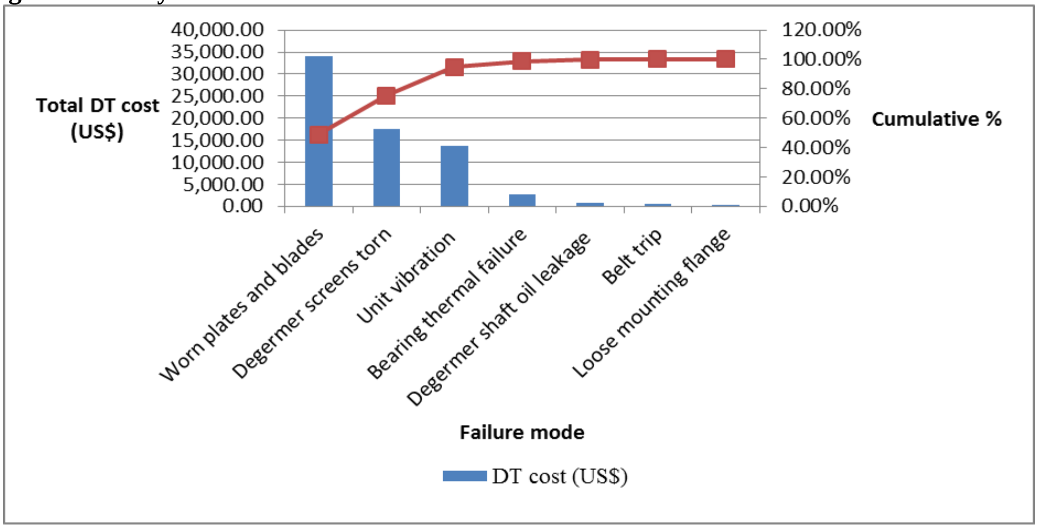

Figure 5: Pareto analysis for degermer sub-system failure modes DT cost

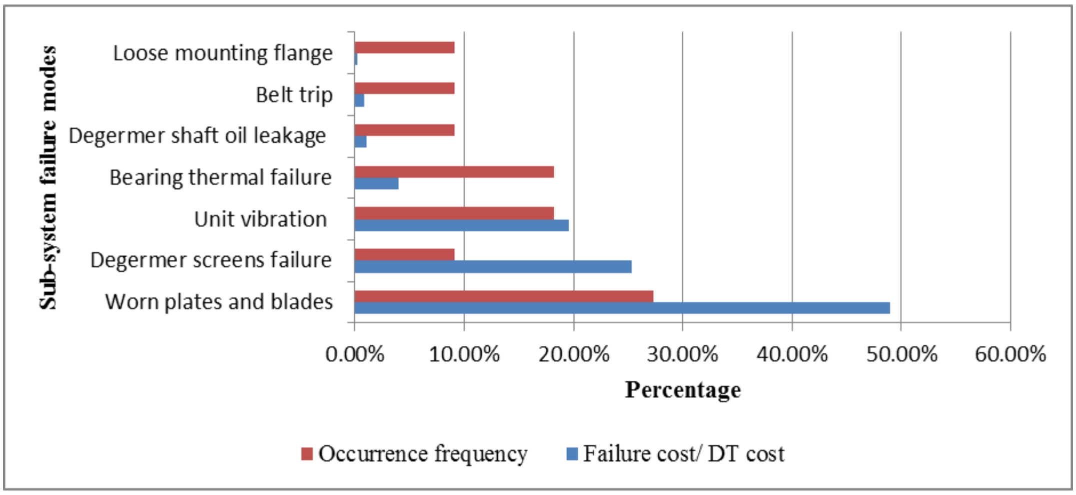

Figure 6: % Failure occurrence rate and % down time for degermer sub-system failure modes

From FMEA for degermer sub-system, Figure 5 and Figure 6, failure due to worn degermer blades and plates was found to exhibit the highest down time rate or failure occurrence frequency of 27.27% of the total unit failures and % DT cost of 48.97% of the total unit DT cost which translated to 34,005.66 US$. This was due to three failures of the total sub-system eleven failures witnessed during the period under review. This was followed by failure of degermer screens and degermer vibration with DT cost of 25.33% (17,587.11 US$) and 19.58% (13,597.97 US$) respectively of the total unit DT cost.

4.2.3 Drive Motor sub-System Pareto FMEA

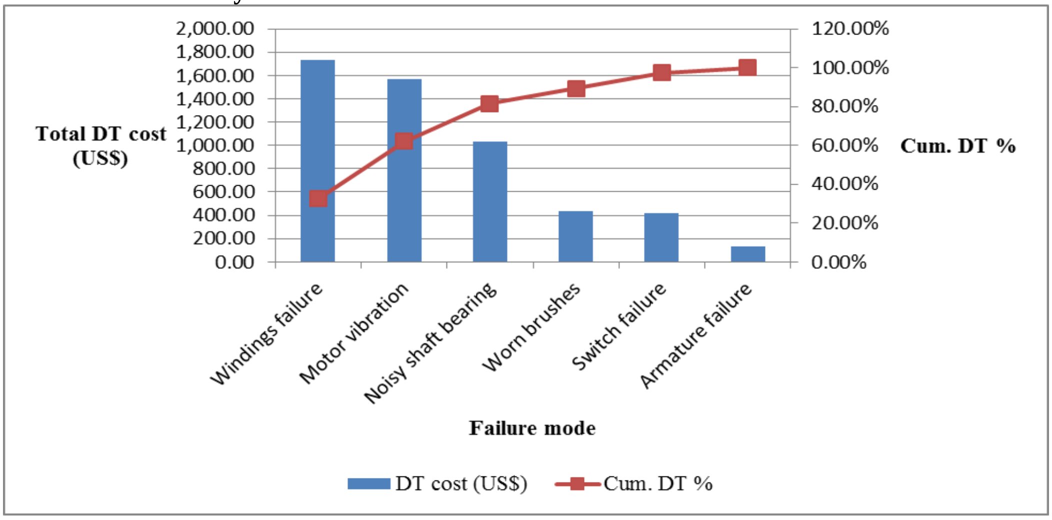

Figure 7: Pareto analysis for drive motor failure modes

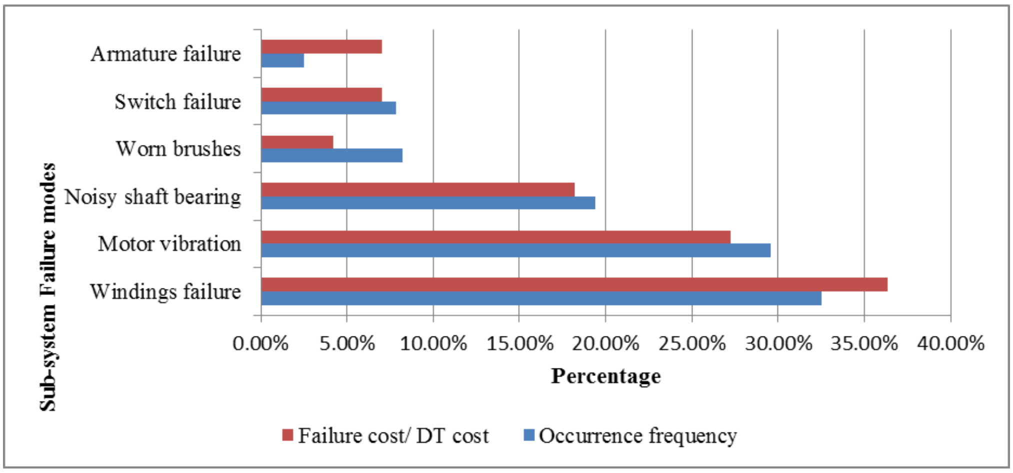

Figure 8: % Failure occurrence rate and % down time for drive motor sub-system failure modes

From FMEA for drive motor sub-system Pareto charting, Figure 7 and Figure 8, motor windings failure was the most critical failure mode exhibiting a % DT cost of 32.51% of the total failures of the unit translating to DT cost of 1,729 US$ and occurrence rate of 36.36% of the total failure frequencies for the unit. Drive motor windings had failed four times out of eleven failures witnessed for the sub-system. This was followed by DM vibration with a % DT cost of 29.56% of the total unit failures, three failures out of eleven failures witnessed, which translates to DT cost of 1,572US$ and % occurrence rate of 27.27% of all the sub-system failures recorded during the period under study.

4.3 FMEA Pareto Summary

From the results of failure analysis done on the three (3) prioritized milling plant sub-systems, five critical failure modes were identified and prioritized as the most critical failure modes and thus recommended to be subjected to Root Cause Analysis (RCA) for failure root cause identification.

V. Conclusion

Proper early failure detection methods and potential failure prediction or detection is fundamental for effective maintenance management. This reduces the probability of failure which leads to plant shut down and thus improving OEE. To reduce the adverse effects of breakdown and to increase the equipment availability at a low cost, FMEA is a key reliability analysis tool that needs to be instituted in industrial set-ups.

From the failure modes Pareto analyses performed on milling plant critical sub-systems, the results identified the most critical failure modes for milling plant sub-systems. The failure effect parameters used in the analysis which included failure occurrence frequency, failure DT and failure DTC explained the sub-systems failure and failure modes criticalities and can be used in milling plants and other manufacturing plant set-ups for failure modes analysis. Use of FMEA as a tool for reliability analysis for failure identification and prioritization if well applied can allow milling plants maintenance team analyse sub-system failure risks and the correct maintenance mitigation measures instituted. Further, the most critical sub-system failure modes can be identified and isolated based the on the risk of failure and thus such failure modes be recommended for further analysis to establish their failure root cause/s using the RCA tool.

This research developed a model for milling plants failure modes and effects evaluation that can as well be used in other industrial set-ups with many interacting sub-systems for failure modes analysis.

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