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Preventive Maintenance Strategy of Gasifier Refractory Brick Based on State Recognition

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Abstract: *In order to ensure the normal and safe operation of gasifier, it is necessary to ensure that the remaining life of refractory brick, the key component of gasifier, is in a healthy range, so it is necessary to formulate a timely and reasonable maintenance strategy for refractory brick. In order to avoid the problem of excessive Maintenance and insufficient Maintenance, CBM (Condition Based Maintenance) related research on gasifier refractory brick. This article first to identify the current state of the gasifier refractory brick, and then based on this state for different refractory brick their preventive maintenance strategy, can largely avoid excessive problem, lack of maintenance and repair in a timely manner to maintain the gasifier refractory reasonably, to extend its service life, guaranteeing the normal safe operation of the gasifier.*

Keywords: *Gasifier, Refractory Brick, State Recognition, Maintenance Strategy*

1. Introduction

Gasifier [1] is the main carrier of the gasification process. Its combustion chamber is subjected to intense gasification reaction, and the operating temperature is kept above 1300℃ for a long time. However, the refractory brick is in the inner layer of the combustion chamber, which is gradually damaged until damaged due to the adverse impact of high temperature and high pressure and the scour of gas slag for a long time [2]. Therefore, to monitor the current status of refractory brick, can provide a reliable basis for the formulation of reasonable and effective maintenance plan, to ensure timely maintenance, improve the accuracy of maintenance, which is of great significance to ensure the normal performance and operation safety of gasifier. The application of data-driven model to identify the current status of refractory brick can provide a reliable basis for the formulation of reasonable and effective maintenance plan, so as to timely carry out maintenance at the time of maintenance, improve the accuracy of proactive maintenance, and thus ensure the normal performance and operation safety of gasifier, reduce the maintenance cost.

Situational maintenance is to develop appropriate maintenance strategies for equipment based on monitoring equipment status and considering different states and degradation processes, which can make up for the disadvantages of "insufficient maintenance" and "excessive maintenance" of regular maintenance [3-6]. Condition monitoring is the basis of condition-based maintenance. Accurate condition monitoring can provide reliable basis for condition-based maintenance. Hidden semi-Markov Model (HSMM) has been widely used in state recognition research due to its strong learning ability, fast training speed and small amount of data. Related researches have been carried out based on HSMM diagnosis and prediction of mechanical fault evolution [7], fault diagnosis of transformer [8], fault prediction of shearer heightening pump [9] and tool wear state monitoring [10].

In this paper, the status recognition of gasifier refractory brick in a company is carried out, and a preventive maintenance strategy is formulated for it combining regular maintenance and on-condition maintenance. The research process is based on the measurement data of effective thickness of gasifier refractory brick under actual working conditions, and a state model database is established for gasifier refractory brick, which contains all the states of refractory brick.

2. Gasifier Refractory Brick State Recognition

Fig.1 shows the steps of state recognition of refractory brick based on HSMM, which can be mainly divided into the following steps:

(1) First, the training data of refractory brick in each state and the initial parameters of each HSMM

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$\pi_{i0}, A_{i0}, B_{i0}, P_{i0}$ are taken as input, and the improved Baum-Welch algorithm is used to train them and the model parameters after reassessment $\overline{\pi}_i, \overline{A}_i, \overline{B}_i, \overline{P}_i$ are obtained, so as to obtain the HSMM corresponding to each state after training. When the HSMM training corresponding to each degradation state is completed, the refractory brick state model library is constructed.

(2) Then the improved Viterbi algorithm is used to calculate the likelihood probability pair values of each HSMM in the test sequence O and state model library and compare the values.

(3) The state corresponding to the maximum HSMM is the state of the test sequence, so as to realize the state recognition of refractory brick.

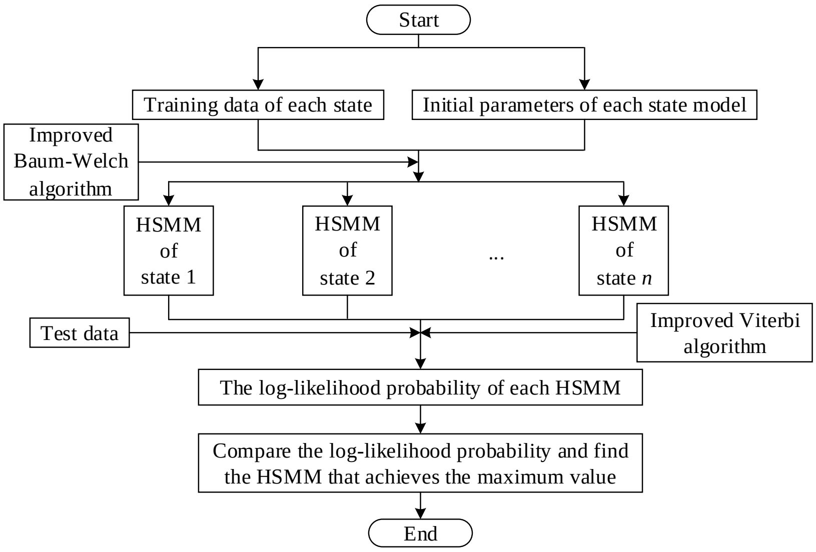

Fig.1: Step of gasifier refractory brick status recognition

According to the actual situation of gasifier refractory brick, the following assumptions are made for the model:

(1) State set $S = \{S_1, S_2, S_3, S_4\}$;

(2) Initial state distribution $\pi = \{1, 0, 0, 0\}$;

(3) Refractory brick can only maintain the current state or the next state transition, not forward or cross-step transition.

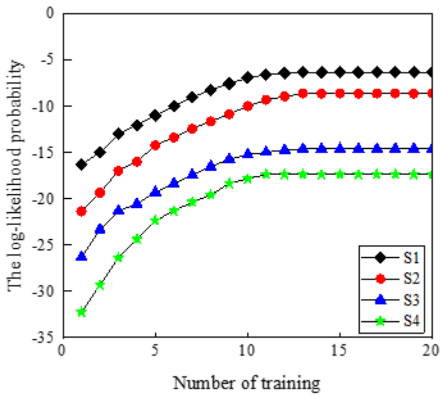

Fig.2: Training process of each state model

The corresponding state model is trained with the training data of refractory brick in the four states, and the process is shown in Fig.2. All state models converge within 20 generations, indicating that the constructed model has good learning ability, fast training speed and small amount of data required.

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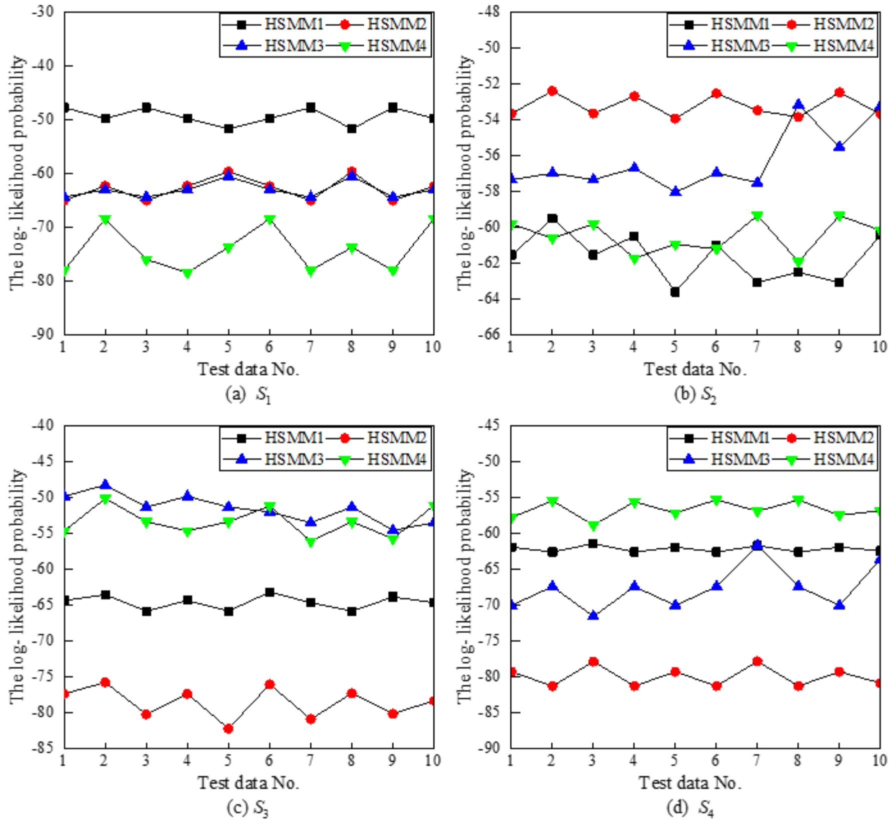

Fig.3: The log-likelihood probability of the test sequence and state model

Fig.3 shows the state recognition model of gasifier refractory brick constructed based on HSMM and the logarithmic likelihood probability of test data of each state. The state recognition results of each test data can be obtained by comparing the logarithmic likelihood probability.

Tab.1: State recognition result

State	S1	S2	S3	S4	Correct rate
S1	10	0	0	0	100%
S2	0	8	2	0	80%
S3	0	0	8	2	80%
S4	0	0	0	10	100%
Total correct rate	/	/	/	/	90%

The state recognition results of test data of each state obtained by using the state recognition model of gasifier refractory brick constructed based on HSMM are shown in Table 1. It can be seen from Tab.1 that the accuracy rate of state recognition for test data S_1 and S_4 is 100%, while that for test data S_2 and S_3 is 80%. It is considered that the initial parameter B_0 is not set reasonably during the training of HSMM2 and HSMM3. As a result, the logarithmic likelihood probability of these two models and the test data in other states is high, which leads to the occurrence of recognition errors. The performance of these two models can be improved and the accuracy and accuracy of state recognition can be improved by re-selecting the initial parameters with other algorithms.

3. Consider Refractory Brick Maintenance Strategy with Imperfect Maintenance

According to the degradation reason and actual degradation law of gasifier refractory brick and the loss reason and maintenance measures of gasifier refractory brick in the actual production process, the selection set of maintenance mode M and the selection set of maintenance period T are formulated.

(1) Selected maintenance mode M = {minor repair, medium repair, major repair}, denoted as $M=\{M_1, M_2, M_3\}$.

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Among them, minor repair is the least workload, mainly refers to the simple daily maintenance of refractory bricks, including inspection and slag removal measures. The workload of medium repair is slightly larger, which mainly refers to the maintenance plan formulated according to the current degradation state of refractory bricks, including repair and other measures. The workload of major repair is the largest, which mainly refers to the overall replacement of refractory bricks after their entire service life is exhausted, and the replacement of refractory bricks that reach the minimum effective thickness threshold is carried out.

(2) Selected maintenance period $T=\{60,120,180,240\}$, denoted as $T=\{T_1,T_2,T_3,T_4\}$, and the unit is day.

In order to minimize comprehensive maintenance cost, a decision-making model of refractory brick preventive maintenance strategy was established. In order to calculate the comprehensive maintenance cost of refractory bricks in different degradation states with different maintenance modes and maintenance periods, the comprehensive maintenance cost equation is established as shown in Formula (1).

$$C_W\left(S_i,M_k,T_l\right)=\left(D_i/T_l\right)\times C_M\left(S_i,M_k\right)+C_R\left(S_i,M_k,T_l\right) \tag{1}$$

$$V_W\left(S_i\right)=\min\left(C_W\left(S_i,M_k,T_l\right)\right) \tag{2}$$

$C_W\left(S_i,M_k,T_l\right)$ is the comprehensive maintenance cost of the refractory brick in S_i with the selected maintenance mode M_k and maintenance period T_l; $V_W\left(S_i\right)$ is the optimal comprehensive maintenance cost of the refractory brick in S_i with different maintenance modes and maintenance periods; D_i/T_l represents the adjustment coefficient, when D_i/T_l =1, take its own value, when $D_i/T_l \le 1$, value 1. $C_M\left(S_i,M_k\right)$ represents the cost of selecting maintenance M_k mode for refractory bricks in S_i. $C_R\left(S_i,M_k,T_l\right)$ represents the risk cost of selecting maintenance mode M_k and maintenance period T_l for refractory bricks in S_i.

Considering the actual degradation of gasifier refractory brick and the maintenance workload and difficulty, the various costs in the maintenance process are assumed as shown in Table 2 and Table 3.

Tab.2: Maintenance cost of refractory brick in different states

State	M1	M2	M3
S1	30000	60000	200000
S2	50000	100000	200000
S3	70000	140000	200000
S4	90000	180000	200000

Tab.3: Cost of routine inspection and outage of refractory brick in different states

State	S1	S2	S3	S4
Cost of routine inspection	1000	1500	2500	4000
Outage cost	100000	100000	100000	100000

Solve the comprehensive maintenance cost equation as shown in Formula (1), calculate the comprehensive maintenance cost of refractory brick in different maintenance modes and maintenance periods, and select the corresponding optimal maintenance scheme, including maintenance mode and maintenance period, for the lowest comprehensive maintenance cost of refractory brick. The results are shown in Tab.4.

Tab.4: Optimal maintenance strategy for refractory brick in various states

State	S1	S2	S3	S4
Maintenance modes	M1	M1	M2	M2
Maintenance periods	T4	T4	T3	T2

As shown in Tab.4, the optimal maintenance scheme obtained is:

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(1) The maintenance mode M_1 (minor repair) is selected for refractory brick in S_1, and the maintenance period T_4 (240 days) is used for preventive maintenance.

(2) The maintenance mode M_1 (minor repair) is selected for refractory brick in S_2, and the maintenance cycle T_4 (240 days) is used for preventive maintenance.

(3) The maintenance mode M_2 (medium repair) is selected for refractory brick in S_3, and the maintenance period T_3 (180 days) is used for preventive maintenance.
(4) The maintenance mode M_2 (medium repair) is selected for refractory brick in S_4, and the maintenance period T_2 (120 days) is used for preventive maintenance.

4. Conclusion

In this paper, based on the current state of the gasifier refractory brick, HSMM recognition and based on the combination of regular maintenance and according to its situation make the preventive maintenance strategy, avoid the gasifier brick "insufficient maintenance" in the process of maintenance and the problem of excess "maintenance", in a timely manner to proper maintenance of gasifier refractory brick, to a great extent, reduce the maintenance cost, Prolong the service life of gasifier refractory brick, so as to ensure the normal and safe operation of gasifier.

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