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Weibull Reliability Assessment of a Piling Machine used in an Asbestos Production Line in Nigeria

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Abstract

This study analyses the reliability of manufacturing equipment utilised in a company in Nigeria. The methodology consists of obtaining failure data of the piling machine made of thirteen main components from the maintenance department of the company for a period of one year (January to December 2011). Parameters were determined using the two-parameter Weibull Distribution. From the data, the reliability of the Piling Machine was evaluated to be 0.5557. The value is low and therefore recommendations are suggested on ways to improve this index of performance.

Keywords: Failure Rate, Reliability, Weibull Distribution, Time to Failure, Time to Repair

1.0 Introduction

In order to reduce the adverse of equipment failure to operation, effective maintenance is essential. Increased reliability can often be achieved through a preventive maintenance programme, which also reduces the effect of ageing or wear out and have a significant impact on the life of the system. According to Ahmad et al [1], the high rate of machine production breakdown in industry is one of the disturbances on the production floor. This result in increased production loss and maintenance cost, hence, profit cannot be maximised. Effective maintenance management is therefore essential and critical as a way to reduce the adverse effect of equipment failures and to maximise equipment availability, with the resultant effect of higher productivity and profitability.

Eti et al [2] have stated that maintenance practices in Nigeria still leave much to be desired. According to them, maintenance is generally regarded as an undesirable cost-generating activity instead of one resulting in improved reliability, greater profitability and higher productivity. Neglect of maintenance is often the case, hence the increase in the associated cost as a percentage of the total operating cost.

Therefore the place of reliability studies in Nigeria is paramount in the light of the aforementioned hence this study focuses on the reliability of a piling machine which is used during the production of Asbestos roofing Sheet.

Reliability is the probability that a piece of equipment will function without failure for a certain period of time within an environment for which it has been designed to operate [3]**.** Most of the literature on reliability studies are foreign. Some reliability studies in Nigeria include Ndinechi et al [4], Adamu et al [5], Omokhafe and Ambafi [6]. These include the reliability assessment of systems such as incandescent light bulbs, Modulation power inverter and electric circuit breakers. Eti et al [2] however dealt with the reliability analysis of the Afam Power Generating Plant in Nigeria. Edokpia and Ovuworie [7] examined how available literature analysed the reliability of series production systems and showed the drawbacks in the application of such models to similar systems in Nigerian, where failure occurrences are mostly exogenous. Hence they proposed the incorporation of a complementary station to the line to address these failures and determined the reliability of this station using a Markovian approach. Some of the foreign contributors include are as follows:

Tsarouhas [8] presented a detailed reliability data analysis of an automated croissant processing line made up of several work stations, each with equipment with several failure modes. He also reported that literature in field failure data of production lines is scarce perhaps because most managers were not ready to share their data and/or they do not know exactly

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how to analyse and exploit it. Dutta et al [9] undertook the reliability analysis of defensive vehicles gear box assembly under preventive maintenance, using field failure data. They chose the Weibull distribution for modelling purpose since it is flexible in addressing the three failure rate phenomena that is, infant mortality, Constant failure and wear-out. The result of the findings, according to them would be useful to the maintenance engineer to find the unreliability of the gear box assemblies and also for future strategic decision making. Tsarouhas [10] presents the reliability analysis of a complex medical equipment using the decomposition method with the aim of increasing the availability and efficiency of the system.

2.0 Production Process Description

The production process is shown in the flow diagram shown in Figure 1.

The manufacturing process is divided into three main stages namely: the preparation stage, wet stage and dry stage.

Preparation Stage – It involves the process of making the mixture (slurry) meant for the production process. This Stage consists of the Centralized Fillers Plant, Centralized Cellulose Plant, Cement Mixer plant, Cone and Final Mixer plant.

Here, the required mixtures (Kaolin + $CaCO_3$ + Water, Cellulose + Water, Cement + Water and PVA fibre), are prepared in mixers and pumped via mild steel pipes, and dosed into the Final mixer, for proper stirring to obtain the slurry for production. The proportion of the mixtures at the various plants are monitored and controlled by the operator, via the Batch Control System.

The prepared slurry is then dosed into the Cistern, where it is stored for the wet stage of production.

Wet Stage – It involves the process of transforming the prepared slurry into green sheet. This stage consists of the Cistern, Selectifier, Pre-mixer, Hatschek machine, and the Waste mixer. Here, the mixture (slurry) is pumped from the cistern through the selectifier to extract all hard particles, and the filtrate dosed into the pre-mixer, from where it enters the hatschek machine. The hatschek machine does the transformation of the slurry to green sheet, base on the principle of elimination of excess water from the slurry and dimensioning.

- *Elimination of excess water* – This happens at five successive stages:
    1. Through the sieve cylinder itself
    2. Water absorption by the felt
    3. Pressing of the couch rollers
    4. Different Vacuum boxes
    5. Between forming drum and drive roller
- *Dimensioning*
    1. The gross width is determined by the useful width of the sieves
    2. The gross length is given by the circumference of the forming drum.

The Transformation

A hollow cylinder, covered with a sieve cloth, rotates in a vat, which is fed with slurry, so that the cylinder is constantly submerged on about 0.75% of its diameter. Due to hydrostatic pressure, the slurry tends to flow through the sieve cloth – a thin layer of fibre cement is retained on the sieve, but some water, together with fine particles will flow inside the sieve (first water elimination). As long as the water can pass through the layer, the thickness will increase.

Due to the rotation of the sieve, the formed layer will come in contact with the felt which is pressing against the sieve, which is pressed against the sieve cylinder by means of couch roller. The felt must be dry enough to suck the layer like a blotting paper (second water elimination). Due to pressure of the couch roller on the sieve, there is third water elimination from layer and felt.

Felt and layer are moved over several vacuum boxes, where again some water is removed (fourth water elimination), finally, the layer undergoes a fifth dewatering between forming and driver roller. The forming drum is picking up the continuous layer till the required thickness is obtained. Then the layer is cut across the width and peeled from the roll to become a flat sheet (green sheet) on the first conveyor belt and is moved into the second conveyor for the final stage.

Dry Stage – it involves the process of transforming the green sheet into the required roofing sheet (product). This is the final stage of the manufacturing process. It consists of the conveyor, Piling machine, Curing Chamber and Depiling machine.

Here, on the second conveyor belt, both the horizontal and the vertical knives cut the flat sheet into three equal sizes as the case may be. The template ranger helps to arrange empty templates on a pendant for the pilling machine use. The pilling machine then piles the sheets on an empty pendant along side with the templates, which is sent to the curing chamber (50 – 70^{o}C) when filled for about 8 hours. At the exit of the chamber, the depiling machine demoulds the sheets and arranges them on pallets.

Note:

(i) One pendant contains 140 sheets and about 90 pendants are produced in a day, implies that 12,600 sheets are produced daily.

(ii) One pallet contains 125 sheets, which implies that about 100 pallets of sheets are produced daily.
(iii) 24 sheets are collected daily for test samples.

3.0 Data Collection

Reliability is commonly quantified by determining the probability of a failure occurring using probability and statistics methods. The hardest part of reliability analysis is getting the data (Barrigner, [11]). Process reliability techniques use data available in the plant [11]. The quality of data is fundamental to properly analyse the reliability of a process or equipment. Quality in this sense involves how the data is obtained, managed and who is responsible for analysing it. Many production outfits have accumulated data for many years but obtaining information that can be used for solving problems is rare. In otherwords, they are unaware of the type of data to capture that are useful for reliability analysis. Sometimes the information available may not be properly recorded. This was particularly noticed in the organisation under study.

The data used for this study were obtained from the maintenance department of the company. The data collated covers a period of one year (January 1 to December 31, 2011).

Hand written records of failures that the line technician kept during each shift were available. By design, the mill operates a continuous system spanning 24hours, 3-shifts a day comprising 8 hours each. However, due to some logistic problems such as lack of availability of raw materials and lack of diesel to power the generator in case of power failure, the production line sometimes did not operate for 24 hours. The records include failure mode that had occurred during each shift and the action taken to repair them. The maintenance manual revealed that assessment of the performance of the line was carried out every hour of operation. From the information available to us, we were able to calculate the downtime for each mode associated with each component of the piling machine, as well as the time to failure (TTF) for the particular failure mode associated with each component were also able to compute the time to repair (TTR).

The TTF of particular equipment at a particular level (failure mode, machine, workstation or the entire line) is defined as the time that elapses from the moment the equipment goes up and starts operating after a failure, until the moment it goes down again and stops operating due to a new failure. TTF excludes the period when the line is not operating due to lack of raw material to process. According to Liberopoulous and Tsarouhas [12], the TTF includes the time between successive proactive maintenance operations on the line which suggests that the TTF may be influenced by the proactive maintenance policy. This, according to them, may not be desirable from a reliability point of view, but it is avoidable because no company is willing to operate a real production line for a long time without performing proactive maintenance just because it wants to collect a pure TTF data. However, at the company under study, we observed that the effect of proactive maintenance policy on the TTF is of little or no effect since most maintenance actions are done at breakdowns, which are corrective rather than preventive. Sometimes, when the equipment fails and the cause of failure diagnosed, the required spares may not be available, which sometimes is the case. Therefore, it would normally take a considerable time for the part to be available and repair effected in order that the equipment hence the line become operational once again.

The above definition of TTF assumes that failures are time-dependent and not operations dependent. According to Buzacott and Shanthikumar [13], failures are classified according to their extent, cause and effect. The extent of a failure refers to the part or parts of the line that are affected by the failure. The cause refers to whether the failure can occur only when the station is processing material (operations –dependent failure) or at any time, even when the station is idle (time-dependent failure). Finally, the effect refers to whether the material in process at the instant of failure must be reworked, repaired or scrapped. When a failure that is time-dependent occurs, most of the line upstream of the failure keeps operating without processing (i.e. it goes through the motions without actually producing) causing a gap in production downstream of the failure. Failures that are operations-dependent, however, behave differently. When such failures occur, the entire line freezes. A group of failures that can be most accurately characterised as operations-dependent rather than time-dependent consists of failures in the supply of electric power or air because when such failures occur, the entire line stops being functional. Most foreign literature are often silent on this type of failure (operation-dependent) and the few that mentioned it say that such failures have negligible impact on the TTF of other failures in the sense that either they occur infrequently or they are very short. They observed that apart from few minor exceptions, failures of all work stations are close to being time-dependent [12]. Most of the failures that occurred were operations dependent, the predominant one being that of power failure which sometimes occurred as a surge, resulting in the failure of electric motors power most of the mechanisms. Only such failures resulting in the failure of the equipment were considered in obtaining failure times from the manual since they usually result in equipment failure.

We visited the plant and worked with personnel as well as a few technical and non-technical personnel unacquainted with reliability analysis. In turn those employees had to answer questions based on disorganised data. In the plant under study, there were only three qualified engineers, three qualified and experienced technicians per shift while the others were inexperienced. In obtaining answers to questions, knowledge of the engineers and the nine technicians were utilised in organising our down time data from the records. Two of the typical problems encountered and the explanations or suggestions offered are presented below.

Problem: Production workers recorded as a downtime interval, a period of time during which the machine was performing no work.

***Explanation**:* The following terms were explained.

(a) '**starved**' to mean that the machine is ready to work but has no work to do,

(b) '**blocked**' to mean that the machine has finished work but has no room downstream and hence cannot unload the workpiece to accommodate another,

(c) '**busy**' to mean that the machine is engaged in productive work, and

(d) '**down**' to mean that the machine has malfunctioned and need service or there is an external failure that causes the system to be down.

The last category represents a downtime interval, while the first three categories collectively represent an uptime interval [14].

Problem: The shortest downtimes go unrecorded because recording them takes nearly as much as repairing them.

Suggestion**:** ideally an additional worker should be assigned to record while the production worker repairs them (e.g., by clearing a jam).

These Issues were raised because it was observed from the interactions with the maintenance staff they lacked understanding of the terms used, hence, the need for explanation in order for us to have an understanding of the information they were capturing in their records. In extracting the relevant information from the manual, the following information is therefore necessary in obtaining downtimes and TTF of the machine for the period covered by this study.

(i) Only the reliability analysis of the piling machine is being determined in this study. This machine is one of the machines utilised at the last stage of production (the drying stage).

(ii) When a failure occurs or when a machine takes an extraordinary long time to complete an operation, the level in the adjacent upstream buffer may rise. If the disruption persists long enough, that buffer fills up and forces the machine upstream of it to stop processing parts. Such a forced state of down machine is called blocking. In the same way, the level of the adjacent downstream buffer may fall during a failure, because the downstream machine drains its contents; so if the failure persists long enough, the adjacent downstream buffer empties and the machine downstream of it stops processing parts. Such a forced state of down machine is, on the other hand, called starvation. Blocking phenomenon propagates upstream the line, starting from the failed machine and with a decreasing effect toward the first machine, while starvation propagates downstream the line, with a decreasing effect toward the last machine. As a result, the throughput of the line decreases. The above considerations were extensively covered in Ovuworie [15].

In so far as the equipment is functional, blockage and starvation occurring upstream and downstream respectively, relative to the occurrence of a fault on any other equipment on the line does not mean that the equipment under study is down even if the process as to be stopped for material to be reworked. In other words, the machine can only be said to be down the failure is from the piling machine.

(iii) From the records, there were periods when there was power surge which led to electric motors being damaged. These faults were usually discovered only when power was restored either by switch-over to the alternative power source or immediate restoration of main power source. The only failure times considered in this case are those incurred that directly affects the machine and causes it not to be functional.

(iv) That there is lack of raw material and other resources needed for processing does not mean that the machine under study has failed even though the line may be shut down. This is idle time and not downtime. The machine is functional but has no material to process. This wrong records of downtime were quite common in the available records.

(v) Failures discovered during inspection of the line do not affect the affect the TTF and TTR of the equipment unless such failures were traceable to the piling machine and such failures disrupt the production process.

Based on these and other appropriate arrangements/plans such as reorganisation of recorded data/information, it was then possible to obtain the failure data presented and discussed in what follows.

4.0 Data presentation and analysis

For the purpose of this study, only the piling machine reliability was analysed. However process parameters were considered in the analysis. Table 1 shows the respective data of Downtime period of the Piling Machine as obtained from the Maintenance department of the company. The information relevant to the preventive maintenance of the components of the piling machines are shown in Table 2. For purposes of computations, the line operated for 24 hr a day, with three eight-hour shifts during each day, for a total of 365 working days in a year.

5.0 Analysis of Data

A Weibull distribution has been assumed for the hazard rate of the equipment to determine the parameters, employing the method of least squares regression approach. The choice of this distribution is based on the fact that it is a very robust distribution and it is one of the most useful probability distributions in reliability analysis as it can be used to model decreasing, constant as well as increasing failure rate phenomena.

The hazard function for this distribution is given thus:

$$\lambda(t)=\left(\frac{\beta}{\theta}\right)\left(\frac{t}{\theta}\right)^{\beta-1} \quad [16] \qquad (1)$$

where β is the shape parameter and θ is the scale parameter. β provides insight into the behaviour of the failure and repair data. A value of β >1 indicates an increasing failure rate. When β = 1, failure rate is constant. When β > 2, the failure rate is increasing and convex. When $3 \le \beta \le 4$, the Weibull distribution approaches the normal distribution and is symmetrical. The scale parameter, θ, influences the mean and the spread of the distribution and as the value increases, the reliability at any given time increases and the failure rate decreases [16].

The least-square fit to the Weibull data was used to estimate the parameters as it is more accurate and less subjective. This method is used for estimating the coefficient "*a*" and "*b*" from a set of *(x, y)* coordinates that have been measured. In reliability analysis, the set *x* is the set time to failures and the set *y* is their corresponding cumulative probability value; "a" is the estimate of the intercept (of the line with the *y*-axis) *"b"* is the estimate of the scope i.e. $y = a + bx$ where *a* is the intercept and *b* is the slope.

$$b=\frac{n\sum_{i=1}^{n}x_i y_i-\sum_{i=1}^{n}x_i\sum_{i=1}^{n}y_i}{n\sum_{i=1}^{n}x_i^2-\left(\sum_{i=1}^{n}x_i\right)^2} \quad [17] \qquad (2)$$

$$a=\sum_{i=1}^{n}\frac{y_i}{n}-b\sum_{i=1}^{n}\frac{x_i}{n} \text{, with n components} \qquad (3)$$

Cumulative distribution of Weibull is given by:

$$F(t)=1-e^{-\left(t/\theta\right)^{\beta}} \quad [16] \qquad (4)$$

$$In\left[In\left(\frac{1}{1-F(t_i)}\right)\right]=\beta Int-\beta In\theta \qquad (5)$$

where, t_i = time to failure of the *i* th components.

By comparison with $y = a + bx$, we have $x=lnt$ and $y=ln[ln(1/(1-F(t))]$

$$\beta=b, \quad \theta=e^{-\left(a/\beta\right)} \quad \text{and} \quad F(t_i)=\frac{i-0.3}{n+0.43} \quad \text{(Ebeling, [17])} \qquad (6)$$

Production time/year = (24 $\times$ 365) = 8760hrs

Table 3 shows the TTF and TTR as obtained in the final analysis.

This yields the following results:

β = 3.65 and θ = 7863.6hrs

From

$$R(t)=e^{-\left(t/\theta\right)^{\beta}} \quad , \quad [16] \qquad (7)$$

we have, $R(t)$ = 0.5557

6.0 Results Discussion

From the analysis, we could see the value of the shape parameter lies between 3 and 4, (3.65) which indicates that the Weibull distribution approaches the normal distribution that is, it is symmetrical and that the failure rate of the system is increasing , an indication that the equipment is approaching wear out. This can account for the high failure rate experienced by the equipment. Form the goodness-of-fit test carried out for the failure data, it showed that within 95% confidence that the distribution is Weibull. The reliability of the Piling machine is about 56% which is quite low. It was observed from the interviews and available records that since the establishment of the plant in 1974, the preventive maintenance has not been reviewed and that even the implementation of preventive maintenance runs contrary to known norms like parts being readily available. Most maintenance actions are usually carried out at breakdowns. The failure rate shows that there are approximately eight failures in a month

7.0 Conclusion

This study underscores the need for the entrenchment of reliability and maintenance culture in the Nigerian industries and the need to train maintenance engineers and technicians in this crucial aspect of industrial performance sustenance. From the records of the asbestos manufacturing plant and interaction with the Production Manager who also oversees maintenance activities, standards for assessing performance of systems are not utilised. This study can therefore serve as the basis for setting the platform for appropriate method for the right data collection for proper reliability analysis. It will also assist management in setting performance targets with the purpose of improving the reliability of the equipment used in the manufacturing process. This in turn will reduce downtimes due to equipment and component failures.

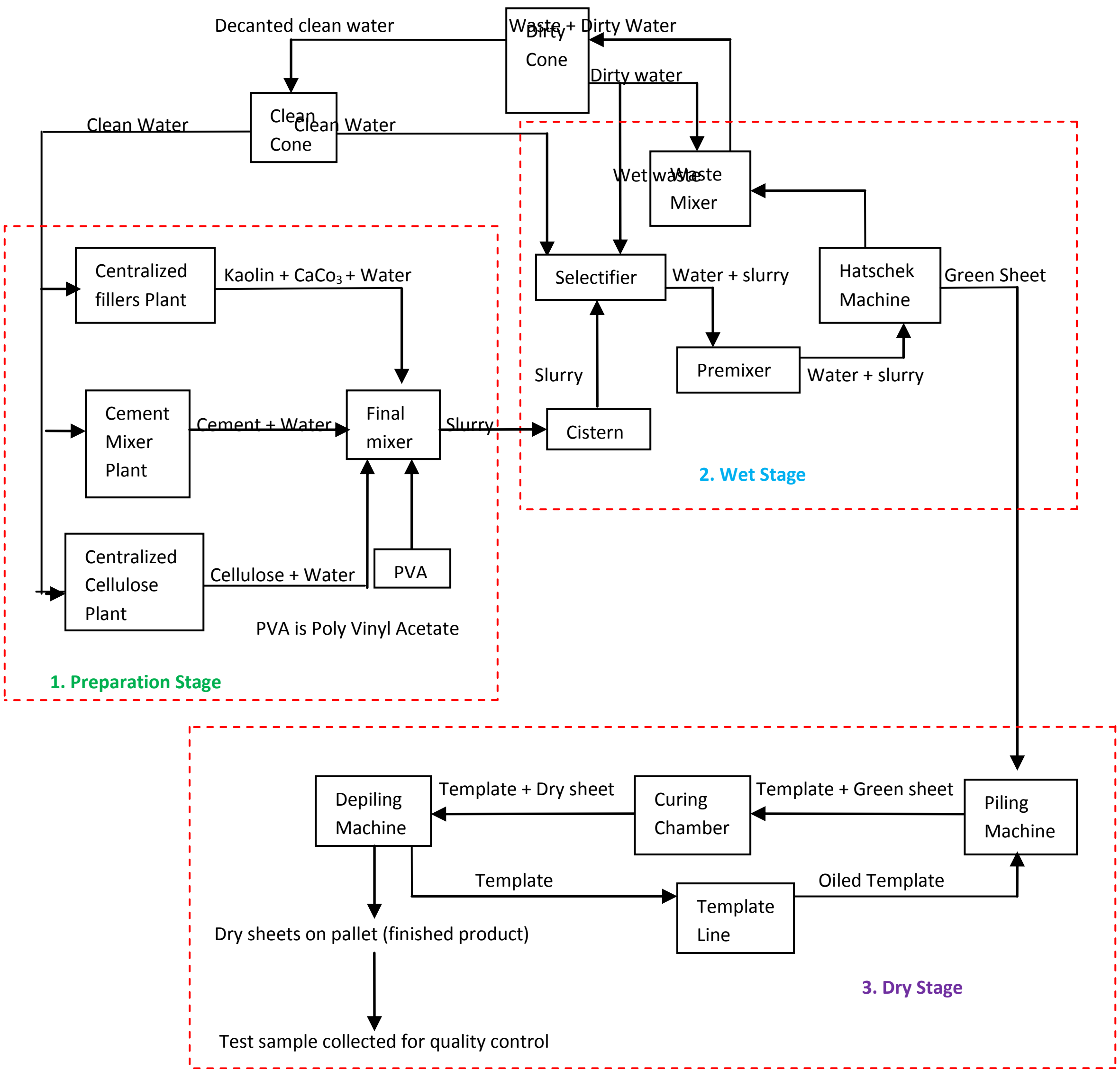

Figure 1: Flow Diagram of the manufacturing Process

Table 1: Piling Machine components downtime

Components	Piling Machine components downtime (hrs) for 2011												Total Downtime (hrs)
	Jan	Feb	Mar	April	May	June	July	Augt	Sept	Oct	Nov	Dec	
Hydraulic Cylinder	183	164	135	193	122	156	136	147	152	108	173	198	**1867**
Lifting belt	159	101	175	183	171	124	163	189	145	195	168	148	**1921**
Vacuum Hose	167	151	188	192	125	145	109	174	159	193	156	122	**1881**
Suction box	208	184	198	201	206	192	204	174	187	192	196	190	**2332**
Vacuum Feeder	196	205	189	183	191	173	198	200	189	188	197	199	**2308**
Aspirating and blowing Control valve	178	109	180	165	174	145	183	176	180	159	171	106	**1926**
Runway	163	158	177	149	189	176	168	147	182	161	125	145	**1940**
Plastic profile	191	175	206	188	198	203	197	185	189	201	194	181	**2308**
Pneumatic cylinder	101	92	93	96	105	87	108	109	104	97	106	98	**1196**
Cable chain	156	172	165	178	189	167	172	158	191	147	150	156	**2001**
Bearing	142	165	148	159	163	158	154	169	181	173	168	151	**1931**
Limit micro switch	164	157	179	171	148	183	167	174	155	149	138	153	**1938**
Pneumatic circuit lubrication	146	173	164	156	179	161	189	168	142	172	151	165	**1966**

Table 2: Preventive maintenance card

Components	Activity	Inspection Frequency n(t)	Operations	Type of intervention
Hydraulic Cylinder	inspection	weekly	Check gasket	Replace gasket
Lifting belt	,,	,,	Check wear	Replacement
Vacuum hose	,,	,,	Check operating	Replacement
Suction box	,,	,,	Clean	Clean
Vacuum feeder	,,	,,	Check wear	Greasing
Aspirating and blowing control valve	,,	,,	Check wear of the gasket	Replacement
Runway	,,	,,	Check wear	Clean and grease
Plastic profile	,,	,,	Check wear	Lubricating
Pneumatic cylinder	,,	,,	Check dripping from pipes and fitting	Pipes replacement
Cable chain	,,	,,	Check integrity and functionality of the cable chain	Total link substitution
Bearing	,,	,,	Check noise and external temperature during machine running	Excessive noise or high temperature means bearing damage, replace it
Limit micro switch	,,	,,	Verify the clearance between the cam and the micro switch	Adjustment
Pneumatic circuit lubrication	,,	,,	Check both the oil level into the lubricators and the emulsion level of the oil	Top the oil or replace lubricators

Table 3 Time to failure and cumulative probability values

i	TTF(t_i)/hr	TTR(r_i)/hr	$F(t_i)$	x_i	y_i	$x_i\,y_i$	x_i^2
1	6428	155.6	0.0521	8.7864	–2.9280	–25.6739	8.5732
2	6452	160.1	0.1266	8.7721	–1.9998	–17.5425	3.9992
3	6452	156.8	0.2010	8.7721	–1.4944	–13.1091	2.2332
4	6759	194.3	0.2755	8.8186	–1.1324	–9.9862	1.2823
5	6794	192.3	0.3500	8.8238	–0.8422	–7.4314	0.7093
6	6820	160.5	0.4244	8.8276	–0.5936	–5.2401	0.3524
7	6822	161.7	0.4989	8.8279	–0.3697	–3.2637	0.1367
8	6829	192.3	0.5733	8.8289	–0.1606	–1.4179	0.0258
9	6834	99.7	0.6478	8.8297	0.0426	0.3761	0.0018
10	6839	166.8	0.7223	8.8304	0.2478	2.1882	0.0614
11	6879	160.9	0.7967	8.8362	0.4657	4.1150	0.2169
12	6893	161.5	0.8712	8.8383	0.7176	6.3423	0.5150
13	7564	163.8	0.9457	8.9312	1.0686	9.5438	1.1919
Total	**88365**	**2126.3**		**114.705**	**–6.9784**	**–61.4793**	**19.2490**

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