Mining Science, vol. 24, 2017, 73−83

www.miningscience.pwr.edu.pl

Mining Science
(previously Prace Naukowe Instytutu Gornictwa Politechniki Wroclawskiej, ISSN 0370-0798 in polish)

ISSN 2300-9586 (print)
ISSN 2084-4735 (online)

Received February 17, 2016; reviewed; accepted June 21, 2017

CONTRIBUTION TO THE MAINTENANCE OF T4 BH DRILLING MACHINE (CASE OF THE MINE OF BOUKHADRA, ALGERIA)

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Abstract: The current paper presents the study of applying the FEMA method to the drill T4 BH. The research focused on the risk indicators used in the FEMA method. Pareto diagram for the description of the frequency and importance of causes that may cause a problem were applied. With participative method of brainstorming information was gathered concerning the failures that can occur in the drill machine T4BH, their causes and their effects, as well as preventive and error detection methods. The information was then processed by means of different quality instrument (cause-effect diagram) resulting in a ranking of risk coefficient used in the FMEA method.

Keywords: *FEMA method; Pareto diagram; cause-effect diagram; drill machine; mine.*

INTRODUCTION

Mining machines are used for the mechanization of all operations related to the mining of minerals useful, in underground and open pit mining.

Condition monitoring in mining industry is not as well developed as it is in other branches (i.e. power engineering, oil industry etc). One of the reasons is that mine is the specific kind of company with harsh environment and dissipation of assets in wide area.(Zimroz & Krol, 2009)

In mining companies whose drilling is imperative, the drilling machines have acquired a major economic importance. It is estimated that almost any amount of ore produced or collected goes through a drilling machine.

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doi: 10.5277/msc172404

The vital role of drilling operation in mining activities reveals that, the performance analysis of drilling machines and their failure and repair behaviors are essential. (Rahimdel et al., 2016)

The increasing concentration of mining operations, by the descent of mining deposits to great depths, and the presence of more difficult climatic conditions, the level of reliability of these machines often differs from that proposed by the manufacturer. (Robert & al., 2009)

In this study, we contribute to maintenance and to improving the availability, reliability and maintenance of the drilling machine by analyzing the modes and causes of failures by an approach called: "optimization of maintenance by FMEA ".

Failure Mode and Effect Analysis (FMEA) was used in 1949 by the US Armed Forces by the introduction of Mil-P 1629 procedure for performing a failure mode effect and criticality analysis... The objective was to classify failures “according to their impact on mission success and personnel/equipment safety.” (USA Military,1949). It was later adopted in the Apollo space program to mitigate risk due to small sample sizes. The use of FMEA gained momentum during the 1960s, with the push to put a man on the moon and return him safely to earth. In the late 1970s the Ford Motor Company introduced FMEA to the automotive industry for safety and regulatory consideration after the Pinto affair. They also used it to improve production and design. In the 1980s, the automotive industry began implementing FMEA by standardizing the structure and methods through the Automotive Industry Action Group. Although developed by the military, the FMEA method is now extensively used in a variety of industries including semiconductor processing, foodservice, plastics, software, aeronautics, automotive, and healthcare, to name a few. (Carlson, 2014) and (Fadlovich, 2007). We can note that FMEA can be applied to the mining industry.

The Boukhadra iron ore mine (under and open cast mine), currently in exploitation, is one of the largest mines in Algeria (figure 1). The Boukhadra mine is located in the southeast of Algeria, near the Tunisian border with a production of 0.5 million tons in 2008, approximately 180 kilometers from Annaba coast. Boukhadra’s operations started in 1927. The drilling occupies a prominent place in the operating chain. We note currently, after examination of the historic of machines, there is a repetitive breakdown of the drill machine T4BH, which results in a considerable downtime, disrupting the continuous exploitation of ore. The detection and elimination or reduction of the problems inherent in the drill machine T4BH using a continuous process improvement tool will be considerably beneficial in the grounds of reduced machine down time, minimized repetitive stops, diminished cost of replacing spare parts and productivity increase.

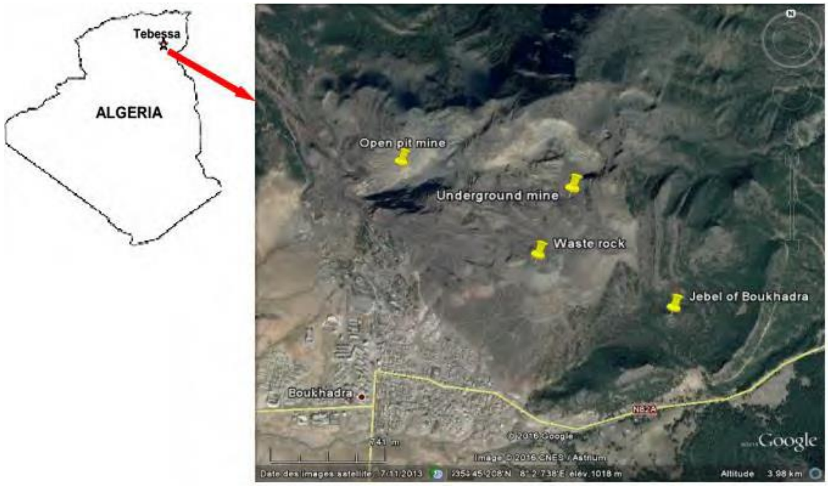

Fig.1. Boukhadra's iron mine (I. Raouaigui et al., 2016)

The purpose of this paper is to analyze the functioning of strategic equipment (drilling machine), considered the most important machines in the mine Boukhadra. Its damage causes the blockage of the operating chain. The cost of lost production and maintenance caused by this blockage is very high. In this context, the FMEA is undoubtedly a real optimization tool maintenance costs. It will be the maintenance method applied for T4BH drill machine.

DEFINITIONS OF FMEA

FMEA provides an organized critical analysis of potential failure modes of the system being defined and identifies the associated causes. It uses occurrence and detection probabilities in conjunction with severity criteria to develop a risk priority number (RPN) for ranking corrective action considerations. (Villacourt, 1992)

Failure Mode and Effect Analysis (FMEA) is defined as a systematic process for identifying potential design and process failures before they occur, with the intent to eliminate them or minimize the risk associated with them. FMEA procedures are based on standards in the reliability engineering industry, both military and commercial (IMCA, 2002).

FMEA can also be defined as a group of activities intended to "recognize and evaluate the potential failure of a product or process and its effects and identify actions that could eliminate or reduce the chance of potential failures".(Kenchakkanavar & Joshi, 2010)

FMEA is a step by step methodology for identifying all potential failures with in the process. "Effect Analysis" denotes to studying the consequences or impact of those failures (Mhetre & Dhake, 2012).

OBJECTIVES OF FMEA

The main objectives of FMEA are to (Degu & Moorthy, 2014) :

- ✓ identify the equipment or subsystem and mode of operation,
- ✓ recognize potential failure modes and their causes,
- ✓ evaluate the effects of each failure mode on the system, and identify measures for eliminating or reducing the risks associated with each failure mode.

1.2. KEY PARAMETERS OF FMEA

Any type of FMEA involves the following key parameters for prioritizing the corrective action:

a) Severity it is an assessment of seriousness of the effect of a failure mode on the customers.

b) Occurrence is an assessment of the likelihood that a particular cause will happen and result in a failure mode.

c) Detection It is an assessment of the likelihood that the current controls will detect the cause of the failure mode thus preventing it from reaching the customer.

d) Risk Priority Number (RPN) It is a mathematical product of Severity (S), Occurrence (O) and Detection (D). It serves in fixing the priority for the process / item to focus for corrective action. It is competed as:

$$RPN=S\times O\times D \tag{1}$$

The three indices (Severity, Occurrence and Detection) are individually assessed on a 1 to 10 scale basis for each failure mode, using the standard guidelines specifically tailored for Design, Process and Machinery FMEA's, to address the objectives and requirements of the selected type of FMEA. Then RPN is calculated using (1) for each process/system/sub-system to rank and prioritize the corrective action plan.

The specifically tailored criteria for ranking FMEA parameters of Severity, Occurrence and Detection are given in Table 1.

Table 1. The criticality scale of FMEA

cotation	Occurrence (O)	Severity (S)	Detection (D)
1	1 failure maximum per year	No stop, production	Visible to the operator
2	1 failure maximum per three months	Stop = 1 hour	Easy detection by a service agent
3	1 failure maximum per month	1 hour <stop <1 day	detection difficult
4	1 failure maximum per week	Stop> 1 day	undetectable

APPLICATION OF FMEA METHOD OF THE INGERSOLL RAND T4BH DRILL MACHINE

DESCRIPTION OF THE RIG INGERSOLL RAND T4BH DRILL

The rig T4BH Ingersoll-Rand (Fig. 2) is a drill platform mounted on a truck, hydraulic transmission, designed for the production of drilling per share rotary / percussive at depths up to 45m using drill rod 7.5 m. The nominal diameter of the holes is 159-165 mm, for drilling applications called "rotary" or "down hole hammer". The T4BH uses a diesel motor directly connected to a reduction gearbox. The air compressor is connected directly to the other end of the motor. The T4BH includes three (3) leveling feet to keep the level, stable machine during drilling. The derrick is built in welded steel tubes. A drill rod changer carousel is part of the derrick and contains up to five drill rods. The ascent and descent of the derrick is provided by hydraulic cylinders. Figure 1 represents the rig T4BH in the mine.(IR, 2003)

Fig. 2. Ingersoll-Rand T4BH Drill Rig in the mine

FUNCTIONAL DECOMPOSITION, OF MACHINE T4BH DRILLING MACHINE

To simplify this study, the systems of the machine (figure 3) have been divided into five functional systems:

- Hydraulic circuit: includes; the principal pump, the drilling feed pump, the rotary motor, the hydraulic cylinders (down) power, filters, valves and controls.
- Drilling motor: drives the compressor and pumps.
- Compressed air circuit: includes: the compressor, pipes, fan, ... radiator.
- Advancement circuit, and drilling: includes head rotation, the hammer, the hoist,
- Auxiliary functions circuit: provides all the spots associated with the drilling process except for the rotation and advance of drilling: up rig, move leveling jacks, dust collector, carousel.

Fig. 3. Elements of Ingersoll-Rand T4BH Drill machine

APPLICATION OF THE PARETO METHOD

After the decomposition of the machine T4BH drill, and view the history of failures, we present the Pareto diagram in Figure 4.

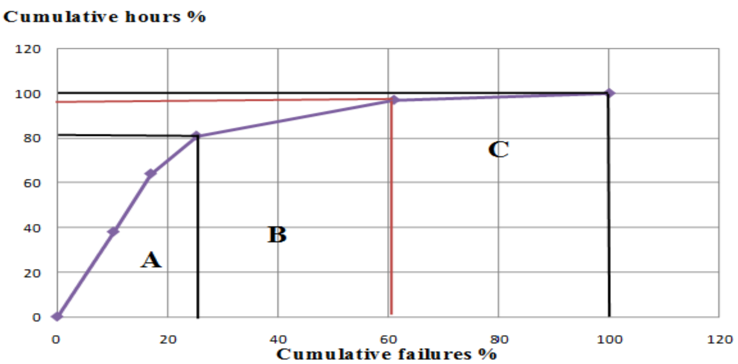

Fig. 4. Pareto diagram

INTERPRETATION OF PARETO DIAGRAM

Zone A: we note that 25.42% of subsets cause 81% of downtime. The equipment concerned by this zone are : drilling motor, compressed air circuit and hydraulic circuit so special attention should be given to these parts.

Zone B: This zone indicates that 35.59% of elements are responsible for 16% of downtime. The concerned equipments are the auxiliary circuit.

Zone C: It consists of advancing and drilling circuit. It represents 61% of equipments, but only 3% of the resulting downtime.

ISHIKAWA DIAGRAM (FIGURE 5):

After studying the Pareto diagram, we sought to understand why the hours of failure of these three subsets are enormous .This which led us to study the Ishikawa diagram. To try to surpass this problem is to know all the causes that may give rise to know " the five M: Machine, Materials, Methods, Manpower and Milieu, to deduce the causes.

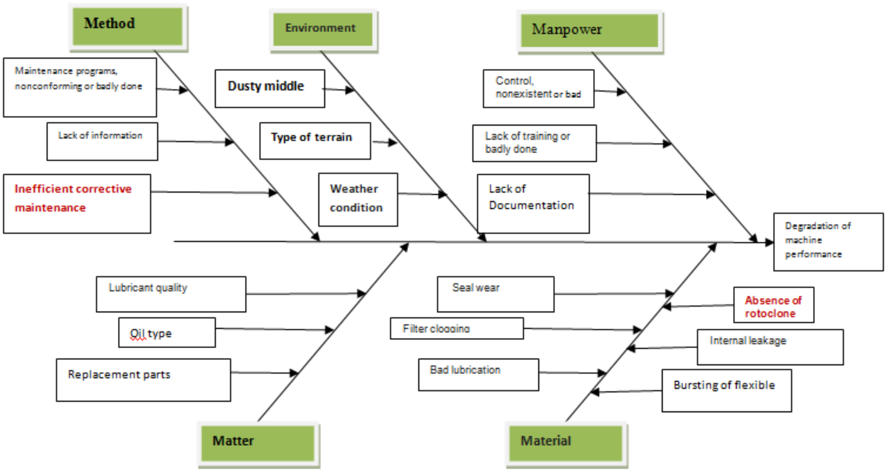

Fig. 5. Ishikawa diagram

INTERPRETATION OF ISHIKAWA DIAGRAM:

According to Ishikawa diagram, we may hire the following:

Material: the type of oil, lubricant quality and improper replacement parts are the factors affecting the profitability of the machine.

Environment: The dusty environment is the major factor that increases downtime. The huge dust is due to the fact that the machine does not have a protective device against dust: Rotoclone. The Rotoclone is a hydrostatic precipitation with an integral fan. It cleans the air by the combined action of the centrifugal force and violent intermingling of the water and the dust-laden air. Its role is to aspirate the dust generated during the drilling operation.

Manpower: The lack of training and qualification of employees are major problems it is imperative to resolve .It there's also a lack of ongoing training and paucity of intervention procedure makes it more difficult spots.

Machines: The machines are typically used in poor conditions (poor lubrication, improper adjustment) that causes internal leakage and bursting flexible and the wear of joints. Lack of rotoclone poses the major problem with the machine in the quarry because the dust affects directly the functioning of the filters, motor and compressor.

Method: The lack of information on the state of the machine and the ineffectiveness of the corrective maintenance makes the task of maintenance personnel, difficult. It becomes necessary to position an intervention team, closer to the machine.

Tab. 2. FMEA analysis

	FMEA machine - Analysis of failure modes their effects and criticality					**Operating phase**				**Corrective Action**
	SYSTEM "drill machine"									
Elements	Function	failure modes	Cause of failure	Effect of failure	Detection mode	criticality				
						O	S	N	RNP	
O- ring	Separator	deformation	wear	Oil loss	visual inspection	3	2	2	12	changing
Oil filter (compressor)	Filtration	function loss	Dust and oil quality	Deterioration of compressor bearings	visual inspection	3	3	2	18	Filter cleaning
hoses	oil transmission	breaking cracking bursting	High load High tempera-ture high pressure	Oil loss Affects the hydraulic system	Visual Manometer	3	3	2	18	Replacing hose
drilling motor	Drives the com-pressor	Do not start	Battery dis-charged Faulty fuel injectors Clogged air filter	Starting impos-sible after arrest breakdown Stopped Produc-tion	Visual Indicator	2	2	2	8	Corrective maintenance
		Overheat	Problem in the cooling circuit		Visual Indicator	3	3	2	18	Conditional preventive maintenance
		Low pressure	Low compres-sion due to the valves		Visual Indicator	2	2	2	8	Corrective maintenance
Oil Filter (hydraulic jack)	Oil filtration	clogged filter or dirty	Dust and oïl quality	Restriction valve opens, and motor stopped	Indicator	3	3	2	18	changing filters
Pump	Debit the lubricant under pressure Alimentation of injectors	No flow	rupture of mating	The pump does not debit	Visual Manometer	2	2	2	8	Changing
		flow insuffi-cient		weak compres-sion		3	3	2	18	
		Excess black smoke	faulty injector Too high injection rate	bad combustion		2	3	2	12	Changing injectors Tuning
Compressor	Ensures the air for pneumatic hammer	short duration operation and stop	High discharge temperature	No pressure	Visual	3	3	2	18	Conditional preventive maintenance
Compressor		works, but does not produce air	The stuck valve	No pressure	Visual	1	3	3	9	Change
Compressor		Excessive oil consumption	Passage of oïl in the discharge flexible	No pressure	Visual	3	3	2	18	Change

Compressor		feeble volume of air	Clogged air filter broken valve		Visual	3	2	2	12	Change
stabilization jack	Ensures the stabilization of the drill	Aging Joints	Blocking	System stopping	Visual	1	2	2	4	Change
		Bursting of Flexible			Visual	1	2	2	4	Change
		Wear of axes deformation of piston	high pressure insufficient greases		Visual	1	2	2	4	Change
hammer	Gives blows	Deterioration	Higher constraints	Drilling Stopping	Visual	2	2	2	8	repair
Belt	Transmit the rotational movement into a translation movement	premature wear Tear	Misalignment of the pulleys manufacturing defect improper tension	preference loss failure	Inspection Visual	2	2	2	8	Changing
jack supply power	Ensures the displacement of the hammer	bursting flexible	blocking	Machine stopping	Inspection Visual	3	3	2	18	Conditional preventive maintenance
		Excessive wear at pivot	high pressure insufficient greasing			2	3	2	12	
		Seal oil leak				3	3	2	18	
Air filter	Protect the motor Eliminate dust in the air	Clogged dirty	The Pollution Damages Impurities from the air flow	Opaque or dark smoke exhaust	Inspection Visual	4	3	2	24	Changing
				Lack of power to the acceleration		4	2	2	16	Changing
				motor wear		3	3	2	18	Changing
Fuel Filter	Filtration	Lost its function	Salt Fuel Consumption	Degradation of function		3	3	2	18	Filter cleaning

FMEA ANALYSIS

FMEA of the T4 BH drill machine done based on the FMEA Severity, Occurrence and Detection criteria outlined in Tables 2:

CRITICALITY EVALUATION

The results summarized in table 3 revealed that for the Risk Priority Number (RPN ≥ 16) for: Oil filter, Flexible, Drill motor, Air filter, principal pump, and Compressor. Hence, utmost priority should be given for said elements to eliminate the failure. The next priority should be given to the element with (RPN ≤ 16) for: stabilization jack, O- ring, Alimentation jack, Hammer, and Belt.

Tab. 3. Criticality evaluation

Criticality Level	Elements	Criticality	Corrective action
RPN ≤16	stabilization jack	4	Curative maintenance
	O- ring	12	
	Alimentation jack	4	
	Hammer	8	
	Belt	8	
RPN ≥16	Oil filter	18	Performance improvement of the element (Systematic preventive maintenance)
	Flexible	18	
	Drill motor	18	
	Principal pump	18	
	Air filter	16	
	Compressor	18	

CONCLUSION

The failure problems of Ingersoll-Rand T4BH drilling Machine in Boukhadra mine was analyzed using FMEA (Failure Mode and Effect Analysis) technique, and corrective actions for quality improvement. Whilst, the ABC (Pareto) method that utilize in this study helps in identifying the causes and their effects. Also, Ishikawa diagrams for the real potential main causes of possible failures in the exploitation of drill machine are showed. The dust problem inherent, in the drill machine, causes a major threat. Once the recommended actions for reducing dust by insertion of rotoclone, and other corrective measures mentioned with a strict adherence to the preventive maintenance, then the RPN values can be recomputed, which are sure to show a marked decrease in its value, owing to reduce severity, occurrence and detection indices, thus improving the life of machines and the overall productivity of mine.

ACKNOWLEDGEMENTS

The authors wish to register their heartfelt gratitude to all management staff and workers of Boukhadra mine (Algeria) for supporting us with necessary technical information and giving feedback about the failure modes for drilling machine.

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