International Journal of Mining Science and Technology 23 (2013) 771–775

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Reliability-based maintenance scheduling of hydraulic system of rotary drilling machines

Mohammad Javad Rahimdel [a,*], Mohammad Ataei [b], Reza Khalokakaei [b], Seyed Hadi Hoseinie [c]

[a] Faculty of Mining Engineering, Sahand University of Technology, Tabriz 51335-1996, Iran
[b] Faculty of Mining Engineering, Geophysics and Petroleum, Shahrood University of Technology, Shahrood 36155-316, Iran
[c] Division of Operation and Maintenance Engineering, Lulea University of Technology, Lulea S-971 87, Sweden

ARTICLE INFO

Article history:
Received 16 December 2012
Received in revised form 13 January 2013
Accepted 9 February 2013
Available online 31 August 2013

Keywords:
Reliability
Drilling
Hydraulic
Maintenance

ABSTRACT

Hydraulic system has a critical and important role in drilling machines. Any failure in this system leads to problems in power system and machine operation. Since the failure cannot be prevented entirely, it is important to minimize its probability. Reliability is one of the most efficient and important method to study safe operation probability of hydraulic systems. In this research, the reliability of hydraulic system of four rotary drilling machines in Sarcheshmeh Copper Mine in Iran has been analyzed. The data analysis shows that the time between failures (TBF) of Machines A and C obey the Weibull (2P) and Weibull (3P) distribution, respectively. Also, the TBF of Machines B and D obey the lognormal distribution. With regard to reliability plots of hydraulic systems, preventive reliability-based maintenance time intervals for 80% reliability levels for machines in this system are 10 h.

1. Introduction

Nowadays, rotary blasthole drilling machines were used in surface mines and in large size quarries for drilling the soft and medium-hard formations. Generally, these machines consist of five main subsystems, as shown in Fig. 1.

Only a hydraulic system is capable for generating the linear motion with very high pressure required for such operations, such as mast raising/lowering and leveling the machine by hydraulic jacks. Also, in many drilling machines, hydraulic system supplies high-pressure hydraulic oil to many hydraulic motors to generate rotary motion. So, in this machine, hydraulic system has a critical role and considering its failure rate and the reliability is essential. Major items of hydraulic system are hydraulic reservoirs, filters, pumps, tubing, valves, motors, cylinders, etc. The functions of components in hydraulic system of drilling machines include the following items [1,2].

(1). Tower raising cylinder

The mast is raised and lowered by means of two hydraulic cylinders. Mast cylinders are often hydraulically extended and mechanically locked so the longer fixed length gives necessary rigidity to the mast.

(2). Jack cylinder

A rotary blasthole machines equipped with four leveling jacks. Therefore, the blasthole drilling machines must be equipped with four hydraulic jacks, unless a very compelling reason exists. This is particularly important in the case of a rotary blasthole drilling machines, because it has a very heavy mast, pipe changer and heavy drill head. All these assemblies take the center of gravity of the rotary blasthole drilling machines to a higher level.

(3). Rod changer

In blasthole drilling machines, after the addition of a drill rod to drill string and its removal and drilling a blasthole to the desired depth, the extra drill rod is to be added. For this reason, almost blasthole machines have an arrangement for storing additional drill rods in the mast, using hydraulic ranch, and mechanically joining them to the drill string. This mechanism is called a rod changer.

(4). Proper motor

On one side of the drill crawler, a sprocket is mounted. The sprocket is also called a drive tumbler. A sprocket has many teeth. These teeth interlock with the track pads. When the sprocket is rotated, the track pads are forced to move. The rotary motion to the sprockets is imparted by means of a high torque hydraulic motor that is known as proper motor.

* Corresponding author. Tel.: +98 4113444311.
E-mail address: mj.rahimdel@yahoo.com (M.J. Rahimdel).

2095-2686/$ - see front matter © 2013 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2013.08.023

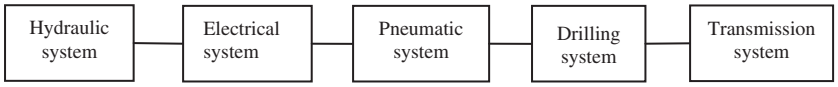

Fig. 1. Block diagram of rotating drilling machine.

(5). Oil cooler

In hydraulic-electric drilling machines, the compressor needs a cooler. The cooler is equipped with a bypass valve to divert oil around the core when the oil is cold. The oil pressure in this condition will be higher than normal. As oil temperature reaches a normal operation rate, the bypass valve closes and forces the oil to go through the core.

(6). Rotary head

The rotary head of a blasthole drilling machines rotates the drill string and exerts feed force on the drill bit through the drill string. The rotary head is fabricated in the form of a box from steel plates. Power to the rotary head is given by hydraulic motors. Trains of gears drive, the main spindle at highly reduced speed and increased torque. The drill string is attached to the lower end of the spindle. The upper end is attached to the air hose through a built-in swivel.

(7). Main pumps

The main pumps are closed-loop hydrostatic transmission package pumps. Loop basically means the complete path of hoses, fitting, valves, motors, and other components which the oil flows through the pump and comes back to it. Rotary drilling machines in Sarcheshmeh Copper Mine have two main pumps that supply enough energy to drill string rotation, propel left track and leveling jacks.

(8). Double pumps

The double pump is a two section fixed displacement vane type pump. Double pump circuit performs all of the tasks associated with the actual drilling process except rotation, drill feed, tower rising and jack operation. Some of these tasks are rod handling, hoisting, dust control and oil cooling. The components of double pump circuit are the pumps, motors, cylinders, filters, coolers and valves needed to perform the drilling functions.

(9). Feed pump

Feed pump is a pump that supplies auxiliary operations such as mast raising/lowering, mast brace, carousel rotation, hydraulic spanner in/out, breakout wrench in/out, breakout wrench lock, breakout wrench rotation, hydraulic oil cooling, water injection pump, oil injection pump, auxiliary winch, radiator cooling fan, other auxiliary operations and cable reel winding.

(10). Dust collector

Rotary blasthole drilling machines flush the hole by compressed air. Dust controls arrangement of the blasthole machine to minimize pollution. The basic operation of any filter dust control system is hydraulic and the basic components of this part of the machine are hydraulic motor, valves, filters, vibrators and dust certain.

In this research, four rotary drilling machines of Sarcheshmeh Copper Mine in Iran have been selected as the case study to collect data for reliability analysis of their hydraulic system. Then, with regard to achieved reliability plots, preventive maintenance time has been calculated. The decomposition of hydraulic system of studied drilling machines is shown in Fig. 2.

2. Theoretical background

2.1. Reliability analysis

Reliability is the probability of failure in functions of equipment and processes when they are operating correctly in a given time interval under stated conditions. The mathematical definition of reliability is presented by Eq. (1) [3].

$$R(t) = 1 - F(t) = 1 - \int_0^t f(x)dx \tag{1}$$

where $R(t)$ is the reliability at time t; $F(t)$ the cumulative failure distribution function; and $f(x)$ the failure probability density function.

Since the assumption of independent and identically distribution (IID) for collected data is normally not valid, validation of the IID of the TBF and TTR data before modeling is essential. Trend test and serial correlation test are two common methods used to validate the IID assumption. The trend test is down with graphical and analytical methods. Graphical method involves plotting the cumulative failure number against cumulative time between failures. If there is any trend in data, non-homogenous Poisson process (NHPP) is used for modeling. In analytical method, the test suggested in MIL-HDBK-189 analyzes the data sets for the presence of trend by calculating the test statistic as the following Eq. (2) [4].

$$U = 2\sum_{i=1}^{n-1} \ln(T_n/T_i) \tag{2}$$

where the data are the failure truncated at the nth failure at time T_n.

Under the null hypothesis of a homogeneous Poisson process, the test statistic U is chi-squared distributed with $2(n-1)$ degrees of freedom.

The presence of serial correlation can be examined by plotting the ith TBF against $(i-1)$th TBF. If the plotted points are randomly scattered without any pattern, it can be interpreted that the TBF date sets are free from serial correlation [5–7]. If there are no trend

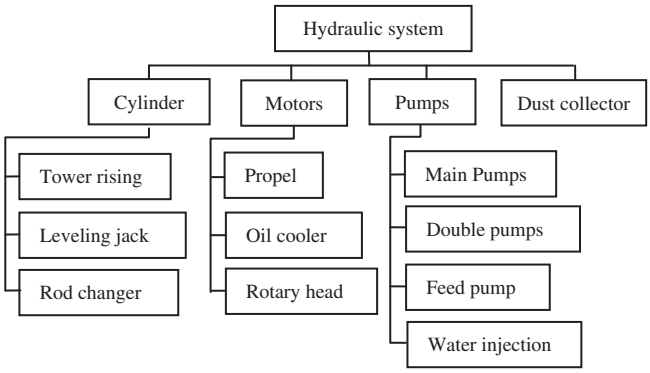

Fig. 2. Decomposition of hydraulic system of drilling machines.