J. Ind. Eng. Int., 7 (12), 39-44, Winter 2011
ISSN: 1735-5702

Steady state behavior and maintenance planning of bleaching system in a paper plant

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Received: 17 March 2008; Revised: 2 September 2008; Accepted: 12 February 2009

Abstract: This paper presents the steady state behavior and maintenance planning of the bleaching system in a paper plant. The paper plant comprises of various systems including feeding, chipping, digesting, washing, bleaching, screening, stock preparation and paper making, etc. One of the most important functionaries of a paper plant, on which quality of paper depends, is the bleaching system, where removal of coloring constituents is done to obtain the desired degree of brightness. The bleaching system consists of two subsystems A and B arranged in series with two states; good and failed. The mathematical modeling is carried out on the basis of Markov birth-death process using a probabilistic approach. An expression for steady state availability is also developed. Based upon the maintenance data available from medium sized paper plant, the effect of each working unit on the system availability behavior has been explained. In this regard, the behavioral chart for bleaching system has been given. Besides, a maintenance schedule has also been suggested and utilized for the purpose of maintenance planning of the bleaching system in a paper plant. The findings of this paper have been discussed with the concerned plant personnel and found to be highly beneficial for enhancing the performance level of the plant concerned.

Keywords: *Bleaching system; Steady state availability; Maintenance planning*

1. Introduction

Nowadays, owing to automation, in the process industries maintenance is considered as an integral part of the production process. It is done by optimal utilization of maintenance resources and by ensuring high availability level. For increasing the productivity and availability of equipment, subsystems and systems in operation must be maintained at the highest order. To achieve high production goals, the systems should remain operative (run failure free) for maximum possible time duration. But practically these systems are subject to random failures due to the poor design, wrong manufacturing techniques, lack of operative skills, poor maintenance, overload, delay in starting maintenance, human errors, etc. These causes lead to non-availability of an industrial system resulting into improper utilization of resources (man, machine, material, money, time, etc.). So, to achieve high production volumes / targets, there should be highest possible system availability (long-run system availability).

2. Literature Review

The available literature reflects that several approaches have been used to analyze the steady state behavior of various systems. The Markovian approach has been frequently used by Dhillon *et al.* (1981) for the availability analysis, using exponential distribution for failure and repair times. Kumar *et al.* (1988, 1989 and 1993) dealt with reliability, availability and operational behavior analysis for different systems in the paper plant. Kumar *et al*. (1988 and 1993) dealt with maintenance planning for the systems in fertilizer and thermal plants.

Shooman (1996) suggested different methods for the reliability computations of systems with dependent failures. Sunand *et al.* (1999) dealt with maintenance management for Ammonia synthesis system in fertilizer plant. Tewari *et al.* (2003) dealt with the determination of availability for the systems with elements exhibiting independent failures and repairs or the operation with standby elements for sugar industry. They also dealt with mathematical modeling and behavioral analysis for a refining system of a sugar industry using Genetic Algorithm. Sunand *et al.* (2007) discussed simulated availability of CO_2 cooling system in a fertilizer plant. Rajiv *et al.* (2008) have developed performance evaluation system for screening unit of paper plant. They also dealt with availability analysis of bleaching system of a paper plant.

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3. Theory

A probabilistic analysis of the system under given operative conditions is helpful in the design modification for minimum failure run of the system and thus to optimize the system performance. The paper plants are complex and repairable engineering systems, comprising of various units namely chipping, cooking, washing, bleaching, screening, stock preparation, paper production etc.

These units are generally arranged in hybrid configuration. The important process of a paper industry, upon which the quality of paper depends, is bleaching process. In the process of paper formation, the chips from storage are fed in to a digester to form the pulp which is processed through subsystems called knotter, decker, opener, washers, etc. Then the washed pulp is kept in a chamber where chlorine at a controlled rate is pressed through the pulp for a few hours.

The pulp is passed over a filter and washer in four stages to get chlorine free white pulp. This pulp is again processed through screen and cleaner for final removal of chlorine, knots and other undesirable materials. The pulp so prepared is stored in a chamber.

3.1. System Description

The bleaching system comprises of two main subsystems, which are as follows:

(1) The filter (A_I) consists of four units to remove chlorine from the pulp received from the washing process. The failure of anyone causes the complete failure.

(2) The washer (B_J) consists of four units to wash the bleached pulp and open the fibers through combing action . The failure of anyone causes the complete failure.

4. Experiment

4.1. Assumptions and notations

The transition diagram (Figure1) of bleaching system shows the two states, the system can acquire. Based on Markov process, a performance evaluating model has been developed. The failures and repairs for this purpose have been modeled as birth and death process. The assumptions and notations associated with the transition diagram of bleaching system are as follows:

4.1.1. Assumptions

(1) Failure/repair rates are constant over time and statistically independent.

(2) A repaired unit is good as new, performance wise for a specified duration.

(3) Sufficient repair facilities are available as and when required.

(4) Standby units are of the same nature as that of active units.

(5) System may work at a reduced capacity.

(6) Service includes repair and/or replacement.

(7) There are no simultaneous failures.

4.1.2. Notations

$A_I B_J$	Represent good working states of respective filter and washer,
$a_I b_J$	Represent failed states of respective filter and washer,
$\lambda_1 \lambda_2$	Respective mean constant failure rates of $A_I B_J$,
$\mu_1 \mu_2$	Respective mean constant repair rates of $a_I b_J$,
d / dt	Represents derivative w.r.t 't',
$P_i(t)$	State probability that the system is in i^{th} state at time t,

4.2. Behavioral chart

The operating behavior of each subsystem depicted in table1.

4.3. Mathematical modeling

The difference differential equations associated with the transition diagram (Figure1) of the bleaching system are as follows:

$$(d / dt + 4\sum_{j=1}^{2} \lambda_j) P_0(t) = \sum_{j=1}^{2} \mu_j \, P_j(t) + \sum_{j=1}^{2} \mu_j \, P_{j+2}(t) + \sum_{j=1}^{2} \mu_j \, P_{j+4}(t) + \sum_{j=1}^{2} \mu_j \, P_{j+6}(t) \quad (1)$$

$$(d/dt+\mu_1)P_i(t)=\lambda_1 P_k(t) \quad (2)$$

Where $k=0,\ i=1,3,5,7$

$$(d/dt+\mu_2)P_i(t)=\lambda_2 P_k(t) \quad (3)$$

Where $k=0,\ i=2,4,6,8$

With initial conditions at time $t=0$,

$$P_i(t)=\begin{cases}1 & for\ i=0\\ 0 & for\ i\neq 0\end{cases}$$

4.4. Steady state analysis

Since the paper plant is a process industry, its every system should be available for long period. Therefore, steady state behavior of the system can be analyzed by setting t → ∞. and d/dt→0. The limiting probabilities from Equations (1) to (3) are:

$$4\sum_{j=1}^{2}\lambda_j p_0=\sum_{j=1}^{2}\mu_j p_j+\sum_{j=1}^{2}\mu_j p_{j+2}$$

$$+\sum_{j=1}^{2}\mu_j p_{j+4}+\sum_{j=1}^{2}\mu_j p_{j+6} \quad (4)$$

$$\mu_1 P_i=\lambda_1 P_k \quad (5)$$

Where $k=0,\ i=1,3,5,7$

$$\mu_2 P_i=\lambda_2 P_k \quad (6)$$

Where $k=0,\ i=2,4,6,8$

Solving these equations recursively, we get:

$$P_1=B_1P_0 \qquad P_2=B_2P_0 \qquad P_3=B_1P_0$$
$$P_4=B_2P_0 \qquad P_5=B_1P_0 \qquad P_6=B_2P_0$$
$$P_7=B_1P_0 \qquad P_8=B_2P_0$$

Where $B_i=\lambda_i/\mu_i \quad i=1,2.$

Use of Normalizing condition i.e. sum of all the state probabilities is equal to one $\left[\sum_{i=0}^{8}P_i=1\right]$ gives:

$$P_0=1/(1+4B_1+4B_2)$$

Now, the steady state availability (Av.) of the bleaching system is given by summation of all the full working and reduced capacity states probabilities.

$$Av=1/(1+4B_1+4B_2)$$

4.5. Behavior analysis of bleaching system

By critically examining the process of bleaching system and taking the relevant values of the failure and repair rates of each subsystem, the effect of these parameters on the system availability has been shown in Tables 2 and 3.

5. Result and discussions

Table 2 reveals the effect of failure and repair rates of filter subsystem on the availability of the bleaching system of the paper plant concerned. It is observed that for some known values of failure rate $(\lambda_2=0.01)$ and repair rate $(\mu_2=0.25)$ of the washer subsystem, as failure rate of filter subsystem increases from 0.01 (once in 100 hrs) to 0.09 (once in 11.11 hrs), the system availability decreases sharply from 0.70093 to 0.28089 i.e. about 42%. Similarly as repair rate of filter subsystem increases from 0.15(once in 6.66 hrs) to 0.55(once in 1.81 hrs), the system availability increases from 0.70093 to 0.81120 i.e. about 11%.Table 3 shows the effect of failure and repair rates of washer subsystem on the availability of bleaching system. It is observed that for some known values of failure rate (λ_1 = 0.01) and repair rate (μ_1 = 0.35) of filter subsystem, as failure rate of washer subsystem increases from 0.01 (once in 100 hrs) to 0.09 (once in 11.11 hrs), the system availability decreases drastically from 0.72413 to 0.28455 i.e. about 44%. Similarly as repair rate of washer subsystem increases from 0.15(once in 6.66 hrs) to 0.55(once in 1.81 hrs), the system availability increases considerably from 0.72413 to 0.84242 i.e. about 12%. From tables 2 and 3, it is observed that for any level of the system availability, various combination of failure and repair times are possible and we have to restrict these system parameters to practically feasible combinations. Besides, a proper maintenance schedule has also been prepared for the bleaching system of the paper plant concerned, which is given in table 4. This maintenance schedule might be helpful to determine the failure and repair behavior for various components and subsystems. On this basis, the effective maintenance planning of the bleaching system may be carried out in future.

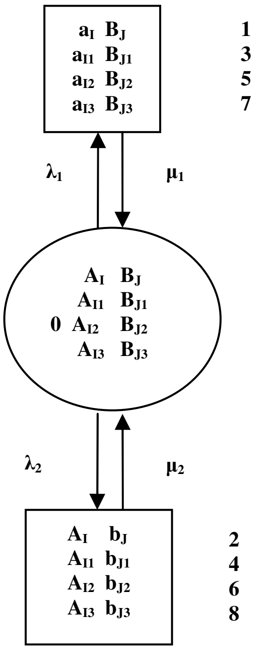

Figure 1: Transition Diagram for the Bleaching System.

Table 1: Nature and behavior of each subsystem.

Behavior	Effect/occurrence	Remedy
Subsystem A_I		
Major failure	Rare	By regular check of oil level in gear box
Minor failure	Often	Repaired by skilled worker
Performance Degradation	Yes	Skilled worker rectifies and repair
Inconvenience in operation	Yes	Maintain the vacuum
Subsystem B_J		
Major failure	Very rare	Shut the system and repair
Minor failure	Rare	Easily repaired by skilled worker
Performance Degradation	Possible	Repair is the only solution
Inconvenience in operation	None	…..

Table 2: Effect of failure and repair rates of the filter subsystem on bleaching system availability.

Availability (Av.) →

λ_1 \ μ_1	0.15	0.25	0.35	0.45	0.55	
0.01	0.70093	0.75757	0.78475	0.80071	0.81120	$\lambda_2 = 0.01$
0.03	0.51020	0.60975	0.66540	0.70093	0.72550	$\mu_2 = 0.25$
0.05	0.40106	0.51020	0.57756	0.62326	0.65632	
0.07	0.33039	0.43859	0.51020	0.56109	0.59912	
0.09	0.28089	0.38461	0.45691	0.51020	0.55150	

Table 3: Effect of failure and repair rates of the washer subsystem on bleaching system availability.

Availability (Av.) →

λ_2 \ μ_2	0.15	0.25	0.35	0.45	0.55	
0.01	0.72413	0.78475	0.81395	0.83113	0.84242	$\lambda_2 = 0.01$
0.03	0.52238	0.62724	0.68627	0.72413	0.75048	$\mu_2 = 0.35$
0.05	0.40856	0.52238	0.59322	0.64154	0.67662	
0.07	0.33546	0.44757	0.52238	0.57586	0.61600	
0.09	0.28455	0.39149	0.46666	0.52238	0.56534	

Table 4: Maintenance schedule.

Schedule	Component	Check/Remarks
Daily	All stationary & rotary equipment, washer	Regular checks by maintenance department
Weekly	Pumps	Monitoring unbalance, misalignment, looseness
	Bearings	Lubricate if required
	Filter	Check the leakage
	Gearbox	Check the oil level
Fortnightly	Pumps	Check the vibration level
	Bearings	Check the temperature
Quarterly	Pumps	Greasing, Sleeve and Coupling inspection
Annual (Two weeks shut down)		Overhauling of stationary & rotary equipment through planned maintenance schedule. By checking all the components of each unit

Table 5: Repair priority of each subsystem.

Subsystem	Increase in failure rate	Decrease in availability	Increase in repair time	Increase in availability	Repair priority
Filter	0.01-0.09	42%	0.15-0.55	11%	II
Washer	0.01-0.09	44%	0.15-0.55	12%	I

6. Conclusion

It can thus be concluded that the steady state behavior of bleaching system can be analyzed with the help of availability model developed. The behavior analysis has also been explained by means of availability Tables (2,3). These availability tables have shown the effect of failure and repair rates of various subsystems on the steady state availability of bleaching system. Besides, the maintenance planning has also been suggested with the help of maintenance schedule, given in Table 4, mainly to enhance the overall availability of bleaching system of the paper plant concerned. The results obtained from these tables also reveal that the repairs in the subsystems of bleaching system should be accorded in the order of preference as given in Table 5.

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