AN EXAMINATION ON THE VIBRATIONAL PROPERTIES OF THE COKE PUSHING RAM WHILE IT IS BEING USED IN THE COKE PUSHING PROCESS

[1]K.Giriprasad,[2]B.Veera
Department Of Mechanical Engineering
Priyadarshini Institute of Science and Technology for Women Khammam.

ABSTRACT:

Serious vibrations in the coke pushing ram may occur during the procedure, and this could have an immediate effect on the coke oven's regular output. Analysis of the coke pushing ram's vibration characteristics is necessary in order to learn more about its vibration characteristics and take steps to prevent vibrations. In order to study the vibration mechanism of a coke pushing ram, a mathematical model of a coke pushing ram in operation during the coke pushing process is built. The coke pushing resistance is estimated in this piece using the coke pushing current. The results show that in the low-velocity and heavy-load coke pushing operation, the coke pushing velocity is less than the critical velocity once the slipper enters the carbonization chamber. This suggests that the coke pushing ram is the source of the stick-slip vibration, and that stiffness, damping, and the variation between the static and dynamic friction coefficients are the main elements influencing the coke pushing ram's stability. Numerical simulation and experimentation are employed to confirm the findings' accuracy.

Among the terms to take into account are the stick-slip mechanism, vibrational ram, mathematical model, and coke pushing resistance.

DOI Number: 10.48047/nq.2018.16.11.1129 **NeuroQuantology 2018; 16(11):116-128**

Introduction

Coke oven production is beneficial for the comprehensive utilization of coal and plays an important role within the metallurgical industry. The coke pushing ram is the core component of coke oven production; it is a box structure with the length of 27 m, width of 0.40 m, height of 5.65 m, and weight of 40 tons, which mainly consists of a coke pushing head, ram, and slipper. A three-dimensional model of coke pushing ram is shown in Figure 1. Figure 2 presents a three-dimensional model of coke pushing process. It can be observed that the coke pushing ram is driven by a gear, and the coke is pushed out from the carbonization chamber via a coke pushing head. However, in the coke pushing process after slipper enters the carbonization chamber, serious vibrations can occur in the coke pushing ram so that the coke cannot be completely pushed out from the carbonization chamber and may directly affect the regular production of coke oven.1 In order to avoid serious vibration, it is necessary to study the vibration characteristics of coke pushing ram. Zhang and Hao2 analyzed the force characteristics of coke pushing ram in the coke pushing process and suggested that the structure of coke pushing ram was not solid enough to cause it to vibrate. Chu and Song3

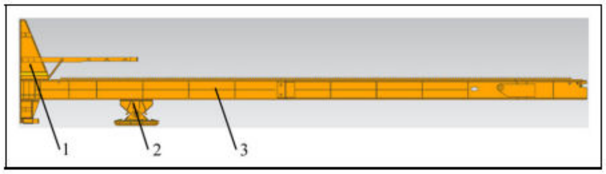

Figure 1. Three-dimensional model of coke pushing ram.1: coke pushing head; 2: slipper; 3: ram.

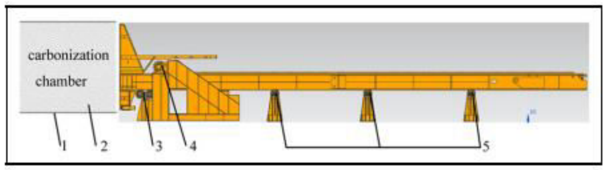

Figure 2. Three-dimensional model of coke pushing process.1: ground of carbonization chamber; 2: coke; 3: front roller; 4: gear, 5: back roller.

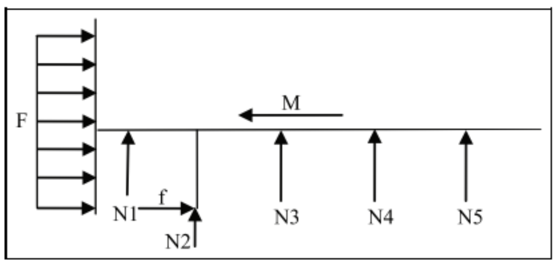

Figure 3. Force analysis of coke pushing ram.

suggested that the force would cause deformation of the structure, which would cause the gear rack not to mesh normally and induce vibration of the coke pushing ram. The above studies are limited to analyzing the vibration phenomenon of coke pushing ram, lacking a theoretical basis. By comparing the vibration frequency and natural frequency of coke pushing ram, it was found that the vibration frequency was close to the natural frequency, leading Gao4 to propose that the vibration of coke pushing ram belonged to self-excited vibration. Using ANSYS, Zhao5 analyzed the vibration amplitude of coke pushing ram in horizontal and longitudinal directions, without further analyzing the vibration characteristics of coke pushing ram. To date, studies on the vibration characteristics of coke pushing ram in the coke pushing process have been very limited, lacking theoretical analysis, numerical simulation, and experimental test. In order to study the vibration characteristics of coke pushing ram, in this article, the coke pushing resistance is derived via the coke pushing current, the coke pushing process is simplified as a physical model and a mathematical model is developed from the physical model to analyze the vibration mechanism of coke pushing ram. In addition, the results are validated by numerical simulation and experiment test.

COKE PUSHING RESISTANCE

In order to study the vibration characteristics of coke pushing ram, the force conditions of coke pushing ram in coke pushing process are first analyzed. Figure 3 shows the force conditions of coke pushing ram in the coke pushing process. M is the force of the gear drive, F is the coke pushing resistance caused by the coke pushing ram pushing the coke, f is the friction between the coke pushing ram and ground of the carbonization chamber generated by the bottom of the slipper contacting with the ground of the carbonization chamber, and N1, N2, N3, N4, and N5 are the support force.

Coke pushing resistance has a great influence on the coke pushing process and can be characterized by the coke pushing current. Based on the coke pushing current–displacement data recorded by the instrument panel of the coke pushing operating room, such as in Figure 4, the coke pushing current–displacement function is fitted, and coke pushing resistance of different displacements segment is derived based on the current variations, which provides basis for deriving the mathematical model of coke pushing ram in the coke pushing process. From Figure 4, it can be seen that the coke pushing current varied significantly between 3.6 and 8 m, and the analysis is as follows:

1. 0–2.95 m: The coke pushing ram is in the startup phase, so the coke pushing current is stable at 230 A.
2. 2.95–3.6 m: Coke pushing phase 1, the slipper has not entered the carbonization chamber. The coke pushing current reaches to the peak at 3.6 m, after a slow downward trend. During the initial phase of coke pushing process 1, the coke pushing ram does not only push the coke, so there still is a need to compact the loose coke. The coke pushing resistance goes from zero to a maximum, such that the current instantly increases. As the coke is compacted and pushed out, the current slowly decreases.
3. 3.6–18 m: Coke pushing phase 2. The coke pushing ram runs to 8 m, and the slipper enters the carbonization chamber.

According to data 1 and 2, it is possible to fit the coke pushing current–displacement function as follows

$$I(m) = \begin{cases} 230, 0 \le x \le 2.95\,\text{m} \\ 200x - 360, 2.95 \le x \le 3.6\,\text{m} \\ 390 - 8.5x, 3.6 \le x \le 18\,\text{m} \end{cases}$$

Coke pushing current is stable at 230 A in the startup phase, so in the coke pushing phase, the current changed is caused by the coke pushing resistance, and the current variations DI—displacement function is as follows

$$\Delta I(m) = \begin{cases} 0, 0 \le x \le 2.95\,\text{m} \\ 200x - 590, 2.95 \le x \le 3.6\,\text{m} \\ 160 - 8.5x, 3.6 \le x \le 18\,\text{m} \end{cases}$$

Based on $P = UI = Fv$, F can be expressed as

$$F = \frac{380\Delta I}{0.45}$$

where DI is the coke pushing current, F is the coke pushing resistance, 380 is the rated voltage, and 0.45 is the coke pushing velocity. Therefore, the formula for the coke pushing resistance can be given as

$$F(m) = \begin{cases} 0, 0 \le x \le 2.95\,\text{m} \\ \frac{380}{0.45}(200x - 590), 2.95 \le x \le 3.6\,\text{m} \\ \frac{380}{0.45}(160 - 8.5x), 3.6 \le x \le 18\,\text{m} \end{cases}$$

The curve of the coke pushing resistance is shown in Figure 5.

VIBRATION MECHANISM

MATHEMATICAL MODEL

In view of the importance and complexity of coke pushing process, the vibration mechanism of coke pushing ram is analyzed by establishing a mathematical model. For convenience, based on the results obtained in the section above, the coke pushing process is simplified as a physical model presented in Figure 6. A mathematical model is developed from the physical model to analyze the main factors affecting the stability of the coke pushing ram.6

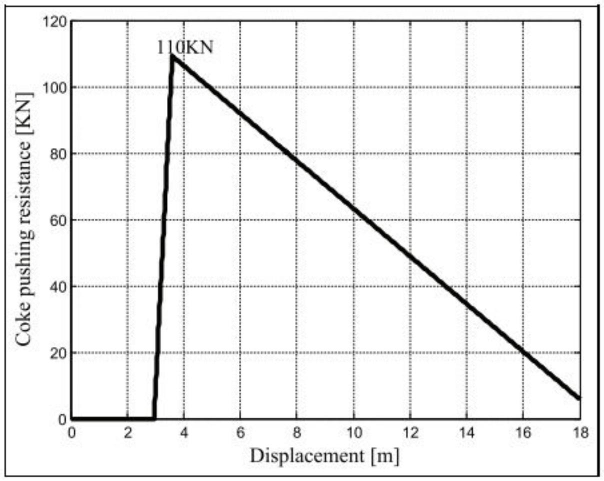

Figure 5. Curve of coke pushing resistance

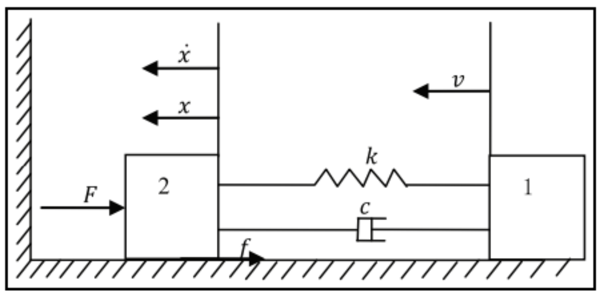

Figure 6. Physical model in the coke pushing process. 1: drive; 2: coke pushing ram; k: stiffness; c: damping; F: coke pushing resistance; f : friction

The drive actuates the coke pushing ram move to the left with the velocity v. Supposing when the drive runs the distance x0, the driving force is equal to the static friction fs such that kx0 = fs. As the driving force overcomes the static friction, the coke pushing ram begins to move to the left and push the coke. After a time t, the displacement of coke pushing ram is x, and the mathematical model can be expressed as

$$k(x_0 + vt - x) - c\dot{x} - f_d - F = m\ddot{x} \qquad (1)$$

where k(x0 + vt x) is the driving force, cx_ is the damping force, fd is the dynamic friction, and m€x is the inertia force. Dynamic friction fd approximation can be divided into a constant component f and component rx_ that changes with the velocity,7 and fd can be expressed as

$$f_d = f + r\dot{x} \qquad (2)$$

Substituting equation (2) into equation (1), the kinetic equation of coke pushing ram can be written as

$$k(x_0 + vt - x) - c + r\dot{x} - f - F = m\ddot{x} \qquad (3)$$

Ordering fs f = Df , where Df is a difference between the static friction and the dynamic friction, then the kinetic equation of coke pushing ram can be written as

$$m\ddot{x} + c + r\dot{x} + kx = kvt + \Delta f - F \qquad (4)$$

Equation (4) is a second-order system, damping ratio $\xi = (c + r)/(2\sqrt{km})$ its different values can cause different characteristics of the system.

1. When 0\j\1, the system is in an under damped state. The input energy is consumed by the friction and the coke pushing resistance,other disturbances will cause the input energy to be lower than the output energy, resulting in unstable velocity and stick-slip vibration to occur.
2. When j = 1, the system is in a critical damped state. The input energy is equal to the output energy, and stick-slip vibration cannot occur in the system.
3. When j.1, the system is in an over damped state. The system is relatively stable, and stickslip vibration cannot occur in the system. From the results above, it can be concluded that the primary cause of vibration is c+ r, where c is the damping and r is the coefficient of friction changing with velocity. There is a direct relation between stickslip vibration and the velocity. It is only when the velocity is lower than a certain value that stick-slip vibration occurs, and the velocity is the critical velocity.

Critical velocity As the stiffness k is larger, j2 ’ 0, and the displacement equation of coke pushing ram can be derived as

$$x = \begin{cases} e^{-\xi\omega_n t}(\mathrm{A}\sin\omega_n t + \mathrm{B}\cos\omega_n t) + vt + \frac{\Delta f + 498,222}{k} \\ -\frac{(c+r)v}{k}\ 2.95 \le x \le 3.6\,\mathrm{m} \\ e^{-\xi\omega_n t}(\mathrm{A}\sin\omega_n t + \mathrm{B}\cos\omega_n t) + vt + \frac{\Delta f - 135,111}{k} \\ -\frac{(c+r)v}{k}\ 3.6 \le x \le 18\,\mathrm{m} \end{cases} \quad (5)$$

where j is the damping ratio, vn is the natural frequency, and A and B are constants determined from the initial conditions, here $\xi = (c + r)/(2\sqrt{km})$ and $\omega_n = \sqrt{k/m.}$. The coke pushing ram pushes the coke instantaneously, t = 0, x_ = 0. The friction varies from the static to dynamic one, the coke pushing ram experiences an acceleration process, so Df = m€x. The initial conditions can be expressed as t = 0, x_ = 0, €x= (Df)=m. Due to j2 ’ 0, A and B can be expressed as 120

$$\mathrm{A} = \frac{v}{\omega_n}(-D\xi - 1)\ \mathrm{B} = \frac{v}{\omega_n}(2\xi - D) \qquad (6)$$

where $D = \frac{\Delta f}{v\sqrt{km}}$ km p Substituting equation (6) into equation (5), the displacement equation of coke pushing ram can be written as

$$x = \begin{cases} vt + \frac{\Delta f + 498,222}{k} - \frac{(c+r)v}{k} + \frac{v}{\omega_n}e^{-\xi\omega_n t}[(2\xi - D)\cos\omega_n t - (1 + D\xi)\sin\omega_n t]\ 2.95 \le x \le 3.6\,\mathrm{m} \\ vt + \frac{\Delta f - 135,111}{k} - \frac{(c+r)v}{k} + \frac{v}{\omega_n}e^{-\xi\omega_n t}[(2\xi - D)\cos\omega_n t - (1 + D\xi)\sin\omega_n t]\ 3.6 \le x \le 18\,\mathrm{m} \end{cases} \quad (7)$$

Equation (7) is to take a derivation with respect to time t, due to j2 ’ 0, the velocity equation of coke pushing ram can be written as

$$\dot{x} = v\{1 - e^{-\xi\omega_n t}[\cos\omega_n t + (D - \xi)\sin\omega_n t]\} \qquad (8)$$

Equation (8) shows that velocity x_ of coke pushing ram included two parts: constant component v and vibration component $ve^{-\xi\omega_n t}[\cos\omega_n t + (D - \xi)\sin\omega_n t]$. If x_.0, then stick-slip vibration cannot occur in the coke pushing ram,9 that is

$$e^{-\xi\omega_n t}[\cos\omega_n t + (D - \xi)\sin\omega_n t] < 1 \qquad (9)$$

Considering a cycle, that is, vnt = 2p, equation (9) can be written as

$$e^{-2\pi\xi}\sqrt{1+(\xi-D)^2}\leq 1 \qquad (10)$$

when equation (10) is in the critical state of $e^{-2\pi\xi}\sqrt{1+(\xi-D)^2}=1,^{10}$ ordering $f(\xi)=e^{2\pi\xi},$ and then

$$\begin{aligned} &e^{-2\pi\xi}\sqrt{1+(\xi-D)^2}=1\\ &\sqrt{1+(\xi-D)^2}=e^{2\pi\xi} \qquad (11)\\ &(\xi-D)^2=e^{4\pi\xi}-1 \end{aligned}$$

Based on the equivalent infinitesimal, when $\xi\to 0,\ \ e^{4\pi\xi}-1\sim 4\pi\xi,$ equation (10) can be derived as

$$D^2\approx 4\pi\xi$$

$$D'\approx\sqrt{4\pi\xi}$$

The critical value of D can be expressed as $D'\approx\sqrt{4\pi\xi}.$.

Table 1. Parameters of the coke pushing ram.

Coke pushing velocity (mm/s)	Stiffness (N/mm)	Damping (N · s/mm)	Coefficient of static friction	Coefficient of dynamic friction
450	1.0E6	2000	0.8	0.65

Table 2. Simulation parameters.

Quality (kg)	Drive velocity (mm/s)	Stiffness (N/mm)	Damping (N · s/mm)	Coefficient of static friction	Coefficient of dynamic friction
4.0E4	450	1.0E6	2000	0.8	0.55/0.65/0.75
4.0E4	450	1.0E5/1.0E6/1.0E7	2000	0.8	0.65
4.0E4	450	1.0E6	500/2000/4000	0.8	0.65

Based on $D=(\Delta f)/(v\sqrt{km})$, it can be concluded that if D reaches to the critical value of D0 , namely, $(\Delta f)/(v\sqrt{km})\approx\sqrt{4\pi\xi}.$ 4pj p , and then the coke pushing velocity reaches to the critical velocity, it can be derived as

$$\begin{aligned} v' &= \frac{\Delta f}{\sqrt{4\pi\xi}\sqrt{km}}=\frac{\Delta f}{2\sqrt{\pi(c+r)\sqrt{km}}}\\ &=\frac{N\Delta\mu}{2\sqrt{\pi(c+r)\sqrt{km}}} \qquad (12) \end{aligned}$$

where N is the positive pressure, Dm is the difference between the static and dynamic friction coefficients. The parameters of the coke pushing ram are shown in Table 1, and the analysis is as follows: 2:95 x 8 m: The slipper has not entered the carbonization chamber, the coke pushing ram is not affected by the friction, and the critical velocity v0 = 0. Due to v.v0 , this indicates that no stick-slip vibration occurs in the coke pushing ram. 8 x 18 m: The slipper has entered the carbonization chamber, the coke pushing ram is affected by the friction, and the critical velocity v0 = 840 mm=s. Due to v\v0 , this indicates that stick-slip vibration occurs in the coke pushing ram. In the low-velocity and heavy-load coke pushing process, after the slipper enters the carbonization chamber, the coke pushing velocity is less than the critical velocity, it can be concluded that stick-slip vibration occurs in the coke pushing ram. In addition, the parameters affecting the coke pushing ram stability mainly include the difference between the static and dynamic friction coefficients Dm, stiffness k, and damping c. Furthermore, decreasing the difference between the static and dynamic friction coefficients and increasing stiffness and damping can decrease the critical velocity, and thus decrease vibration of the coke pushing ram.

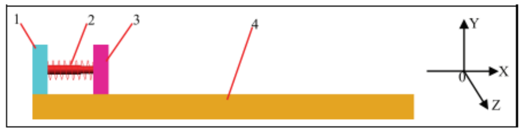

Figure 7. Simulation model. 1: drive; 2: equivalent spring; 3: coke pushing ram; 4: ground of carbonization chamber.

Numerical simulation

In order to validate the results of theoretical analysis, a simulation model is established by ADAMS to simulate the effects of the difference between the static and dynamic friction coefficients, stiffness and damping on the stability of coke pushing ram. The simulation model is shown in Figure 7, and the simulation parameters are shown in Table 2. Figures 8–10 present the simulation results. It can be observed that before the slipper enters the carbonization chamber, the coke pushing velocity is stable and the displacement in the Y and Z directions are smaller, with no obvious vibration occurring in the coke pushing ram. After the slipper enters the carbonization chamber, different degrees of vibration occur in the coke pushing ram, and the analysis is as follows: Figure 8 presents the effect of the difference between the static and dynamic friction coefficients on the stability of coke pushing ram. The main parameters such as drive velocity, stiffness, and damping remain unchanged, with a decrease of the difference between the static and dynamic friction coefficients, fluctuation of the coke pushing velocity is less obvious, the displacement in the Y and Z directions decrease noticeably, and stick-slip vibration decreases noticeably.11 Figure 9 presents the effect of stiffness on the stability of coke pushing ram. The main parameters such as

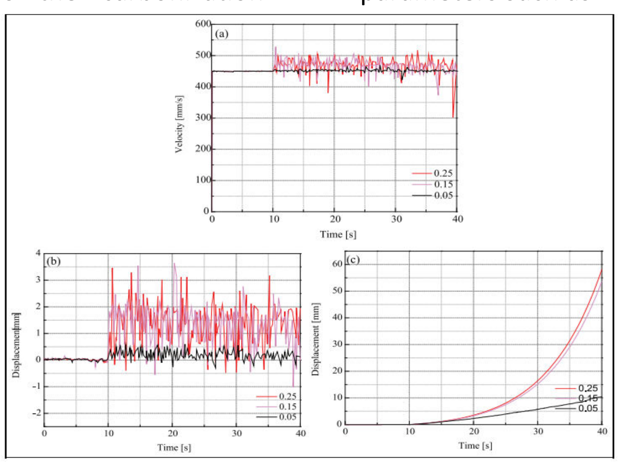

Figure 8. Effect of the difference between the static and dynamic friction coefficients on the stability of coke pushing ram: (a) coke pushing velocity in X direction, (b) displacement in Y direction, and (c) displacement in Z direction.

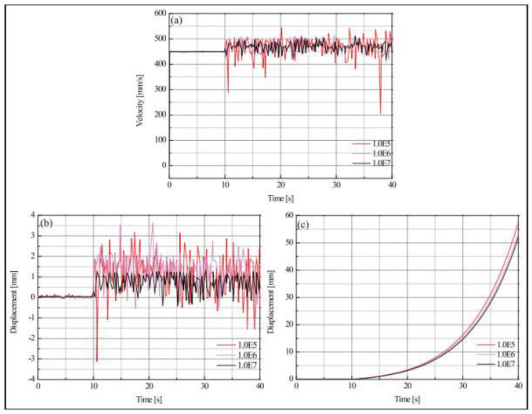

Figure 9. Effect of stiffness on the stability of coke pushing ram: (a) coke pushing velocity in X direction, (b) displacement in Y direction, and (c) displacement in Z direction.

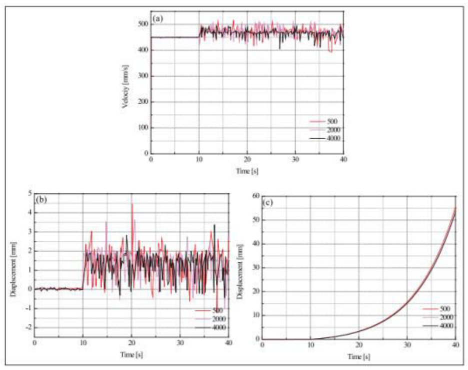

Figure 10. Effect of damping on the stability of coke pushing ram: (a) coke pushing velocity in X direction, (b) displacement in Y direction, and (c) displacement in Z direction.

Table 3. Material parameters of coke pushing ram.

Part	Material	Modulus of elasticity (GPa)	Poisson's ratio	Density (kg/m^3)
Coke pushing head	Q235-B	210	0.274	7830
ram	Q235-A	212	0.288	7860
Slipper	Q235-A	212	0.288	7860

drive velocity, difference between the static and dynamic friction coefficients and damping remain unchanged, with the increase of stiffness, fluctuation of the coke pushing velocity is less obvious, the displacement in the Y and Z directions decrease gradually, and stick-slip vibration decreases gradually.12 Figure 10 presents the effect of damping on the stability of coke pushing ram. The main parameters such as drive velocity, difference between the static and dynamic friction coefficients and stiffness remain unchanged, with the increase of damping, there is a slight decrease for fluctuation of the coke pushing velocity and the displacement in the Y and Z directions, indicating that stick-slip vibration has decreased slightly. From the simulation results above, it can be concluded that after the slipper enters the carbonization chamber, the stick-slip vibration occurs in the coke pushing ram, moreover, decreasing the difference between the static and dynamic friction coefficients and increasing stiffness and damping can decrease vibration of the coke pushing ram, which validates the results of theoretical analysis.

Modal analysis

In order to study the vibration characteristics of coke pushing ram, the natural frequencies of the coke pushing ram are obtained via modal analysis. Material parameters of the coke pushing ram are shown in Table 3. A finite element model of the coke pushing ram is shown in Figure 1113 and the grid number is 594753. For modal analysis, the modal extraction method used is PCG Lanczos, with the frequency range of 0.01– 1000 Hz. As the vibration frequencies of the coke pushing ram is mainly concentrated in the low frequency range of 0–100 Hz (as shown in Figure 14), the first 30 orders natural frequencies are selected for analysis, as shown in Table 4.

Table 4. First 30 orders natural frequencies of coke pushing ram.

Order	Natural frequencies (Hz)	Order	Natural frequencies (Hz)	Order	Natural frequencies (Hz)
1	1.846	11	26.335	21	66.577
2	5.199	12	28.447	22	67.206
3	5.575	13	30.889	23	75.438
4	8.079	14	36.499	24	76.840
5	9.201	15	41.011	25	82.496
6	9.899	16	45.072	26	83.969
7	11.257	17	48.006	27	92.838
8	13.552	18	50.256	28	94.831
9	15.006	19	60.371	29	97.588
10	17.792	20	61.910	30	109.50

Table 5. Test instruments

Vibration signal acquisition system	Vibration acceleration sensor
INV306S data acquisition and analysis system	121A100

Figure 11. Finite element analysis model of coke pushing ram.

Experimental test

Experimental method Vibration signals of the coke pushing ram in the coke pushing process are acquired via an experiment, and the vibration frequencies and vibration time of coke pushing ram are obtained by time–frequency analysis; furthermore, the vibration characteristics of coke pushing ram are analyzed by comparing the vibration frequencies, natural frequencies, and excitation frequency.

Table 6. Test background.

Length of chamber	Temperature of chamber	Coke pushing velocity	Excitation frequency	Sampling frequency	Sampling time
18 m	Around 800°C	0.45 m/s	2.8 Hz	2048 Hz	50 s

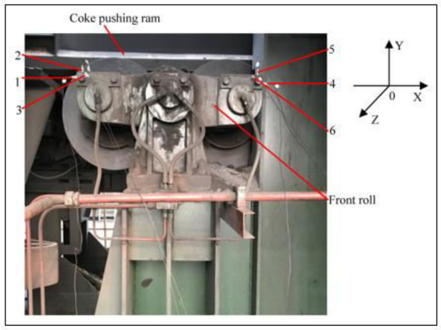

Figure 12. Vibration sensors arrangement. Sensors 1 and 4 collect vibration signals in the X direction for coke pushing direction. Sensors 2 and 5 collect vibration signals in the Y direction for vertical direction. Sensors 3 and 6 collect vibration signals in the Z direction for both sides of the coke pushing ram.

Table 5 lists the test instruments, and Table 6 lists the test backgrounds. To push out the coke, it is necessary for the coke pushing ram to enter the carbonization chamber, and due to the complicated production site, vibration sensors are placed on the front roller to acquire the vibration signals of coke pushing ram. Vibration sensors arrangement is shown in Figure 12. Experimental analysis In view of non-stationary and non-linear characteristics of vibration signals of the coke pushing ram, the Hamming window is selected for short-time Fourier transform of the vibration signals.14,15 Sampling.

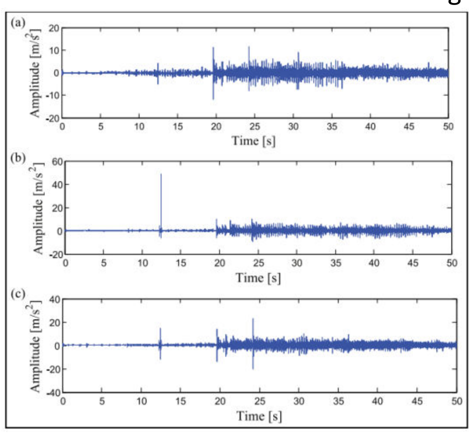

Figure 13. Vibration signals of coke pushing ram: (a) X direction, (b) Y direction, and (c) Z direction.

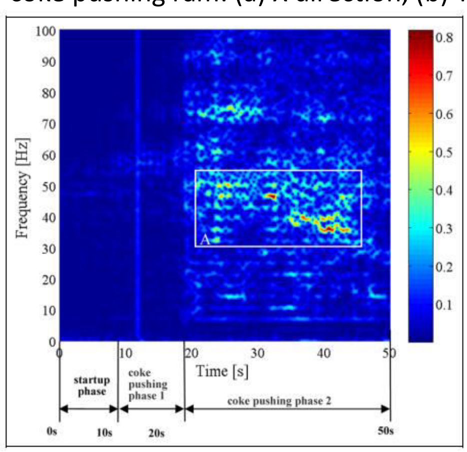

Figure 14. Time–frequency in Y direction.

frequency Fs is 2048 Hz, Nfft is 20480, frequency resolution Df is 0.1, and window length is 2048 3 1.5.16 Based on the coke pushing characteristics of coke pushing rod, the coke pushing process can be divided into three phases: startup phase, coke pushing phase 1 (before the slipper enters the carbonization chamber), and coke pushing phase 2 (after the slipper enters the carbonization chamber).

Figure 13 shows the vibration signals in the X, Y, and Z directions. When the vibration signals in the X, Y, and Z directions are transformed by short-time Fourier transform, it is found that serious vibration occurs in the X, Y, and Z directions, and mainly occurs in the low frequency range of 0–100 Hz. Since the vibration frequencies in the three directions are extremely close, the vibration signal in the Y direction is selected for further analysis.17

Figure 14 presents the time–frequency in the Y direction, and the analysis is as follows:

0–10 s: Startup phase. The coke pushing ram runs 2.95 m into the carbonization chamber and prepares to push the coke.

10–20 s: Coke pushing phase 1. At 10 s, the coke pushing ram begins to push the coke. At 12 s, coke pushing resistance reaches to a maximum, and the coke pushing ram is impacted. No obvious vibration occurs in the coke pushing ram in this phase.

20–50 s: Coke pushing phase 2. At 20 s, the slipper enters the carbonization chamber, and the coke pushing ram continues to push the coke; at 50 s, coke pushing process is completed. Serious vibration occurs in the coke pushing ram in this phase.

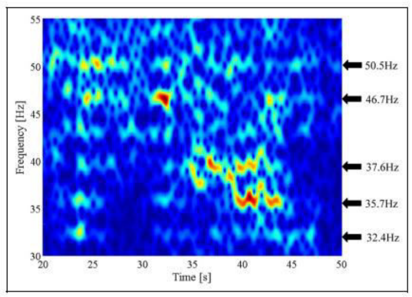

Figure 15. Time–frequency of area A.

Figures 13 and 14 indicate that vibration of the coke pushing ram is serious during the coke pushing process between 20 and 50 s, that is, vibration of the coke pushing ram occurs mainly after the slipper enters into the carbonization chamber, with the maximum amplitude of vibration in the Y direction reaching to 0.8 m/s2 . Therefore, the serious vibration in area A is selected to analyze the characteristics of vibration in the coke pushing ram.

Figure 15 shows the time–frequency of area A, it can be observed that the vibration frequencies mainly include 32.4, 35.7, 37.6, 39.7, 46.7, and 50.5 Hz, Which are close to the natural frequencies of 30.889, 36.499, 48.006, and 50.256 Hz, and different from exciting frequency of 2.8 Hz; moreover, the first order natural frequency is 1.846 Hz, which is also different from exciting frequency of 2.8 Hz, this indicates that self-excited vibration occurs in the coke pushing ram.18

Experiment results indicate that after the slipper enters the carbonization chamber, the vibration occurs in the coke pushing ram and the form of vibration is self-excited vibration, which proves the results of theoretical analysis.

Conclusion

The vibration characteristics of the coke pushing ram are investigated using theoretical analysis, numerical modeling, and actual testing in order to prevent vibration and its impact on the regular production of coke oven. The findings demonstrate that, in the low-velocity and heavy-load coke pushing operation, the coke pushing velocity is smaller than the crucial velocity following the slipper's entry into the carbonization chamber. This suggests that the coke pushing ram is where stick-slip vibration occurs. Furthermore, stiffness, damping, and the differential between the static and dynamic friction coefficients are the primary elements influencing the stability of the coke pushing ram. Moreover, lowering the critical velocity and so lowering the vibration of the coke pushing ram can be achieved by raising stiffness and damping, minimizing the difference between the static and dynamic friction coefficients, and so on.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study is supported by Key Technology Breakthrough Project of Coal Machine in Shanxi Province, China (grant number MJH2014-08).

References

1. G. J. Liang, C. X. Zhang, and Y. L. Li, "Experimental Study on Vibration and Noise Characteristics of Coke Oven," Journal of Mechanical Engineering, vol. 50, no. 6, pp. 79-85, June 2014.
2. L. R. Zhang and X. F. Li, "Dynamic Analysis and Optimization of Coke Pusher Mechanism," Mechanical Systems and Signal Processing, vol. 24, no. 4, pp. 1031-1040, April 2010.
3. J. C. Wang and D. H. Liu, "Vibration Control of Coke Pusher System Using Advanced Techniques," Journal of Vibration and Acoustics, vol. 136, no. 3, pp. 031005, July 2014.
4. H. Y. Zhang and M. S. Wu, "Study on the Dynamic Characteristics of Coke Oven Pusher Mechanism," Coal Preparation Technology, vol. 12, no. 2, pp. 53-60, February 2013.
5. X. Y. Chen and Z. X. Huang, "Analysis and Improvement of Coke Pusher Vibration Based on Finite Element Method," International Journal of Mechanical Sciences, vol. 55, no. 2, pp. 202-209, January 2012.
6. B. H. Liu and S. Z. Liu, "Investigation of the Vibration Characteristics of Coke Pusher Mechanism," Journal of Mechanical Design, vol. 132, no. 5, pp. 051003, May 2010.
7. C. Y. He and X. G. Zhang, "Nonlinear Vibration Analysis of Coke Oven Pusher System," Journal of Sound and Vibration, vol. 331, no. 10, pp. 2300-2312, December 2012.
8. J. L. Liu and Z. J. Yang, "Dynamic Analysis and Optimization of Mechanical Systems," Applied Mechanics Reviews, vol. 66, no. 5, pp. 050803, September 2014.
9. P. F. Zhang and J. Q. Gao, "Study on Stick-Slip Oscillations in Mechanical Systems," Journal of Tribology, vol. 131, no. 3, pp. 031401, July 2009.
10. H. T. Wu and L. H. Xu, "Vibration Analysis of Complex Mechanical Systems," Mechanism and Machine Theory, vol. 60, pp. 37-52, February 2013.
11. W. Y. Li and Y. H. Wang, "Investigation of Vibration Characteristics in Industrial Equipment," Journal of Vibration Engineering, vol. 27, no. 2, pp. 199-208, April 2015.
12. T. S. Lin and H. L. Chen, "Dynamic Characteristics and Vibration Control of Mechanical Systems," Journal of Mechanical Science and Technology, vol. 27, no. 4, pp. 1105-1115, April 2013.
13. F. R. Liu and C. H. Zhang, "Analysis of Stick-Slip Phenomena in Rotating Machinery," Journal of Sound and Vibration, vol. 332, no. 15, pp. 3683-3692, August 2013.
14. Y. L. Chen and J. S. Sun, "Dynamic Modeling and Vibration Analysis of Complex Mechanical Systems," International Journal of Mechanical Sciences, vol. 47, no. 9, pp. 1515-1527, September 2005.
15. X. W. Zhao and Y. T. Guo, "Vibration Analysis of High-Speed Rotating Machinery Using Wavelet Transform," Mechanical Systems and Signal Processing, vol. 19, no. 5, pp. 1165-1182, May 2005.

16. H. Q. Xie and Z. L. Liu, “Nonstationary Signal Analysis and Fault Diagnosis in Mechanical Systems,” Journal of Vibration and Acoustics, vol. 135, no. 5, pp. 051004, October 2013.
17. M. W. Yu and L. Y. Wang, “Time-Frequency Analysis of Nonlinear Vibrations Using Short-Time Fourier Transform,” Journal of Mechanical Engineering Science, vol. 228, no. 9, pp. 1532-1543, September 2014.
18. J. W. Zhang and L. Q. Wang, “Modal Analysis and Vibration Control of Complex Mechanical Structures,” Computers & Structures, vol. 132, pp. 84-94, February 2014.
19. L. S. Sun and M. G. Zhang, “Experimental and Theoretical Study of Vibration in Mechanical Systems,” Journal of Applied Mechanics, vol. 77, no. 1, pp. 011015, January 2010.
20. R. D. Li and J. H. Zhou, “Analysis and Control of Stick-Slip Oscillations in Mechanical Systems,” International Journal of Non-Linear Mechanics, vol. 67, pp. 139-148, August 2014.