FAULT DIAGNOSIS OF EXCESSIVE PIPE VIBRATION DUE TO BEATING PHENOMENON

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Abstract: This paper presents a case study in diagnosing an excessive pipe vibration due to beating phenomenon. The outdoor process pipes in a sewage plant were found to vibrate viciously and resulted in emitting loud hamming noise that affecting the surrounding community. The process pipes were connected to two identical blower units, each driven by a motor via belt and pulley system. Besides the loud noise, the excessive pipes vibration had also posed a concern to the plant personnel that a possibility of premature machine failures may occur if the problem persists any longer. A comprehensive vibration investigation was conducted to map-out the vibrations of the entire machine train that includes pipes, blowers, motors, skid, plinth and floor slab of the blower house. Vibration investigation found that pipes vibration was most severe when the two units of blowers were operated simultaneously. It was found that the root cause of the excessive pipe vibration was caused by beating phenomenon of which two adjacent machines operated under slightly different speeds. In this case, the two blowers were operated at 41.88Hz and 41.72Hz respectively. Beating is a phenomenon of constructive and destructive interference of two identical waveforms with slightly different frequency. As such, the remedy measure undertaken was thus to fine tune the operating speed of the two blowers. It was found that pipes vibration had subsided considerably when the two blowers' speeds were adjusted to be 7.5 Hz apart. As a result, the loud humming noise emitted from the pipes was noted to be completely mitigated with the remedial action taken.

Keywords: Pipe; beating; vibration

1. Introduction

This paper presents a case study on noise and vibration investigation that had conducted at a sewage treatment plant in Malaysia. The outdoor process pipes in the sewage plant were found vibrated viciously and thus resulted in emitting loud hamming noise affecting the residential houses nearby. Besides the loud noise, the excessive pipes vibration had also posed a concern to the plant personnel that a possibility of premature machine failures may occur if the problem persists.

Our initial investigation found that the noise originated from the sewage treatment plant has spilled to the environment primarily via the severely vibrated pipe that connected to the two blower units inside the blower house. The process pipes that connected to the two identical blower units were driven by motors via a pulley system. Besides this, the air-borne noise from the operation of the machines inside the blower house was also noted to have escaped and spilled to the environment via the exhaust and fresh air openings of the plantroom. However, the air-borne noise originated from the internal of the plantroom was found to be less severe or prominent as compared to the humming noise from the outdoor process pipe.

The objective of the investigation is to identify the root causes of the severe pipe vibration and thus provided recommendations on the remedial actions needed to resolve the problem.

2. Measurement Strategy and Procedure

Noise and vibration measurements were conducted to confirm the characteristics of the prevailing pipes vibration before any remedial works were to be performed at site. The noise and vibration measurement were carried out at the interior and the exterior of the blower house. The locations of measurement at the blower house and at the blower units itself were shown in Figure 1 and Figure 2 respectively. In short, the vibration measurement undertaken measured vibration levels of the blower house walls and floor, pipes that connected to the blowers, blower units, motors, skid, and plinth.

The measured vibration spectrum of the machines were used to identify the dominant vibration frequency peaks associated to the blowers and piping. The vibration investigation focused on identifying the root cause of excessive pipes vibration when two units of blowers (Blower 2 and 3) were ran at the same time.

Controlled tests by switching on and off the different units of blowers, and by changing the operating speed of the blowers were also carried out on site. This is conducted in order to understand the cause and effect of the changes in blower operation to the resulted vibration (and noise) levels of the machines and its connected pipes.

On top of this, ambient noise levels at the property boundary of the plant were also measured during the controlled tests. Noise measurements using a Class 1 sound level meter was deployed throughout the entire investigation work.

Point	Description
1	Wall
2	Wall
3	Wall
4	Wall
5	Floor
6	Floor
7	Floor
8	Floor
9	Pipe (Large)
10	Pipe (Small)

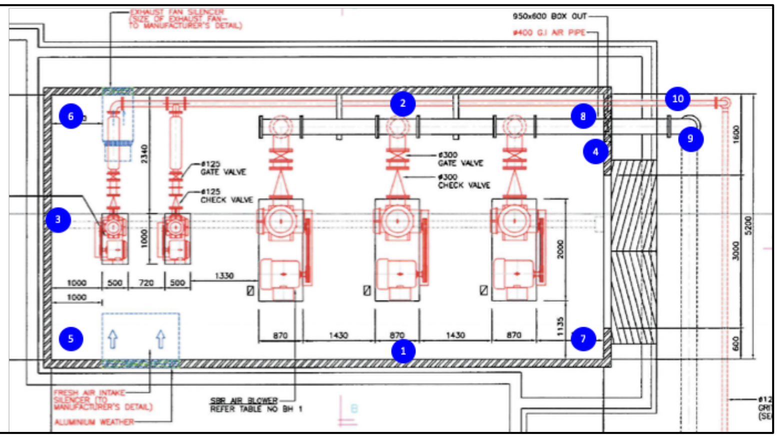


Figure 1: Vibration measurement locations at the blower house

Point	Description
1	Motor Footing
2	Blower Footing
3	Before Air Bellow (Blower Side)
4	After Air Bellow
5	Pipe (U-clamp Support)
6	Pipe (Flange)
7	Plinth
8	Raised Floor
9	Floor

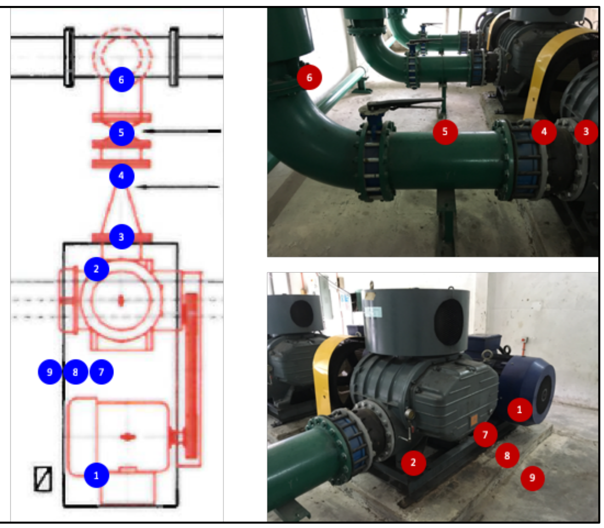


Figure 2: Vibration measurement locations at the blower units

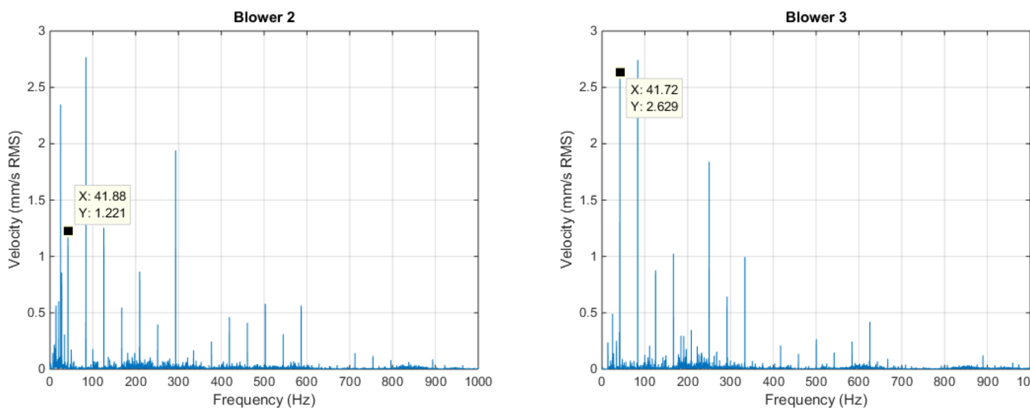
3. Results and Discussion

Table 1 tabulates the noise levels measured before the remedy works were performed at site. The noise level at the SBR Tank area was noted to have increased by 16 dB when two blowers were simultaneously ran as compared to the case with only one blower ran at a time. The increase of 16 dB can be interpreted as three times louder as perceived by the receivers.

Table 1: Noise levels at interior and exterior of the blower plantroom

Location	Single Blower in Operation	Two Blowers in Operation
Blower House (Exterior)	69 dBA	82 dBA
SBR Tank	67 dBA	83 dBA
Plant Boundary	63 dBA	71 dBA

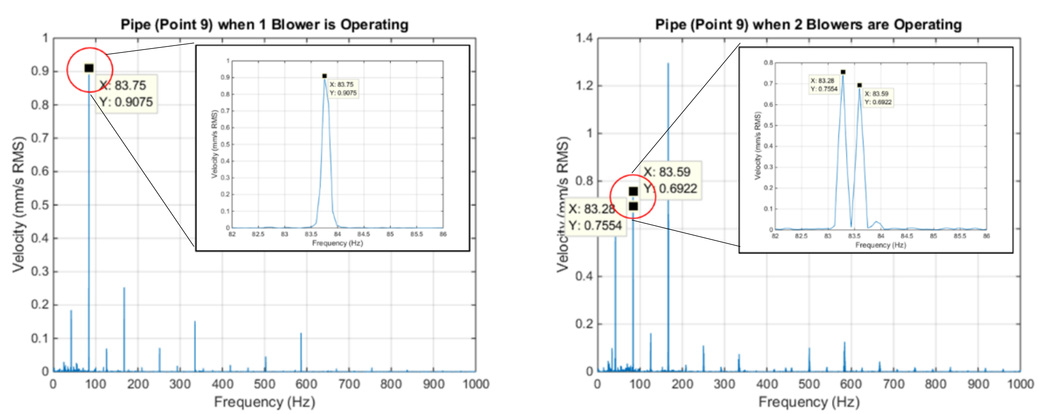
Figure 3 illustrates the vibration spectrum measured when Blower 2 and 3 were set to run discreetly or one at a time. It was found that when the two machines were set to run discreetly, the vibration peaks as seen in Figure 3 were mainly governed by the harmonics of its own operating frequency that is at 41.88Hz and 41.72Hz respectively.



(a) Vibration spectrum of Blower 2 b) Vibration spectrum of Blower 3

Figure 3: Vibration spectrum measured at (a) Blower 2 and (b) Blower 3

Figure 4 illustrates the vibration spectrum of outdoor pipe (Point 9) with single blower and two blowers ran simultaneously. It was found that the zoom-in vibration peak at 84Hz (the second harmonics of the blower's operating speed) was actually made out of two discreet vibration peaks of 83.26Hz and 83.59Hz when two blowers were ran simultaneously.



(a) Single blower ran b) Two blowers ran

Figure 4: Vibration spectrum of pipe with single and two blowers ran simultaneously

Beating phenomenon can be observed when two machines are operating at approximately but not exactly the same speed. In this case, the two blowers (Blower 2 and 3) were ran at 41.88Hz and 41.72Hz respectively. Beating is known to cause by the constructive and destructive interference of two sinewaves due to slight phase difference. Figure 5 illustrates an example of a beating wave. Beating phenomenal is widely reported in many engineering structures and machinery such as in large floating structure [1] and also in a smaller machinery such as in motor [2]. The characteristics and phenomenon of beating was also well documented in many vibration handbooks [3] and machinery diagnostic books [4].

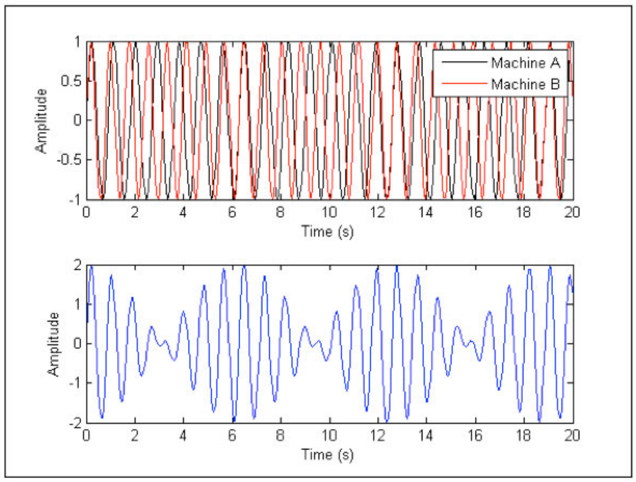


Figure 5: Example of a beating wave.

A control test was conducted by deliberately switched on Blower 2 and 3 by stages and at the same time the vibration response of the outdoor pipe (Point 9) was measured. Figure 6 depicts the vibration spectrums measured during the transition period of a single blower ran to two blower ran simultaneously. Beating wave can be clearly observed after the second blower was switched on and stabilised. The waveform of the two-blowers-ran was noticed to exhibit the characteristics of beating waveform as showed in Figure 5. Figure 6 illustrates the vibration spectrum of the beating waveform. A zoomed-in displays of the individual peak in the vibration spectrum revealed that there were actually formed by two or more individual peak which corresponding to the harmonics of the operating frequencies that triggered the beating process in the pipes.

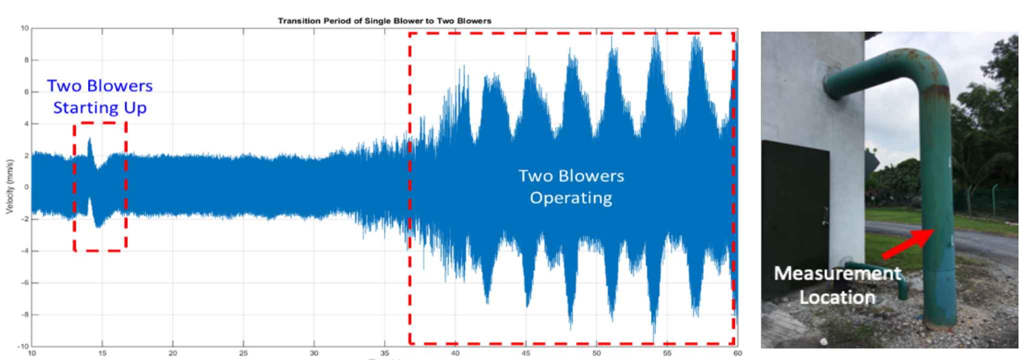


Figure 5: Vibration spectrums of the transition of single blower to two blowers' operation

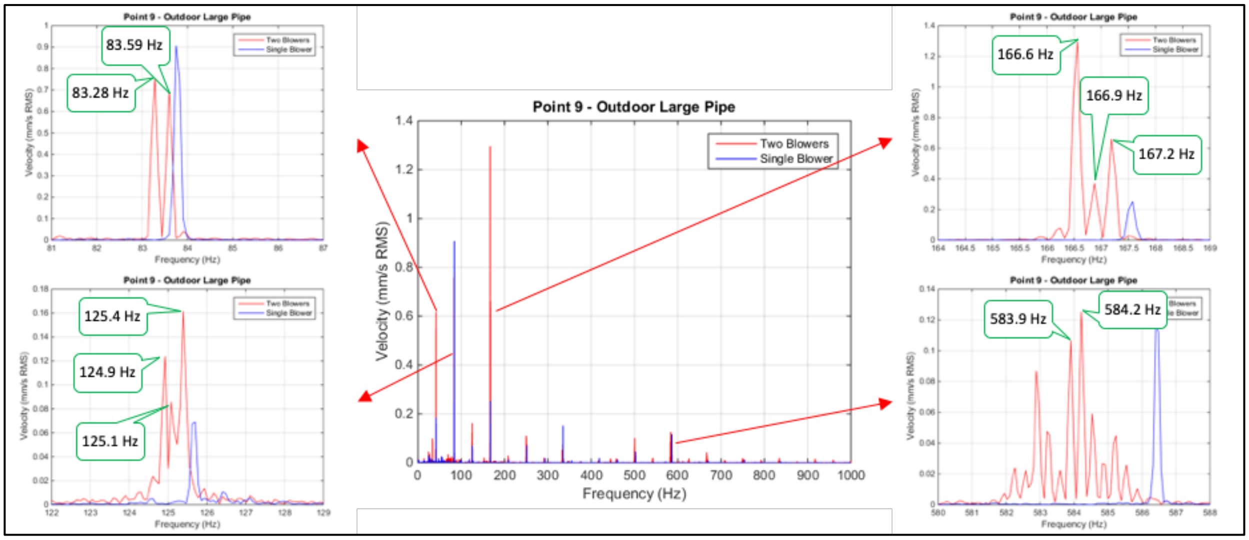


Figure 6: vibration spectrum of the beating waveform with zoomed in displays

4. Remedial Actions Proposed and Implemented

Based on these evidences, beating phenomenon was confirmed to be the root cause of the excessive noise and vibration occurred to the process pipes outdoor.

Beating can be mitigated by avoiding the presence and interaction of two or more closely spaced frequency peaks that transmitted to the same structure. As such, the remedial measure proposed in this study was to fine-tune the operating speeds of the two blowers to be either perfectly matched or reasonably far apart to eliminate the sources of the vibration waveforms that enable beating.

Subsequently, a second controlled test was carried out in the attempt to fine-tune the operating speeds of the two blowers. In short, the operating speed of Blower 2 were gradually increased from 40Hz to 50Hz while the operating speed of Blower 3 was maintained at 50Hz (and in one case at 45Hz). The corresponding vibration response of the outdoor pipe was measured and recorded for comparisons.

Table 2 provides the resulted pipe vibration levels in correspondence to the changes in blower operating speeds. It was noted that piping vibration reduced significantly under the most optimised operating speeds. It was found that the most optimised operating speed of the two blowers was when the difference of the operating speed were 7.5Hz apart or the two blowers were set to run at 42.5Hz and 50Hz respectively. The vibration levels of pipes reduced from 23.31 mm/s under the worst case scenario to only 10.91 mm/s under the most optimised operating condition.

Table 2: Pipe vibration levels in correspondence to the changes in operating speeds

Blower 2 and 3 Operating Speeds	pk-pk Vibration (mm/s)
50.0Hz & 50.0 Hz (Beating)	23.31
42.5Hz & 45.0Hz	14.10
42.5Hz & 50.0Hz	10.91
43.5Hz & 50.0Hz	12.15
44.0Hz & 50.0Hz	51.70
45.0Hz & 50.0Hz	12.64

5. Noise and Vibration Levels After the Remedial Actions Taken

Noise levels of before and after the remedial action at the exterior of the blower house were given in Table 3. It was found that the noise levels measured before remedial action was about 82 dBA. After the remedial action (by operating the Blower 2 and 3 at 42.5Hz and 50Hz), the resulted noise levels were about 73 dBA. This represents a significant 9 dB reduction, in which can be subjectively perceived as twice as quiet based on the subjective perception of loudness for human being.

Table 3: Comparison of noise levels before and after remedial actions

	Before Remedy Action	After Remedy Action
Noise Level at Blower House (Exterior)	82 dBA	73 dBA

Beside this, the vibration level of the pipes with two simultaneous blowers run was also noted to reduce significantly and matched the vibration level of a single discreetly run blower after the remedial action taken.

6. Conclusion

This paper provides a case study on beating phenomenon that occurred in process pipes which connected to two identical machines that ran under a slightly different operating speeds. It was shown that beating phenomenon can be identified with a comprehensive vibration investigation study. As beating is a phenomenon of constructive and destructive interference of two identical waveforms with slightly different frequencies, the remedy action undertaken was thus to fine-tune the operating speeds of the machines to eliminate the sources of the vibration waveforms that enable beating. This paper showed that beating in pipes can be effectively mitigated by fine-tuning the operating speeds of the machines.

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