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APPLICATION OF RELIABILITY ANALYSIS FOR PREDICTING FAILURES IN GLASS INDUSTRY

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ABSTRACT

This paper dwells on the use of reliability analysis for predicting failures of machines in the glass industry. This research was necessitated by the need to accurately predict failures of glass making machines thereby effectively planning the preventive maintenance schedule and reducing down times. Data pertaining to the down times of the machines studied, spanning a period of six years were applied to Weibull Model in order to obtain the reliability model of the machines. It was concluded that application of the reliability model obtained could be used as an important tool for forecasting future failures and hence effectively planning towards such failures.

KEYWORDS: Weibull, Reliability, Model, Forecasting, Failures, Down-time.

INTRODUCTION

According to Baringer (1996), reliability engineering provides the theoretical and practical tools whereby the probability and capability of parts, components, equipment, products and systems to perform their required functions for desired period of time without failure are determined. It takes a long time for a company to build up a reputation for reliability and only a short time to be branded as "unreliable". According to Igor (2004), the price of unreliability is very high, the cure is reliability.

Reliability evaluation of a product or process can include a number of different analysis, depending on the phase of the product life cycle. According to David (2001), reliability engineering activities should be an ongoing process, starting from the conceptual phase of a product life cycle.

Mechanical reliability is typically estimated, either from experience or test, by a mean time to failure (MTTF) for each machine. The connection between machine level of reliability and system level of productivity was explored by many researchers. They recognized that productivity is intimately tied to machine system reliability. Total assessments of reliability requires the quantitative estimate of three distinct and separate classes of failures that is early life, event related and wear out. This paper therefore is aimed at tracing the three stages of failure and then developing a model for predicting the likely failure times of the various components in the glass making machine under study.

METHODOLOGY

Data Collection

Reliability Data was collected from the log book of a glass production company in Delta State, Nigeria. The data collected consist of the down time and number of failures for two identical machines code named IS machine 21 and IS machine 22. Each of these machines is made up of thirteen components namely the scoop, baffle, invert, final blow, plunger, necking, take out, wiper, blank mold, blow mold, valve block, dead plate and funnel. The components were arranged in series therefore the failure of one implies the failure of the entire machine since production would stop. The data covers a period of six years spanning year 2000 to 2005.

Procedure

Data collected from the logbook of the glass production company were used to evaluate the total down time of machines and the failure rates over six years. The data were also subjected to life testing via Weibull model which lead to the modeling of the failure rate of the machines.

Total Down- Time

The total down time for the machines were determined by summing the monthly down times of all the 13 components of the two machines over the study period of six years. The total down times of the two machines are presented in tables 1 and 2.

Table 1: Total Down Time of MK 22

Component (Mechanism)	2000 (D/T (min)	2001 (D/T (min)	2002 (D/T (min)	2003 (D/T (min)	2004 (D/T (min)	2005 (D/T (min)	TDT (min)
Scoop	145	215	285	900	784	350	2679
Baffle	370	125	173	440	425	75	1608
Invert	35	150	225	130	85	245	870
Final blow	100	85	395	170	295	120	1190
Plunger	440	390	310	750	895	1015	3800
Neck Ring	255	190	418	187	610	860	2520
Take out	110	205	220	340	773	430	2078
Wiper	730	376	739	1950	1300	1025	6120
Blank mold	40	90	110	315	435	165	1155
Blow mold	260	105	335	930	575	420	2625
Valve Block	75	140	345	180	485	440	1598
Dead Plate	38	40	278	1470	465	205	2563
Funnel	168	80	55	-	75	45	423
						TOTAL	29,229

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Table 2: Total Down Time of M/C 21

Component (Mechanism)	2000 (D/T (min)	2001 (D/T (min)	2002 (D/T (min)	2003 (D/T (min)	2004 (D/T (min)	2005 (D/T (min)	TDT (min)
Scoop	-	-	20	175	55	-	250
Baffle	105	215	215	165	25	60	785
Invert	65	-	105	25	-	25	220
Final blow	155	160	390	105	225	50	1085
Plunger	600	585	1075	575	1230	1185	5250
Neck Ring	160	35	40	5	55	35	330
Take out	370	315	265	265	255	160	1630
Wiper	750	1100	790	1320	1255	915	6130
Blank mold	60	185	155	32	350	145	927
Blow mold	278	218	175	135	330	105	1241
Valve Block	45	30	-	-	-	35	110
Dead Plate	224	325	235	185	235	45	1249
Funnel	20	15	45	45	10	210	345
						TOTAL	19,552

FAILURE FREQUENCY OVER TIME

Data from glass Production Company's logbook were used to determine the failure frequency variation with time. This was done by dividing the cumulative number of failures by the cumulative time of use of machine in hours to obtain table 3 and 4. The data in tables 3 and 4 were then used to plot the failure rate graphs in figures 1 and 2.

Table 3: Failure frequency over time for M/C 21

Year		2000	2001	2002	2003	2004	2005
Cumulative time of use (hours)		8784	17544	26304	35064	43848	52,608
MC/ 21	Cum. Fail. Freq.	232	448	684	943	1240	1431
	Failure Rate	26.4 x10^{-3}/hr	26 x10^{-3}/hr	26.7 x10^{-3}/hr	28.4 x10^{-3}/hr	28.4 x10^{-3}/hr	27.2 x10^{-3}/hr
Plunger	Cum. Fail. Freq.	50	100	146	205	290	326
	Failure rate	5.7x10^{-3}/hr	5.7x10^{-3}/hr	5.6x10^{-3}/hr	5.85x10^{-3}/hr	6.6x10^{-3}/hr	6.2x10^{-3}/hr
Wiper	Cum. Fail. Freq.	81	146	227	341	465	553
	Failure rate	9.2x 10^{-3}/hr	16.6x 10^{-3}/hr	8.6x 10^{-3}/hr	9.73x 10^{-3}/hr	10.5x 10^{-3}/hr	10.5x 10^{-3}/hr

Table 4: Failure frequency over time for M/C 22

Year		2000	2001	2002	2003	2004	2005
Cumulative time of use (hours)		8784	17544	26304	35064	43848	52608
MC/ 21	Cum. Fail. Freq.	209	367				1944
	Failure Rate	23.8x10^{-3}/hr	20.9x10^{-3}/hr	24.4x10^{-3}/hr	34.4x10^{-3}/hr	37.7x10^{-3}/hr	37x10^{-3}/hr
Plunger	Cum. Fail. Freq.	35	69	98	157	223	264
	Failure rate	3.99x10^{-3}/hr	3.93x10^{-3}/hr	3.73x10^{-3}/hr	4.48x10^{-3}/hr	5.09x10^{-3}/hr	5.02x10^{-3}/hr
Wiper	Cum. Fail. Freq.	98	148	248	469	616	712
	Failure rate	11.16x10^{-3}/hr	8.44x10^{-3}/hr	9.43x10^{-3}/hr	13.4x10^{-3}/hr	14.05x10^{-3}/hr	13.5x10^{-3}/hr

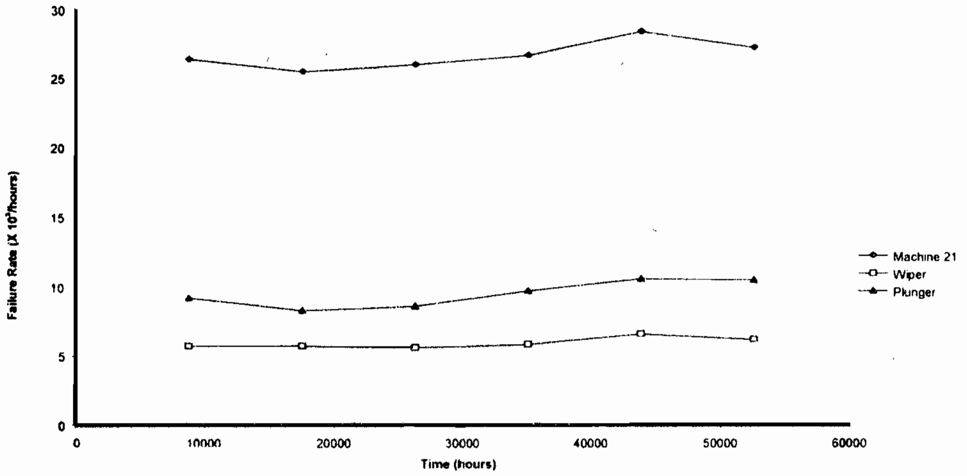

Figure 1: Failure Rate of IS M/C 21 and Critical Components

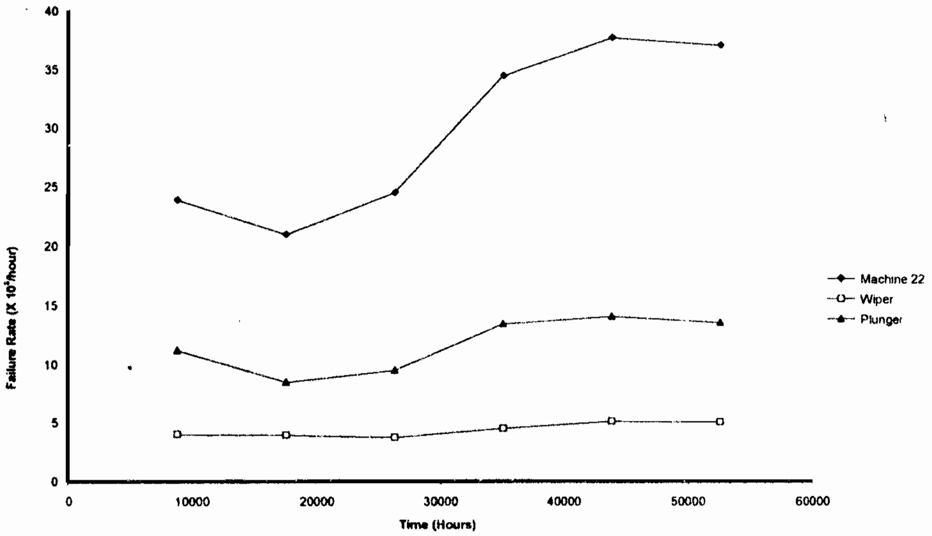

Figure 2: Failure Rate of IS M/C 22 and Critical Components

MODELING OF THE FAILURE RATE

In the modeling of the failure rate, the Weilbull model was chosen as basis because according to Lyonnet (1991), it is most suitable for the reliability analysis of mechanical component.

According to O'Connor (1991), Weibull failure rate function is given by

$$Z(t) = \alpha\beta t^{\beta-1} \qquad (1)$$

Where α = the scale parameter

β = the shape parameter, also known as the Weibull slope.

t = variable time.

According to Lyonnet (1991), the Weibull distribution is given by

$$\ln\ln\frac{1}{R(t)} = \ln\alpha + \beta\ln t \qquad (2)$$

where the failure density is $F(t_i)=1-R(to)$, the Weibull distribution transforms to

$$\ln\ln\frac{1}{1-F(t)} = \ln\alpha + \beta\ln t \qquad (3)$$

Hence using the Estimator $F(t_i) = \frac{i-\frac{1}{2}}{n_i}$ as recommended by Lyonnett (1991), where n = sample times = 6 corresponding to six years of study, and using the various yearly intervals in hours the method of least square could be applied to determine β and α for the two machines under study. This is presented in tables 5 and 6. The tables were thus obtained by transforming equation 2.

$$y = \beta x + \ln\alpha$$

Where $x_i = \ln t_i$, $y = \ln\ln\frac{1}{1-F(t)} = \ln F(t)$

$$F(t_1) = \frac{1-\frac{1}{2}}{6} \qquad F(t_3) = \frac{3-\frac{1}{2}}{6}$$

$$F(t_2) = \frac{2-\frac{1}{2}}{6} \qquad F(t_4) = \frac{6-\frac{1}{2}}{6}$$

To ascertain the suitability of linear regression for this data the correlation is determined.

According to Stevenson (1991), correlation

$$r^2 = \left[\frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{n(\sum x^2)-(\sum x)^2}\sqrt{n(\sum y^2)-(\sum y)^2}}\right]^2 \qquad (4)$$

$$= \left[\frac{6(-55.16)-(61.05)(-5.71)}{\sqrt{6(623.33)-(61.05)^2}\sqrt{6(9.49)-(-5.71)^2}}\right]$$

= 0.996

Hence the independent variable is a good predictor of the dependent variable therefore regression is very suitable.

Slope, $\beta = \dfrac{n(\sum xy)-(\sum x)(\sum y)}{n(\sum x^2)-(\sum x)^2}$

$$= \frac{6(-55.16)-(61.05)(-5.71)}{6(623.33)-(61.05)^2} = 1.37$$

y intercept, ln α =

$$\frac{(\sum y)-\beta(\sum x)}{n} = (-5.71) - 1.37(61.05) = -14.89$$

$\ln\alpha = -14.82$, $\alpha = e^{-14.89} = 3.415 \times 10^{-7}$

For M/C 21

$Z(t) = 4.67 \times 10^{-7}\, t^{0.37}$

$\text{MTTF} = \mu = \alpha^{-1/p}\,\Gamma(1 + {}^{1}/_{p})$

$= 3.41 \times 10^{-7(-1/1.37)}\,\Gamma(1 + 1/1.37)$

$= 52{,}555.4\,\Gamma(1.7)$ [where Γ(1.7) is gamma function obtained from standard table to be 0.9086]

= 52555 x.4 x 0.9086

MTTF = 47,752 hours

For M/C 22

Apart from the second column of table 6 the other columns are the same with table 5. Hence the failure rate model for the two machines are the same and the mean time to failure is equally the same.

Table 5: Regression Analysis for M/C 21

F(t)	**t_i**	**x_i**	**y_i**	**x_iy_i**	**X^2**	**Y^2**
0.08	8737	9.08	-2.53	-22.97	82.45	6.401
0.25	17444	9.80	-1.39	-13.62	76.04	1.920
0.42	26146	10.17	-0.87	-8.85	103.43	0.16
0.58	348.55	10.46	-0.55	-5.75	109 41	0.303
0.75	43572	10.68	-0.29	-3.10	114.06	0.0841
0.95	52283	10.86	-0.08	-0.87	117.94	0.0064
		$\sum x=61.05$	$\sum y=-5.71$	$\sum xy=55.16$	$\sum x^2=623.33$	$\sum y^2=9.49$

Table 6: Regression Analysis for M/C 22

F(t)						
0.08	8738	9.08	-2.53	-22.97	82.45	6.401
0.25	17461	9.80	-1.39	-13.62	96.04	1.937
0.42	26157	10.17	-0.87	-8.85	103.43	0.76
0.58	34787	10.46	-0.55	-5.75	109.41	0.303
0.75	43451	10.68	-0.29	-3.10	114.06	0.0441
0.95	52121	10.86	-0.08	-0.87	117.94	0.0064
		$\sum x = 61.05$	$\sum y = -5.17$	$\sum xy=-55.16$	$\sum x^2 = 623.33$	$\sum y^2 = 9.49$

Reliability Model

The reliability model is obtained by substituting for α and β in equation 2 and is therefore;

$$\ln\ln\frac{1}{R(t)} = \ln 3.41\times10^{-7} + 1.37\ln t$$

DISCUSSION OF RESULTS

Total Down -Time

The total down time of machine 22 over the six years period under study, presented in table 1 shows that the total down time for the machine is 29,229 minutes. However, of all the thirteen components that consist this machine two components stand out for contributing 34% of the down time. The components are the plunger and the wiper, contributing 3800mins and 6120mins respectively. Observation of table 2 also shows the same trend but this time contributing over 58% of the down times in machine 21 which has a total down time of 19552 min. The two components, plunger and wiper could therefore be classified as critical components as the reduction of the down times of these two components would adversely reduce the down times of the machines.

Failure Rate Graphs

The ideal failure rate graph otherwise known as Bathtub curve may be divided into three portions; the early life (with decreasing failure rate), the useful life (with constant failure rate) and the wear out life (with increasing failure rate). Observation of the graph presented in fig 1 shows that whereas the machine (M/C 21) and its plunger are still within the useful life portion with approximately constant failure rates the wiper appears to have erratic failure rate, tending towards the war out life portion. Similarly observation of fig 2 shows that the slope of the wiper is similar to the slope of machines indicating that the wiper failure rate adversely affecting the overall failure rate of the machine, which is tending towards the wear out portion while the plunger is still within the useful life with approximately constant failure rate. It is therefore expected that reducing appreciably the failure rate of the wiper would push the machine generally back to the useful life stage away from the wear out stage.

Modeling

The failure rate model obtained for the two IS machine M/C 21 and M/C 22 could serve as a very important tool in extrapolating the likely failure rate with time and hence appropriately scheduling planned maintenance that would reduce the down time of the machines and hence increase productivity.

CONCLUSION AND RECOMMENDATION

From the foregoing study shows that the two critical components namely the plunger and the wiper indicate the tend of failure of the IS machines therefore reducing the failure rate of these two components by advising the manufacturer to arrange these component in parallel rather than the series arrange and as this will increase appreciably the useful life of the machine since the fail of any of that component will trigger the parallel pair to take over its function and have reduce the overall down time of the machine.

The failure rate obtain could also be used as an important tool for predicting or forecasting further future failure rate and hence planning against it.

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