Vibration Analysis of the Support Structure of the Raw Material Banana Sieve

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Abstract

A three-dimensional finite element model of a coupling system consisting of a raw material banana screen frame and equipment in an alumina refinery was established using the finite element method. Natural vibration characteristics of the plant structure and resonance re-examination were analysed. By adjusting the stiffness of the plant building, the loading weight of the banana screen, and the natural vibration frequency of the system, based on simulation calculations of the plant floor and measured dynamic responses, this study investigated the changes in the natural vibration frequency of the raw material banana screen and the corresponding stiffness requirements of the plant building after implementing spring and damping shock absorbers for vibration reduction. The results indicate that the use of spring and damping shock absorbers has significantly reduced the overall vibration frequency of the banana screen; however, floor vibrations within the resonance zone remain pronounced. In practical applications, it is recommended to increase the stiffness of the plant building to prevent resonance. These findings provide a solid foundation for the anti-vibration design of plant structures in the raw bauxite slurry grinding step of alumina production.

Keywords: Raw material banana screen, Natural vibration characteristics, Dynamic response.

1. Introduction

Ball mills and banana screens are both heavy-mass, high-frequency vibration equipment commonly used in the raw bauxite slurry grinding process of alumina refineries. During operation, they generate significant vibration and noises, which may pose structural safety issues and varying degrees of noise pollution, potentially endangering the physical and mental health of personnel [1, 2] and causing substantial economic losses. Therefore, strict vibration design standards are applied in the raw bauxite slurry grinding process. Since ball mills are placed directly on the foundation, vibration amplitude and the structural vibration response of the main building can be reduced through foundation treatment, adding base counterweights of equipment, separating the equipment foundation from the main building structure, and implementing vibration mitigation measures [3, 4]. However, due to process requirements, banana screens are often installed at elevated positions, and their operation areas frequently serve as key zones of personnel activity. Hence, investigating the causes of banana screen frame vibrations and exploring effective vibration mitigation methods are important topics that warrant thorough academic attention.

Taking the frame of a specific banana screen as a case study, this paper analyses the vibration reduction effects of dampers on the raw material banana screen and the structural response patterns to different vibration frequencies. Based on actual dynamic response measurements of the equipment floor slab, supplemented by software simulations, it provides a reference for anti-vibration design of banana screen frames.

2. Computational Model and Working Conditions

2.1 Computational Model

Based on an engineering example, a three-dimensional finite element model of the equipment floor of the banana screen frame was created according to actual dimensions. During the model establishment process, the floor slabs and shear walls were modelled using shell elements, the beams beneath the equipment floor and the frame columns were modelled using frame elements, and the banana screen was represented by mass sources applied at the centre of mass of the equipment, based on its normal operating weight. The bottom nodes of the frame columns and shear walls were fully fixed. The finite element model of the banana screen frame concrete structure is illustrated in Figure 1.

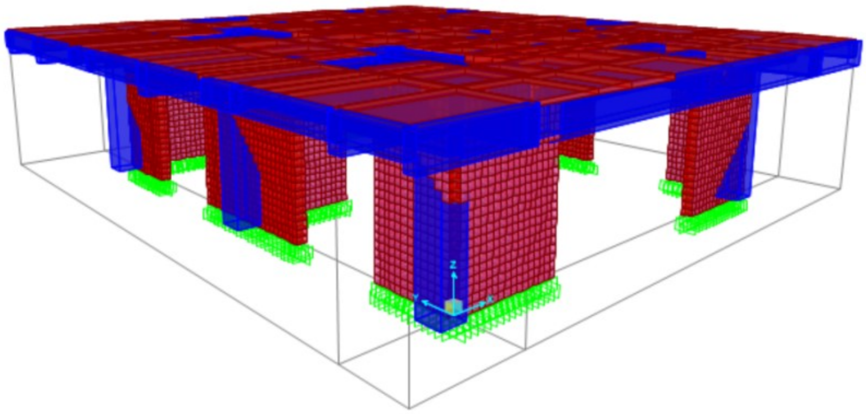

Figure 1. Finite element model of the banana screen frame concrete structure.

2.2 Working Conditions

The vibration characteristics of the banana screen frame were studied from the following aspects: (1) the vibration response behaviour of the equipment floor under varying operational frequencies of the banana screen; (2) the impact of vibration coupling and increased load when multiple banana screens are operated simultaneously, particularly in terms of vibration transmission; and (3) the influence of different loading quantities on vibration performance when the equipment operates at the same frequency. Detailed working conditions are presented in Table 1. The five working conditions listed correspond to different equipment and loading quantities, and include the natural vibration frequency of the banana screen during normal operation (15.6 Hz), as well as four reduced frequencies (14.66 Hz, 13.73 Hz, 12.2 Hz, and 11.5 Hz).

Table 1. Working conditions.

Nb of Operating Units	Loading quantities	Working Conditions
2	Normal	Conditions 1 to 5
	Full	Conditions 6 to 10
1	Full	Conditions 11 to 15

3. Natural Frequency and Resonance Re-examination of the Banana Screen Frame

First, the self-vibration characteristics of the banana screen frame structure were analysed using the modal analysis method to calculate the first 10 natural frequencies of the model. The first 20 natural frequencies are presented in Table 2. Specifically, the 10th mode corresponds to the vertical vibration of the middle floor slab, the 12th mode represents the vertical vibration of the equipment support beam, and the remaining 18 modes all indicate vertical vibrations of the concrete beams in the cantilever operation platform.

Table 2. Natural frequencies of the banana screen frame structure (Hz).

Mode	1	2	3	4	5	6	7	8	9	10
Freq	11.174	14.720	14.736	14.945	15.039	15.375	16.499	17.229	18.251	18.731
Mode	11	12	13	14	15	16	17	18	19	20
Freq	19.280	20.302	21.657	21.909	22.299	23.575	26.960	27.908	29.655	32.733

The natural frequencies of the banana screen equipment adjusted by frequency converters under operating conditions are shown in Table 3. The selected measurement points in this study include the cantilever beams, mid-span floor slabs, and equipment support beams that exhibit noticeable vibration in the 1st, 10th, and 12th vibration modes. Among these structural components, the natural frequencies of the mid-span floor slabs and equipment support beams differ by more than 20 % from the vibration frequencies of the banana screen under various operating conditions. In contrast, the difference between the first natural frequency of the cantilever beams and the vibration frequency of the banana screen remains within 20 % in most operational scenarios. Therefore, it can be concluded that the mid-span floor slabs and equipment support beams are unlikely to experience resonance, whereas the cantilever beam structures may be susceptible to resonant vibrations.

Table 3. Operating frequencies of banana screen equipment (Hz).

Condition	1,6,11	2,7,12	3,8,13	4,9,14	5,10,15
Freq	15.6	14.66	13.73	12.2	11.5

4. Vibration Behaviour of the Banana Screen Frame

The banana screen equipment is connected to the frame equipment floor via spring shock absorbers and damping shock absorbers. As the vibration load and frequency of the equipment pass through these shock absorbers, they are effectively reduced. Based on the resonance analysis of the equipment floor structure as above, it can be concluded that the frame will not experience resonance in the middle span floor or the equipment support beam structure; however, resonance may occur in the cantilever beam structure. To assess this, vibration testing of the banana screen frame was carried out. The vibration response characteristics of the banana screen frame structure were analysed by examining variations in vibration responses, specifically displacement amplitude and velocity, under different operating conditions. The cantilever beam structure, middle span floor, and equipment support beam were designated as measurement points 1, 2, and 3, respectively.

The vibration measurement results at Points 1 to 3 indicate the following that under operational loads, the banana screen frame primarily exhibits significant vertical vibration responses, while longitudinal and transverse vibrations are relatively minor. At Points 1 and 2, the horizontal displacement amplitude is approximately 30 % of the vertical displacement amplitude. At Point 3, the horizontal displacement amplitude is comparable to the vertical. The horizontal vibration velocity at Point 1 is only about 15 % of the vertical velocity, while at Points 2 and 3, the horizontal vibration velocity is approximately 30 % of the vertical.

4.1 Impact of Different Frequencies

By analysing the vertical vibration velocity and displacement amplitude at measurement points 1 to 3 during normal and full-load operation of the banana screen at various frequencies, the following conclusions are drawn:

(1) As the operating frequency of the banana screen decreases, both the vibration velocity and displacement amplitude at measurement point 1 show abrupt increases and decreases. Subsequently, as the operating frequency continues to drop, the vibration response of the banana screen frame decreases (see Figures 2 and 3). This indicates that the load frequency passed through the resonance zone of measurement point 1. Once the operating frequency deviated from the structure's resonance zone, the vibration response of the structure declined. The vertical vibration velocities at measurement points 1 and 2 exceed 10 mm/s within the resonance range, surpassing the limits defined in the "Standard for Allowable Vibration in Building Engineering" [5] for general industrial buildings and office areas in terms of human comfort.

(2) The vibration responses of measurement points 2 and 3 exhibit the same trend as that of measurement point 1 with respect to changes in equipment frequency. Since the frequency variation does not traverse the resonance zones of these measurement points, the vibration responses remain at 25–30 % of the levels observed at measurement point 1.

(3) At measurement point 1 (with a natural frequency of 11.17 Hz), both the vibration velocity and displacement amplitude peaked under Working Conditions 2 and 7 (operating frequency of 14.66 Hz), showing significant resonance. It can be concluded that the spring shock absorbers and damping shock absorbers installed beneath the banana screen equipment have significantly reduced the equipment's vibration frequency, decreasing the vibration load frequency by approximately 25 %.

In summary, under varying frequency loads, the vibration response trends of measurement points 1 to 3 exhibit a consistent pattern. However, measurement point 1, being located within the structural resonance range during variable frequency operation, experiences more pronounced response variations.

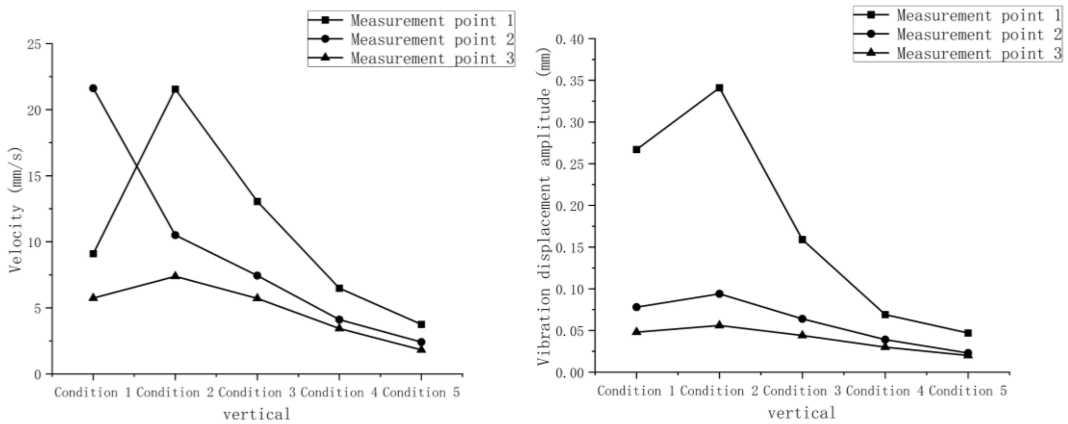

Figure 2. Vertical vibration response at each measurement point under different frequencies with equipment normally loaded.
Left: vibration velocity, Right: vibration displacement amplitude.

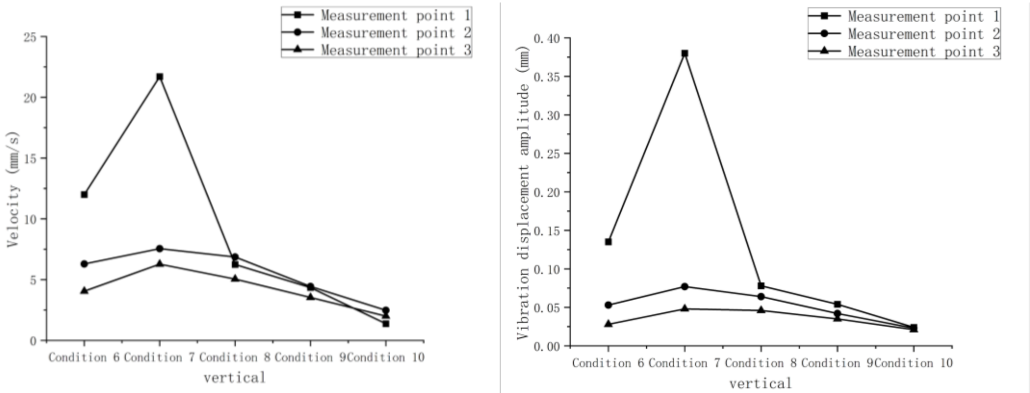

Figure 3. Vertical vibration response at each measurement point under different frequencies with equipment fully loaded.
Left: vibration velocity, Right: vibration displacement amplitude.

4.2 Effect of Operating Mass

By analysing the vertical vibration velocity and displacement amplitude at measurement point 1 under normal and full-load conditions at different frequencies, the following is observed:

(1) The operating frequency of the banana screen equipment decreases from high to low under varying loading quantities. The vibration velocity and vibration displacement amplitude at measurement point 1 exhibit a consistent variation trend, as illustrated in Figure 4. With an increase in the equipment's loading quantity, the vertical vibration response of the structure becomes more pronounced.

(2) Within the resonance range, the vertical vibration response of the structure intensifies as the equipment's material loading increases. When the equipment operates at full load, the amplitude of structural vibration displacement is 11.4 % higher compared to normal operating conditions. In contrast, within the non-resonance frequency range, the vertical vibration response under full-load operation is reduced by 10–50 % relative to normal operating conditions.

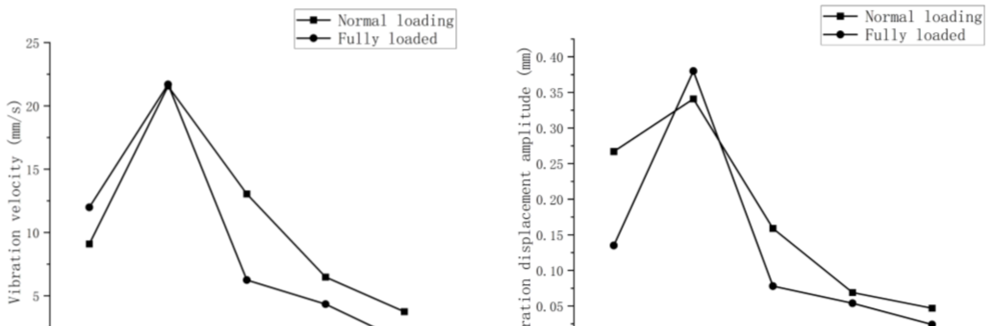

Figure 4. Vertical vibration response at measurement point 1 under different frequencies and loading conditions. Left: vibration velocity, Right: vibration displacement amplitude.

In conclusion, as the loading quantity increases, the vibration response of the structure exhibits a consistent trend across varying operational frequencies. The increase in equipment mass leads to a rise in the structural natural frequency, resulting in a reduction in vibration response outside the resonance range. Within the resonance range, however, the increased equipment mass results in higher resonance energy, thereby amplifying the structural vibration response by 11 %.

4.3 The Influence of Number of Operating Units

It can be inferred from the analysis of the vertical vibration velocity results at measurement point 1 that, when varying quantities of banana screen operate under normal conditions at different frequencies, the following observations can be made:

When a single banana screen is operating under normal conditions, the resonance frequency at measurement point 1 is higher than when two banana screens are operating simultaneously (as illustrated in Figure 5). Additionally, the vertical structural response within the resonant frequency range is greater compared to the case where both machines are operating normally. However, in the non-resonant frequency range, the structural response is reduced due to the lower vibration mass and energy, with the response of a single machine accounting for only 25–40 % of that observed when both machines are in operation.

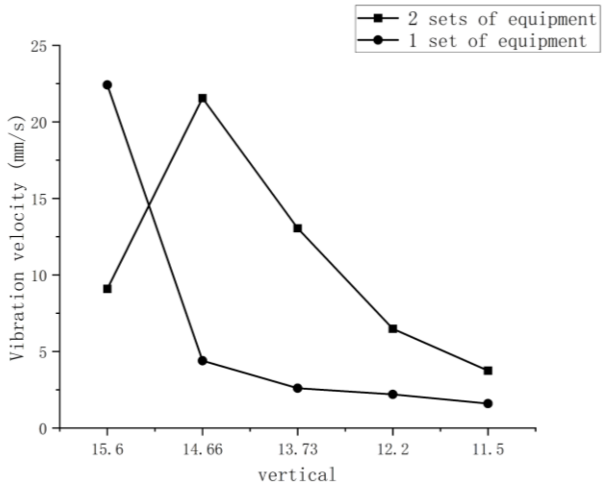

Figure 5. Vertical vibration velocity at measurement point 1 under different frequencies with different number of screens operating normally.

5. Conclusions

(1) The frame structure of the banana screen demonstrates a predominant vertical vibration response under the operational load of the equipment, while longitudinal and lateral vibration responses remain relatively minor, with the horizontal vibration response amounting to approximately 30 % of the vertical vibration response.

(2) Spring shock absorbers and damping shock absorbers can reduce the vibration frequency of banana screening equipment by approximately 25 %.

(3) When the banana screen and its supporting frame resonate, the vibration response of the structure can become significantly amplified. Prolonged resonance may compromise the safety and well-being of on-site personnel. In practical design, it is essential to enhance the rigidity of the main structure and regulate the natural vibration frequencies of structural components to ensure they remain above the resonance range of the banana screen equipment.

6. References

1. *Standard for Design of Dynamic Machine Foundations* – GB 50040-2020 (in Chinese).

2. *Standard for Vibration Control Design of Industrial Buildings* – GB 50190-2020 (in Chinese).
3. *Code for Calculation and Vibration Isolation Design of Bearing Structures of Buildings under Mechanical Dynamic Load* – YBJ 55-90 (in Chinese).
4. *Code for Design of Vibration Isolation* – GB 50463-2008 (in Chinese).
5. *Standard for Allowable Vibration in Building Engineering* – GB 50868-2013 (in Chinese).