American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-8, pp-65-69
www.ajer.org
Research Paper Open Access

Prediction and Scheduling of Maintenance by Condition Monitoring

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ABSTRACT: *This work is concerned with the use of the system's characteristics to predict the time to failure of machine, constantly monitored in a condition based maintenance system. A model was structured and defined input data of the system applied on the model after reaching the alarm limit specified. The result obtained from this study was successfully in predicting the time to failure of machines in the system. This method is highly recommended for an inspection based condition maintenance system.*

Keywords: *Inspection, prediction condition monitoring, scheduling, maintenance.*

Date of Submission: 14 -07-2017 Date of acceptance: 14-08-2017

I. INTRODUCTION

Condition based maintenance (CBM) is an equipment maintenance procedure based on detecting the condition of the equipment in order to evaluate whether it will fail during some future period and then acting appropriately to avoid the consequence of that failure (Bengston, 2004). It is maintenance action furthered on actual condition derived from tests. Maintenance is not carried out until there is an obvious need which will increase the availability of the equipment, as well as lower the maintenance cost. The acquired data could be used to determine whether the system is running at a normal operating condition. If the limits of the preset values are exceeded, the reason behind it can be adduced and prediction made for future equipment breakdown and failure. The available information is used to plan maintenance actions (Bengston, 2004). The system/component could be monitored continuously, in which case, the monitoring equipment is fixed on the system and connected to the computer for real time monitoring. The seven specific different layers needed for online condition monitoring are: sensor module, signal processing, condition monitor, diagnostic module, prognostic module, decision support and presentation. On the other hand, the monitoring equipment can be a hand held device out in the field or manufacturing system and the data taken at intervals and analysed afterwards. It is how the information is used that determines if condition based maintenance is in place. Conditioned based maintenance requires taking the result of the analysis and planning the maintenance afterwards. Utilization and communication of condition monitoring data within the establishment requires a structure (Evans, 2003). Such question as when, where and what maintenance actions should be performed for a specific piece of equipment are important factors. This obviously calls for the participation and intervention of the human experts as necessary ingredients for all these activities.

Condition monitoring is concerned with predicting the time to failure of the designated plant or equipment by the measurement of temperature and other conditions parameters like quality of products, vibration, wear, pressure, force, displacement, contamination, etc. against time. Temperature may be measured by thermometer, vibration with a transducer, quality of product by the quality department and wear by oil analysis and so on. Condition monitoring is important to the maintenance manager as it allows it plan preventive work ad possible serious consequences of breakdown (Koboa-Aduma 1991).Condition monitoring otherwise known as predictive maintenance has planned maintenance strategy a step further to rationality and has been found to reduce maintenance cost by 45% (Guerin,1977).

There are many techniques available for condition monitoring strategy. Unfortunately very few techniques meet all the specifications for the ideal predictive maintenance technique. The typical purpose of condition monitoring is to identify potential catastrophic failure with the intension to accurately schedule urgent maintenance activity so as to prevent operational interruption.(Laakso, *et al* 2002) . The sophistication of most of the techniques and the problems associated with their use reduces the advantages of predictive maintenance. According to Henry (1979) an ideal predictive or condition monitoring maintenance technique should have the following characteristics.

Condition monitoring techniques include thermal analysis, vibration analysis, corrosion and erosion monitoring, lubricant analysis, motor flux leakage, etc.

Failures in the industry can be classified as mechanical, thermal or chemical (Banga *et al.*1992).Mechanical failure may be due to bad or worn out bearing, creep of materials at high temperatures subjected to stresses, fatique of machines members , excessive force due to misalignment and unbalance rotors, excessive induced vibrations caused by eddies and turbulence while fluid is flowing .In order to anticipate mechanical failures, the maintenance term must be equipped with instruments such as meter, shockpules meter, vibration analyzer, mechanical or electrical strain guage, and ultrasonic flow detector .A vibration analyst measures the amplitude of vibration at different frequencies so as to know the reason for undue high vibrations. A mechanical or electrical strain guage measures deflection of critical structural parts like foundations , column ,etc. An ultrasonic flow detector t detects minute cracks. Thermal failures are due to overheating because of the following reasons: electrical insulation failures, lack of lubrication , inadequate cooling. In order to anticipate thermal failures maintenance team must be equipped with instruments such as infrared thermometer and thermovision. An infrared thermometer detects hot spots in bearings and other parts of the machinery by remote sensing. A thermovision is an instrument, which scans the surface of a particular piece of equipment with infrared thermometer and displays o the video screen. Chemical failures may be due to corrosion or erosion as a result of failure of protective linings like glass, rubber etc. These may also be due highly corrosive or corrosive fluids containing abrasive particles. In order to anticipate chemical failures , the maintenance team must be equipped with instrument such as ultrasonic flow meter, ultrasonic leak detectors, ultrasonic or eddy current meter, An ultrasonic flow meter measures flow of liquids in pipes, heat exchangers etc. to know the extent of shocking etc. An instrument leak detector helps to detect of gases at high pressure, which cannot be otherwise seen or heard. An ultrasonic or eddy current thickness meter measures the thickness of paints, coatings etc, It can be used also to measure the thickness of pipes and tubes for finding out wear rates.

A good record keeping is essential for a condition monitoring system to be successful. For this purpose the following records are generally maintained namely-times of monitoring, raw data from such monitoring, results of analysis, frequency of breakdowns and maintenance work carried out. With the help of these records possible cause for major repetitive failures can be examined and rectified before they re-occur. According to Banga *et al* (1992) analysis made on the basis of these records help in preventing defects rather than rectifying after breakdowns, knowing the machines reliability and thus helping in production planning, deciding life of the machine, forecasting defects and planning to rectify them before the failure occurs, deciding frequency of inspection and check ups, and finally in deciding the purchase time of a machine. Note that in spite of best planned and condition monitoring measures failures are bound to occur but they can be reduced to a large extent. The essential of asset monitoring and condition based maintenance are to increase the reliability and availability of the component/system. Maintainability is improved as more timely information on the condition of the assets are gotten thus enabling maintenance personnel, spares and other resources to be made available ahead of time before degradation reaches its specified limit. The majority of these techniques rely on the fact that most failures give some warning that they are about to occur. These warnings are known as potential failures (Moubray, 2002). It is identifiable physical conditions which indicate that a functional failure is about to occur or is in the process of occurring.

The objective of this work is to investigate how a structured model of Goode *et al* (1998) can be used to predict time to failure of a machine in CBM system.

II. METHODOLOGY

The machines in a flow station of a major oil company in Nigeria were used in the case study. For privacy policy, it is kept anonymous .Data were obtained from this source and also elaborate discussions with managers, supervisors, engineers and maintainers were made on CBM implementation in the organization. A structured model of Goode *et al* (1998) was used in the investigation. Relevant data like mean time to failure, lower limit, alarm limit, and upper limit designate for the machines were used to predict the vibration levels and hence the time to failure of the machines in the system.

III. MODELS

In this study an exponential distribution is assumed.

$$f_i(t) = \lambda_i e^{-\lambda_i t} \qquad (1)$$

Where λ_i is the failure rate of the CM component in machine i.

The failure rate is given as

$$\lambda_i = \frac{n_{fi}}{T} \qquad (2)$$

Where n_{fi} the actual is number of failure of machine i in a planning horizon.

T is the time unit (in this case one year)

$$\lambda_i = \frac{1}{MTBF_{ni}} \qquad (3)$$

Where the mean time to failure is given as

$$MBTF_{ni} = \frac{U_T}{n_{fi}} = t2 \qquad (4)$$

U_T is the uptime of machine i

The cumulative distribution function (CDF) of the failure distribution represents the probability that a system fails before a given or expected period of time t, that is

$$\overline{F}(t_{ij}) = 1 - F_{i,j}(t) \qquad (5)$$

For an exponential distribution,

$$F_{i,j}(t) = \int f_i(t)dt \qquad (6)$$

In practical terms once the machine has exceeded the threshold limit upon inspection, due to malfunctioning of the monitored components in the machine the machine is scheduled for maintenance based on (ISO 2372(10816) or similar standards.

However, it is necessary to predict when such a system will likely reach its threshold value.

Goode *et al* (1998) model for a weibull distribution in the failure zone is given by:

$$TTF = C_2(-\ln(1 - F(t))^{\frac{1}{m_2}} - t2 \qquad (7)$$

Where TTF is time to failure C_2 and m_2 are constants and F(t) is the specified distribution and $t2$ is the time the machine has exceeded the alarm limit. It is initialized.

If the shape factor of a Weibull distribution is unity, the distribution reduces to an exponential distribution (Law, 2008). Thus, this property is adopted and applied subsequently in this work.

Once the measured vibration signal reaches the alarm limit (AL), prediction of the future vibration signal (for example) of the machine is obtained from Goode *et al* (1998):

$$X(t) = LL + (AL - LL)e^{\left(\frac{\frac{\ln(UL-LL)}{AL-LL}}{tf}\right)(t)} \qquad (8)$$

$X(t)$ is the predicted value after the machine has passed the alarm limit

UL, the upper limit , LL, the lower limit, and AL, alarm limit (ISO 2372(180616).

tf , mean time before failure of the unit and t, the time.

The time to failure of the machine after the signal has passed the alarm limit is given by Goode *et tal* (1998) as:

$$TTF = C_2(-\ln(1 - F(t))^{\frac{1}{m_2}}\left(1 - \frac{\frac{\ln(X(t) - LL)}{AL - LL}}{\frac{\ln(UL - LL)}{AL - LL}}\right) \qquad (9)$$

IV. RESULTS AND DISCUSSION

Table 1 shows the system's characteristics used in the study. The system has three pumps (M/C1, M/C2, M/C3) and one generator(M/C4).

Table 1: Machines limits and characteristics of the system

Machines	M/C1	M/C2	M/C3	M/C4
Lower limit(mm/s)	4.5	4.5	4.5	4.5
Alarm limit(mm/s)	7.1	7.1	7.1	7.1
Upper limit(mm/s)	11.2	11.2	11.2	11.3
t2(year)	0.9945	0.9973	0.9973	0.4960
λ (per year)	1	1	1	2
C_2	0.83	0.83	0.83	0.41
m_2	5	5	5	5

The scheduling of maintenance in the system was done using CBM reference standards. A typical standard is the vibration standard (ISO 2372(180616). Table 2 shows the results obtained by applying the system's architecture and the vibration standard to the units. The lower vibration limit is 4.5mm/s, alarm limit 7.1mm/s and the failure limit fixed at 11.2mm/s. Once the lower alarm limit has been reached , the prediction of the time to failure of the machine was done. For machine one in table 1,: tf $(MBTF)$ is 0.9945years, C_2 is 0.83 and m_2 is 5 (Goode *et al* (1998)); the predicted vibration signal X(t)) in the next one month(0.083 year) is 7.315mm/s; three months(0.25 year) is 7.799mm/s, and six months(0.500 year) is 8.685mm/s. The corresponding remaining time to failure (TTF) of the machine is: 0.915year (11 months), .0.657 year (6 months) and 0.407year(4months) This prediction provides an effective guide for maintenance scheduling. For machine four in the Table 2. The predicted value exceeded the upper limit in the sixth month, and therefore maintenance ought to have been performed on the system between the fourth and fifth months as shown in figure 1.

Table 2: Prediction of the Time to Failure of a Machine Using Vibration Standard

Tni(year)	X(t) mm/s				TTF (year)			
	M/C 1	M/C 2	M/C 3	M/C 4	M/C 1	M/C 2	M/C 3	M/C 4
0.083	7.315	7.314	7.314	7.548	0.915	0.916	0.916	0.387
0.167	7.547	7.546	7.546	8.074	0.783	0.784	0.784	0.285
0.250	7.799	7.796	7.796	8.670	0.675	0.675	0.675	0.201
0.33	8.071	8.068	8.068	9.412	0.578	0.579	0.579	0.126
0.417	8.366	8.361	8.361	10.259	0.489	0.490	0.490	0.059
0.500	8.685	8.679	8.679	11.251	0.407	0.408	0.408	-0.003
0.583	9.030	9.023	9.023	13.780	0.330	0.331	0.331	-0.059
0.667	9.404	9.395	9.395	13.780	0.256	0.258	0.258	-0.111
0.750	9.809	9.798	9.798	15.379	0.187	0.188	0.188	-0.159
0.833	10.247	10.234	10.234	17.235	0.120	0.122	0.122	-0.204
0.917	10.722	10.706	10.706	19.453	0.057	0.059	0.059	-0.245

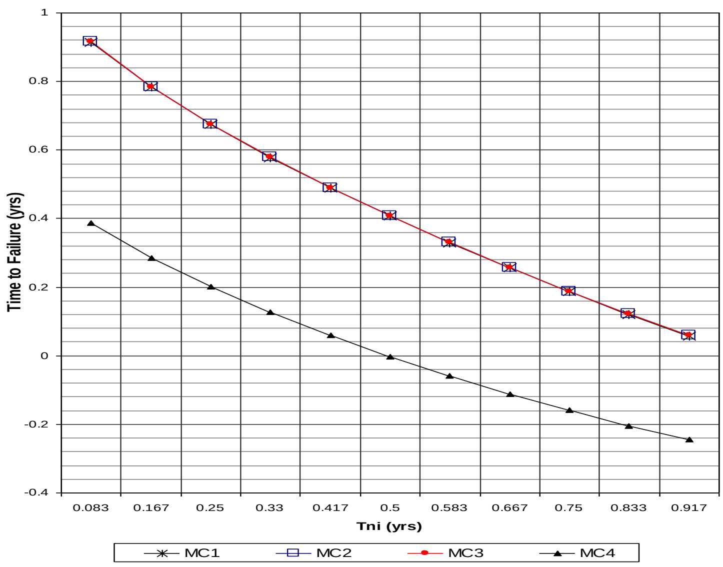

Figure 1: Plot of the Time to Failure of Machines

V. CONCLUSIONS

The structured maintenance scheduling model presented in this work is effective to predict the time to failure of the machine in the system. The failure rate has a predominant effect on the time to failure of the machine. A study on the time to failure using other distributions is highly recommended.

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*Akpan, W. A;" Prediction and Scheduling of Maintenance by Condition Monitoring " American Journal of Engineering Research (AJER) 6.8 (2017): 65-69.