Purdue University
Purdue e-Pubs

International Compressor Engineering Conference | School of Mechanical Engineering

2016

Vertical-Vibration Suppressing Design of Accumulator with New Vibration-Measuring Method

Hikaru Wada
DAIKIN INDUSTRIES,LTD, Japan, hikaru.wada@daikin.co.jp

Hideki Matsuura
DAIKIN INDUSTRIES,LTD, Japan, hideki.matsuura@daikin.co.jp

Satoru Takanezawa
DAIKIN INDUSTRIES,LTD, Japan, satoru.takanezawa@daikin.co.jp

Ayumi Ogawa
DAIKIN INDUSTRIES,LTD, Japan, ayumi.ogawa@daikin.co.jp

Vertical-Vibration Suppressing Design of Accumulator with New Vibration-Measuring Method

Hikaru Wada[1]*, Hideki Matsuura[2], Satoru Takanezawa[3], Ayumi Ogawa[4]

[1]*Technology and Innovation Center, Daikin Industries, Ltd.
1-1, Nishi-Hitotsuya, Settsu, Osaka, 566-8585, Japan
(Phone: +81-6-6195-7074, hikaru.wada@daikin.co.jp)

[2]Technology and Innovation Center, Daikin Industries, Ltd.
1-1, Nishi-Hitotsuya, Settsu, Osaka, 566-8585, Japan
(Phone: +81-6-6195-7074, hideki.matsuura@daikin.co.jp)

[3]Technology and Innovation Center, Daikin Industries, Ltd.
1-1, Nishi-Hitotsuya, Settsu, Osaka, 566-8585, Japan
(Phone: +81-6-6195-7074, satoru.takanezawa@daikin.co.jp)

[4]Daikin Device Suzhou Co., LTD.
256, Chang Yang Street Suzhou Industrial Park,
Suzhou, 215126, China
(Phone: +86-512-6283-8668, ayumi.ogawa@daikin.co.jp)

*Corresponding Author

ABSTRACT

A compressor was developed using R32 which was a low GWP R32 refrigerant for coping with global warming. However, there is a tendency for vibrations of a compressor to also increase because the circulation of refrigerant increases according to specification for using R32 refrigerant. Since large vibrations of a compressor causes outdoor units to generate solid propagation sound, there is a need for a technology that can reduce vibration of a compressor. However, a vibration-measuring method to analyze such vibration had not been fully developed and it was difficult to specify the cause. Accordingly, a new vibration-measuring method was developed specifically for compressors. The use of this measuring method allowed to discover that one of the unresolved problems with sound of outdoor units was the vertical vibration of the accumulator housed in the compressor. Moreover, it was found that the accumulator vibrates vertically due to the acoustic resonance inside the casing, which led to develop a new (accumulator) design with a focus on resonance. There is a type of spatial resonance inside an accumulator that has a phase difference with the antinode of sound pressure appearing at the upper and lower ends of the space. The vertical force caused by the difference in the sound pressure becomes excitation force, which then causes vertical vibration of the accumulator. Therefore, preventing this resonance from occurring can help suppress the vertical vibration. In order to prevent the generation of resonance, a plate-shaped reflection member was placed inside the accumulator, and it proved to be effective in suppressing the vertical vibration.

1. INTRODUCTION

A compressor was developed using R32 which was a low GWP R32 refrigerant for coping with global warming. There is a tendency for vibrations to also increase because the circulation of refrigerant is increase according to specification for using R32 refrigerant, so there is a need for a technology that can reduce such vibration. However, it was difficult to identify the cause because a method to support compressors during measurement of vibrations had not been fully developed.

Accordingly, a measuring method that can analyze vibrations was developed that does not inhibit the compressor movement via the use of a flexible support. In this report, we describe the method of measuring compressor vibrations that uses a flexible support and introduce a case that used this new method to develop a vibration-suppression seed.

2. VIBRATION-MEASURING METHOD FOR COMPRESSORS AND THE ISSUE

One of the issues with the outdoor unit was the sound caused by vibrations of the compressor housing. For example, it is shown that the same compressor was mounted in an outdoor unit to concurrently measure the vibration of the compressor and the sound from the outdoor unit. Figure 1 shows a contour map of 1/3 octave band sound from the outdoor unit and Figure 2 shows the overlaid acceleration spectrums of acceleration vertical vibration of the accumulator. The accumulator is hereafter referred to as "Accm.". Figure 2 shows a graph with a focus on the vertical vibration of the Accm, on which the vibration-acceleration spectrum per compressor rotation was overlaid on a single sheet. In this case, the outdoor unit generated a loud sound in the 500 Hz band, which indicated that the Accm vertical vibration was the cause of the sound from the outdoor unit.
Meanwhile, before we conducted the sound and vibration test on the outdoor unit, also conducted the vibration test on the compressor alone. Figure 3 is a picture showing the state of vibration of a compressor alone being evaluated with the conventional method. Suction piping was connected to the copper facility piping and discharge piping to the iron refrigeration piping, and the legs were placed on rubber support legs. A handy vibrometer and acceleration sensor were placed so that they come in contact with the compressor and piping surfaces to measure vibrations. Figure 4 shows a graph with a focus on the vertical vibration of the Accm, on which the vibration-acceleration spectrum per compressor rotation was overlaid on a single sheet. Unlike the vibration test on the outdoor unit, the vertical vibration significantly decreased in the 500 Hz band when the compressor was evaluated alone.
This suggests that there were cases in which the compressor vibration, the cause of the sound from the outdoor unit, could not be properly evaluated with the conventional vibration-measuring method for a compressor alone.

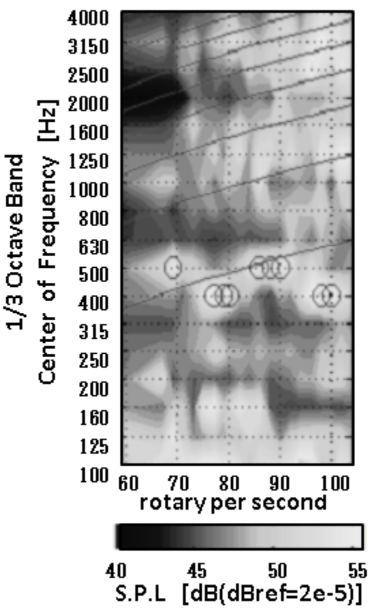

Figure 1: Contour map of 1/3 octave band sound from an outdoor unit

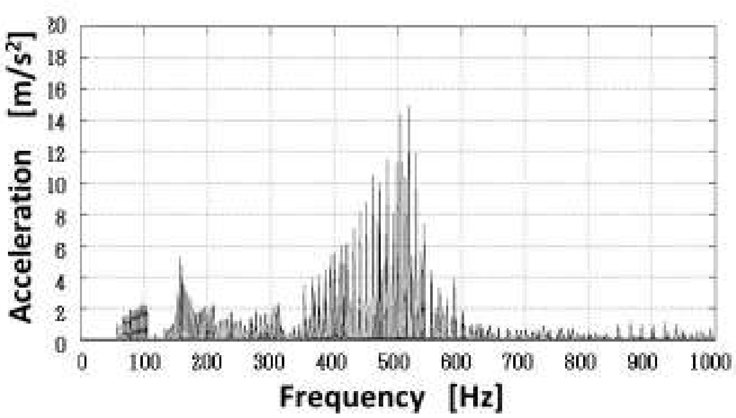

Figure 2: Overlaid acceleration spectrums of Accm vertical vibration when mounted in an outdoor unit

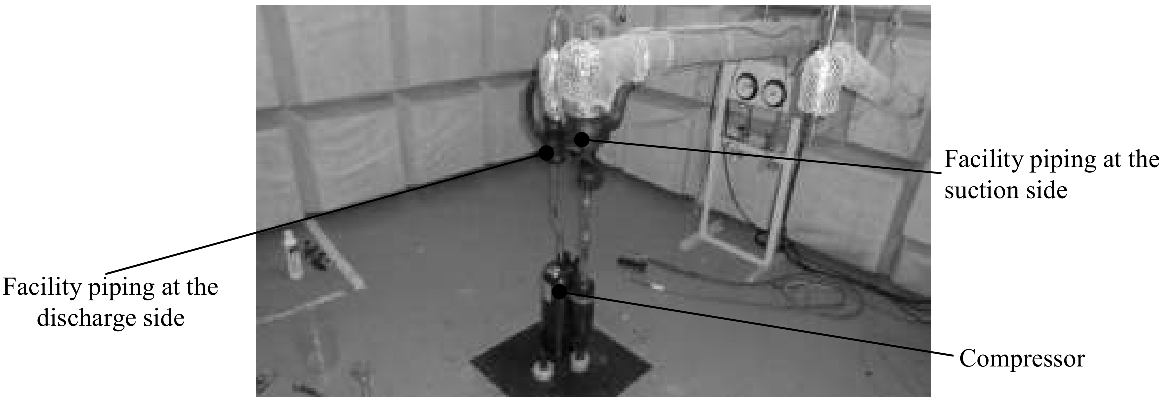

Figure 3: Evaluation of vibrations of a compressor alone: Conventional method

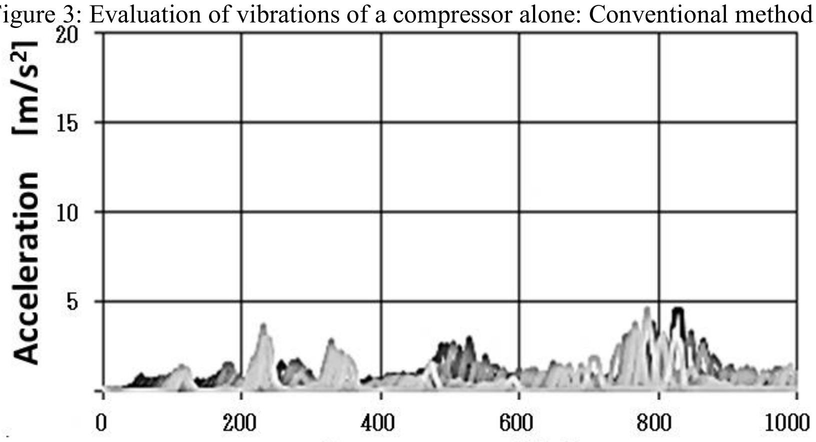

Figure 4: Overlaid acceleration spectrums of Accm vertical vibration of a compressor alone

3. Vibration-measuring method for compressors

3.1 Flexible support structure

As the reason for the difference described in Section 2, we considered smaller compressor vibrations due to the large piping mass and high support rigidity associated with the equipment to measure the vibrations of the compressor alone. This led to develop a new vibration-measuring method that incorporates a flexible support. Figure 5 shows vibration of a compressor being evaluated by the new vibration-measuring method.

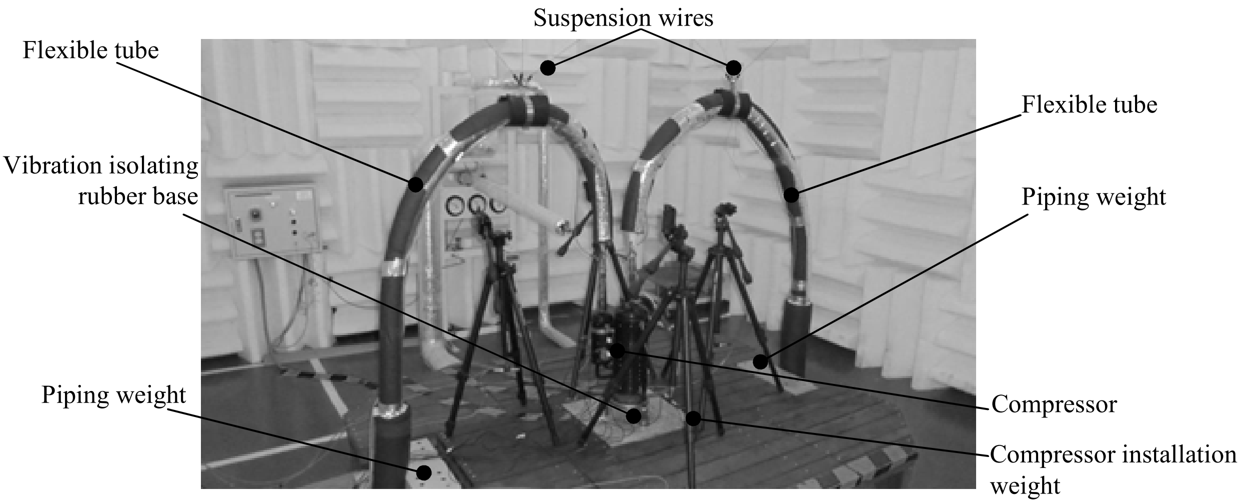

Figure 5: Evaluation of vibrations of a compressor alone: New method

The following describes the effect of each part.

- Flexible tube: Supports the compressor flexibly.
- Piping weight: Places approximately 150 kg of mass onto the connection between the flexible tube and system piping in order to isolate the vibrations from the system piping.
- Suspension wire: Prevents the gravity of the flexible tube from being applied onto the compressor. Has a tension adjustment mechanism to allow for the evaluation of compressors with different heights.
- Compressor installation weight: A foundation with approximately 200 kg of mass to prevent the ground vibrations from being transmitted to the compressor.
- Vibration-isolating rubber base: An increase in the compressor vibrations due to the use of a flexible support may cause the compressor to fall down. Therefore, the base is fixed to the installation weight to allow for testing to be conducted safely.

3.2 Confirmation of the effects

As described in Section 2, the vertical vibration was measured while flexibly supporting the compressor. Figure 6 shows the overlaid acceleration spectrums of the Accm vertical vibration. The flexible support enabled the measurement of previously difficult-to-measure vertical vibrations of an Accm.

4. Development of a compressor that suppresses the vertical vibration of an Accm

4.1 Assumption of a mechanism that generates vertical vibration

In order to specify the cause of 500 Hz vertical vibration of an Accm examined in Section 3, an acoustic eigenvalue analysis was conducted on the Accm internal space. Figure 7 shows the results of the eigenvalue analysis on the Accm internal space. It was found that there were acoustic modes in the 500 Hz band with the antinode appearing at the top and bottom and the node appearing in the center of the Accm.

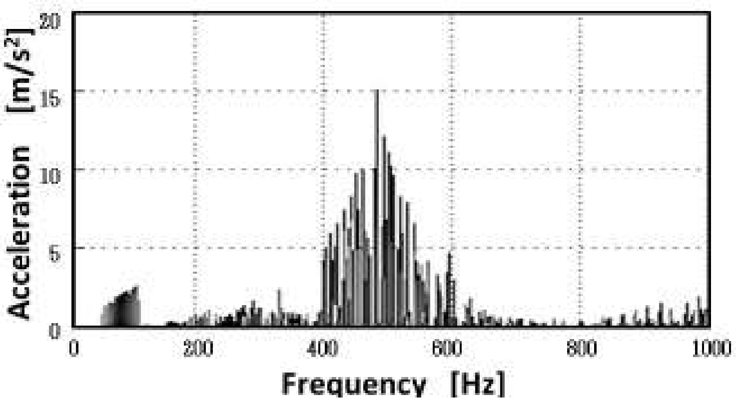

Figure 6: Overlaid acceleration spectrums of the Accm vertical vibration of a compressor alone: New evaluation method

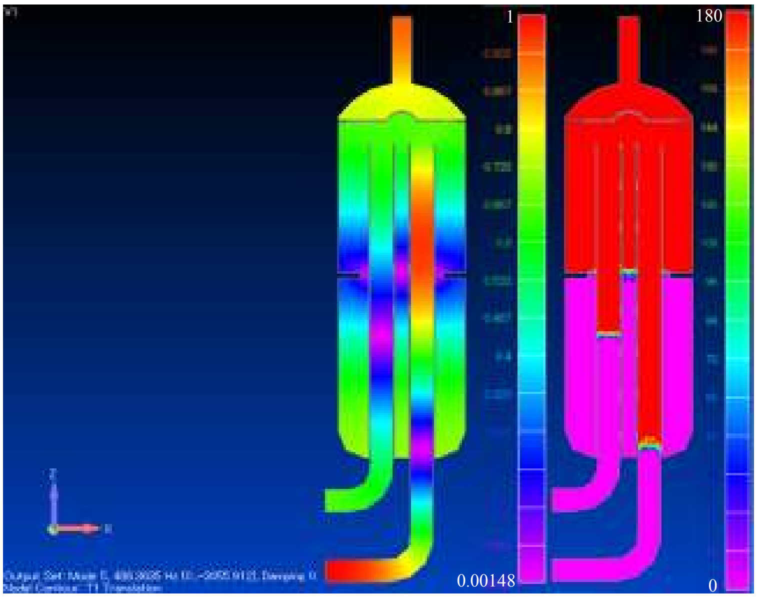

Figure 7: Acoustic eigenvalue analysis of the Accm internal space

In addition, the vibration and internal pressure of the Accm were concurrently measured. For the measurement of internal pressure, pressure sensors were inserted on the top and bottom of the Accm, and the pressure difference was calculated to determine the excitation component that vibrates the entire casing. Figure 8 shows the overlaid acceleration spectrums of the Accm vertical vibration and Figure 9 shows the overlaid pressure difference from top of Accm to bottom of Accm spectrums and the phase difference. These figures show that the peak of the vertical vibration roughly coincides with the peak of the pressure difference. They also show that the phase lag occurs in the band frequencies where the peaks are observed, which demonstrates that the spatial mode exists as indicated by the results of the eigenvalue analysis.
Therefore, it was shown that the pressure difference due to the acoustic mode that exists in the 500 Hz band acts as excitation, causing the vertical vibration.

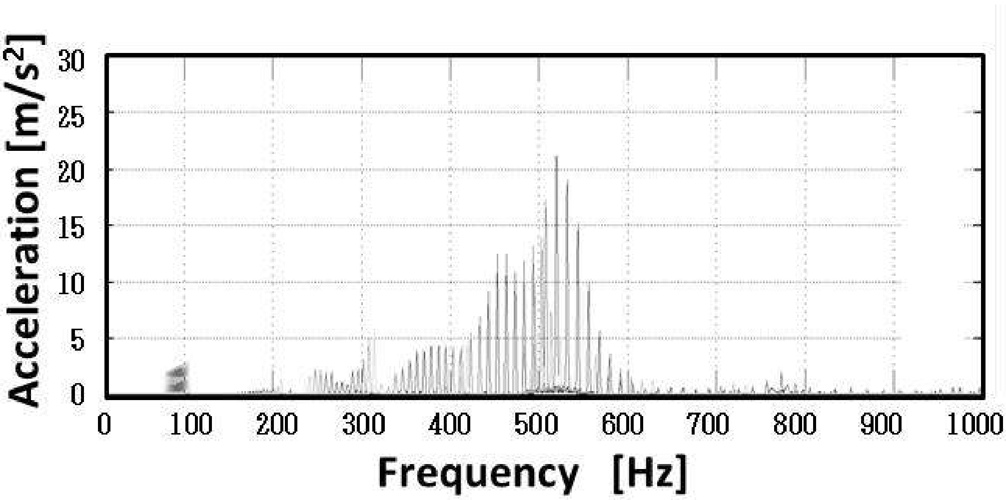

Figure 8: Overlaid acceleration spectrums of the Accm vertical vibration

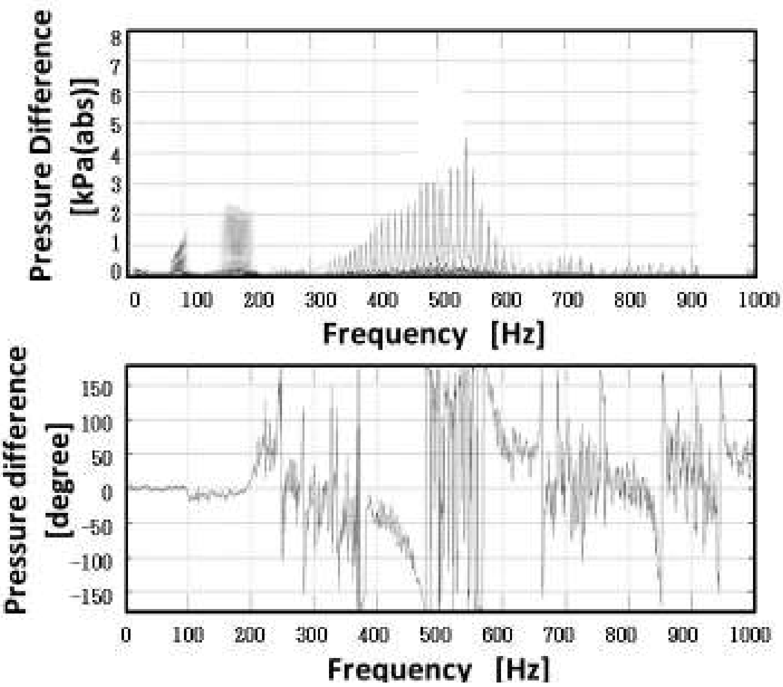

Figure 9: Pressure differences between the top and bottom of the Accm
(Upper: Overlaid amplitude differences; Lower: Phase differences)

4.2 Accm with a countermeasure against vertical vibration

Figure 10 shows the cross-sectional views of a conventional Accm and an Accm equipped with a countermeasure against vertical vibration of the Accm. In consideration of reduction of the mode excitation, a part that prevents pressure fluctuations ("countermeasure part" in the figure) was attached to the antinode of the acoustic mode inside the Accm.

To verify the effect (of the countermeasure part), the acoustic response analysis was conducted on the conventional Accm and countermeasure Accm. Figure 11 shows the excitation of the acoustic pressure point and response point at the acoustic response analysis and Figure 12 shows the results of the analysis.

It was shown that the pressure fluctuations caused by the acoustic mode in the 500 Hz band at the suction side was reduced in the countermeasure Accm to approximately one-third that of the conventional Accm. The vertical vibration was also measured while the compressor was being supported flexibly. Figure 13 shows the vertical-vibration acceleration spectrums of the Accm. It was shown that the peak from 400Hz to 600Hz of the conventional Accm was approximately 19m/s2 and the peak of the countermeasure Accm was approximately 14m/s2. It confirmed that the vertical vibration has been reduced by approximately 27 percent.

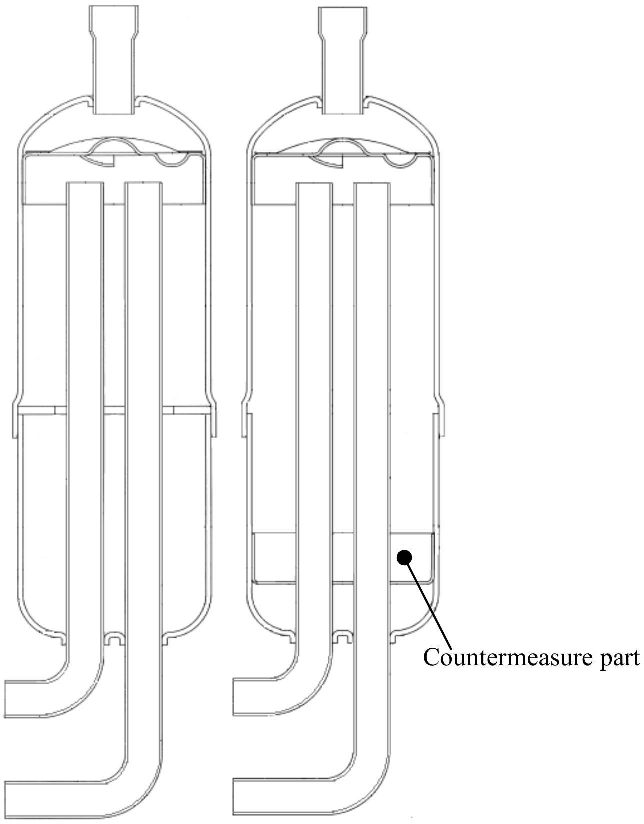

Figure 10: Cross-sectional views of Accms
(Left: Conventional Accm; Right: Countermeasure Accm)

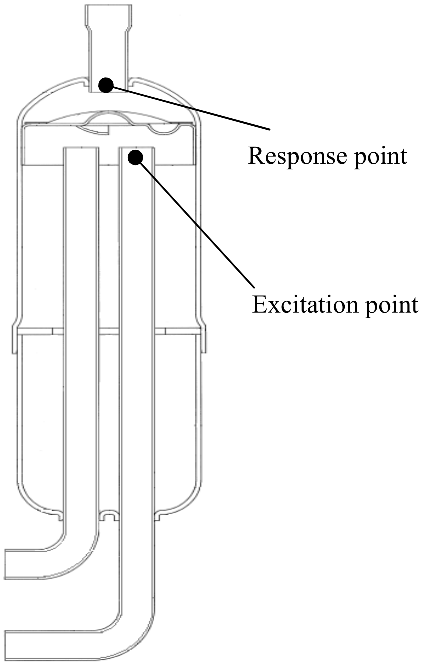

Figure 11: Excitation and response points
in the acoustic response analysis of the Accm internal space

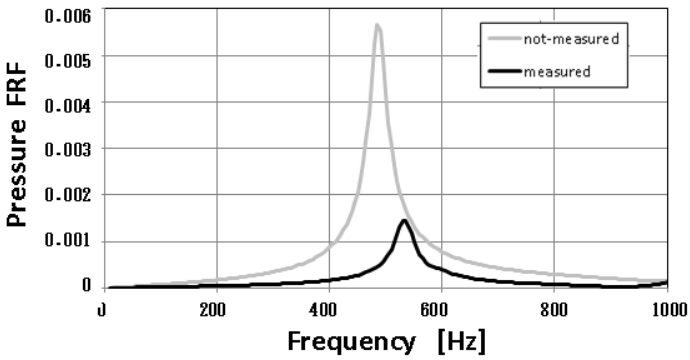

Figure 12: Acoustic response analysis of
the Accm internal space: FRF

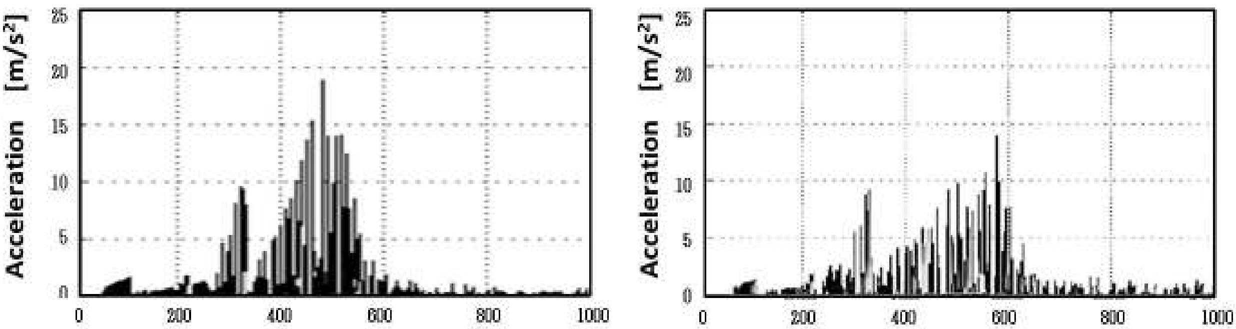

Figure 13: Overlaid acceleration spectrums of Accm vertical vibration of a compressor alone: New evaluation method
(Left: Conventional Accm; Right: Countermeasure Accm)

5. Conclusion

In this report, we introduced a method of measuring compressor vibrations that uses a flexible support in order to examine the compressor vibrations that cause the outdoor unit sound. The following is the summary of the report.

- The conventional vibration-measuring method for a compressor alone was unable to evaluate the vertical vibration of the Accm that can cause the outdoor unit sound. Accordingly, a vibration-measuring method that utilizes a flexible support was developed, which enabled the evaluation of vertical vibration of the Accm.
- As the new method allows for the evaluation of vertical vibration, the mechanism generating such vibrations was examined. Based on the concurrent measurement of vibration and pressure as well as the acoustic eigenvalue analysis, it was shown that the acoustic mode in the 500 Hz band with the antinode appearing at the top and bottom and the node appearing in the center of the Accm inside the Accm was the cause of the vertical vibration.
- In consideration of reduction in the acoustic mode excitation, a part that prevents pressure fluctuation was attached to the antinode of the acoustic mode. Based on the acoustic response analysis as well as the vibration measurement that utilized a flexible support, it was confirmed that the vertical vibrations had been reduced by approximately 27 percent.