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AN EXPERIMENTAL INVESTIGATION INTO THE NOISE OF A CONTINUOUS POSITIVE AIRWAY PRESSURE DEVICE

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The noise source and sound pressure level of a functional continuous positive airway pressure device has been investigated in this paper. This paper outlines the experimental study conducted on this device to determine the noise source and identify the root cause of the noise generation in the continuous positive airway pressure device and hence reduce the noise generated. At the end of this paper the conclusions suggest that the major noise source was Structure Borne and the noise was caused due to rotational imbalance of the rotor inside the blower of the device which was deducted from valid experimental results showing that the first harmonic vibration was dominant. In addition to detecting the noise source, solutions to reduce the noise level have been suggested. Most effective method to isolate vibration was found to be addition of an isolation mount. Research was conducted on isolation mounts which included material of mount, mechanism of isolation, active and passive isolation approaches to reduce the noise and vibration generated from rotational imbalance.

Keywords: (sound pressure level, structure borne, air borne, noise, vibration, rotational imbalance, isolation mount)

1. Introduction

Sleep apnoea is a common disorder which is found in people of all ages and genders. The physical phenomena is caused due to unwanted vibration in the soft palate (mainly), hard palate and tongue when a person respires during sleeping.[1] Heavy snoring contributes vitally to Obstructive Sleep Apnoea. To this date, the most effective remedy for OSA has been identified as the use of a Continuous positive airway pressure (CPAP) device[2]. CPAP device is worn orally by patients during sleeping, as this device blows in air throughout the night at a certain pressure that makes sure that the airway is open all the time. As air is blown in, the blocking organs and tissues exert a direct pressure that opens up the airway thus, reducing snoring noise and also establishing a proper respiratory balance for the patient. Other than the blower, there is a humidifier chamber, a spacing unit for airflow to enter a hose which is directly connected to a gasmask which is orally worn by the patient. The major concern with the usability of this device is that it generates a noise that disturbs the patient and the partner sleeping with the patient[3]. It is reported that the noise generated from this device has created a significant discomfort of users resulting in the rejection. In order to make this device more user friendly (comfortable to use), the noise generated has to be reduced and if possible to be eliminated completely. This paper illustrates a detailed experimental study conducted on a CPAP device to identify the major noise source and measure sound pressure levels in order to determine the necessary approach to be taken to reduce the noise level and make the device more user acceptable.

Honeycomb structure can reduce vibration and noise due to its high stiffness while reducing the mass of the whole system. It can also be filled with granular material which has damping effect to further reduce vibration. [4] The mass and location of the granular material have a great effect on the isolation performance. The vibration can be significantly reduced with appropriate mass and distribution of the granular material. Another research shows the scissor-like structured platform can also effectively isolate the vibration.[5] Compared to the traditional mass–spring–damper systems, this structure has beneficial nonlinear stiffness and damping and better loading capacity. Scissor-like structured platform can have high isolation performance by designing the system parameters.

From vast research done on material for the mount, MBS tough rubber material, which exhibits quasi zero stiffness material property, was found to be an ideal material for the mount. According to research conducted by Valeev and Kharisov[6], where three different quasi zero stiffness materials were tested to find the material which showed the least axial deformation under similar loads applied, it was found that MBS tough rubber deformed the least and was the most suitable material.

2. Structure borne and air borne noise source

In order to determine the major noise source, a fundamental and standard noise and vibration analysis approach is applied. The most basic technique to assess noise and vibration levels is to use measurement apparatus like microphones and accelerometers. A free field experimental set up was used to measure the noise in order to avoid echoing effects of sound from nearby surfaces. The key objective was to identify the noise source, which can be further classified into air borne or structure borne. Vibration level would reflect the direct vibrating effect of the tested object which could be classified as structure borne noise. In order to isolate the vibrating modes of the test object from those of the mounting system, the simplest apparatus used is a standard stand with bungee cords that can be used to suspend the test object on the stand. In short, the noise measurement analysis would identify all noise sources and their respective sound pressure levels, whereas the vibration analysis would help to identify all the structure borne noise generated. Thus, comparing both the measured noise and vibration results, the structure borne and air borne noise sources can be differentiated.

3. Experimental Design and Procedure

Experimental analysis of the noise generated from the CPAP device was the key objective of this research. For testing purpose, a prototype CPAP device was provided, as shown in Figure 1. This experiment was conducted in RMIT University and the major analysis was done using ‘B & K Pulse Lab shop’ software, which was used for:

1. Recording Sound Pressure level for a constrained time frame.
2. Recording Vibration level of a test object for a constrained time frame,
3. Playing back recorded sound and vibration track.
4. Frequency analysis of the recorded sound pressure and vibration signals including the background noise sound pressure signals in a certain frequency range.

Figure 1: CPAP device

In order to assess the noise, figure 2 and figure 3 show the experiment set up and the experimental procedure and test conditions were followed:

1. Test was done on the device with four different pressure configurations which reflects the blower rotational speed of the CPAP test device. The four pressure configurations are the air flow pressure of 4cm H_2O (reflecting the minimum operational pressure), 10cm H_2O (reflecting a standard operational pressure), 20 cm H_2O (reflecting a high operational pressure) and 25cm H_2O (reflecting a maximum operational pressure).
2. Test was done on two different device assembly set-ups which were (i) the entire CPAP device (ii) the CPAP device without the humidifier cover located at the rear of the device.
3. Each test run was time constrained to 60 seconds.
4. Background noise contribution to test results had to be eliminated, hence the background noise was recorded for 60 seconds.
5. Major data acquisition transducers used were a microphone and an accelerometer
6. Microphone was calibrated and placed 1m away in the same height as the test device and parallel to the test device to ensure the standard ISO test conditions.
7. Accelerometer was installed on top of the CPAP device (just above the blower location).
8. The hose which is connected to the patient's gasmask was inserted into an acoustic quiet box to eliminate the air borne noise due to air flow fluctuation. This acoustic quiet box was placed at the bottom end of the stand.
9. A stand frame and Bunge cords were used to suspend the test device and to isolate vibration from the surroundings

Figure 2: Experiment set up for CPAP device

Figure 3: CPAP device without cover

4. Data Processing

First, the peak frequency of the background noise was recorded. Second, after eliminating the background noise, the peak frequencies found in sound pressure spectrum and vibration spectrum were compared to each other. When the peaks of sound pressure level and vibration level occurred at the same frequency, the sound was mainly caused by the vibration which was structure-borne noise. When the peaks only existed in the sound pressure level spectrum, the noise was the air-borne. Then, for these peak frequencies, the corresponding peak values of the sound pressure and vibration spectra were recorded. The totals level of the sound pressure or vibration spectrum was calculated by

$$L_\Sigma = 10 \cdot \log_{10}\left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + \cdots + 10^{\frac{L_n}{10}}\right)\ \mathrm{dB} \tag{1}$$

Then the harmonics were calculated by

$$\textit{Harmonic Number} = \frac{\textit{Peak Frequency (Hz)}}{\textit{Rotational speed (Hz)}} \tag{2}$$

The peak frequency divided by rotational speed frequency of the blower is the value of the harmonic number.

5. Results and discussion

5.1 The measurement results of the structure borne noise of the entire device

Table 1: The measurement results of the structure borne noise of the entire CPAP device.

The air pressure	Peak frequency (Hz)	Sound pressure spectrum peaks (dB)	Vibration spectrum peak (dB)
4cm of H_2O	1090	32	-22.8
10cm of H_2O	290.1	22.8	-7.72
20cm of H_2O	409.7	29.5	-2.69
25cm of H_2O	459.7	38.9	-16.4

Table 2: The calculated SPL and vibration level sums and measured total SPL and vibration levels.

The air pressure	The measured total SPL(dB)	The calculated SPL(dB) sum of the peaks	The measured total vibration(dB)	The calculated vibration level (dB) sum of the peaks
4cm of H_2O	52.9	37.35	-17.2	-17.95
10cm of H_2O	52.8	42.11	-7.45	-7.54
20cm of H_2O	53.2	43.86	-2.48	-2.63
25cm of H_2O	53.3	42.65	-13.7	-15.9

The most outstanding frequency peaks are listed in Table 1. The measured total SPL or vibration level values were obtained directly from the software analysis, as shown in table 2. These values were affected by the background noise. The calculated sum values were contributed only by the frequency peak values, which are more focused on the structure borne noise than the measured total values. In this test, most of the peaks of the sound pressure and vibration spectra coincided at the same frequency. The vibration caused most of the noise, which indicated the major noise source was structure borne. The blower of the tested device has 13 blades. So except the calculated harmonic numbers, 13^{th} harmonic should also be paid attention to. Table 3 shows the peak frequencies and harmonic numbers.

Table 3: The peak frequencies and harmonic numbers

Pressure settings	Rotational speed (Hz)	Vibration spectrum peak frequency (Hz)	Harmonic numbers
4 cm H_2O	184	183, 1090 (outstanding), 2441	1, 6 (outstanding), 13
10 cm H_2O	290	290.1 (outstanding),, 1728, 3652	1 (outstanding), 6, 13
20 cm H_2O	408	409.7 (outstanding),, 2441, 5464	1 (outstanding), 6, 13
25 cm H_2O	455	459.7 (outstanding),, 2738,5788	1 (outstanding), 6, 13

Most of the outstanding frequency peaks are at the first harmonic except when the blower was operated under the air flow pressure of 4cm H_2O, which is the 6^{th} harmonic. The 1^{st} harmonic indicates that there is an imbalance in the shaft or a presence of rotational imbalance. The 13^{th} harmonic is the vibration result of one sweep of 13 blades in one rotation of the blower. The 6^{th} harmonic is a half of the 13^{th} harmonic. This may be caused by the loose or gap in the blower blades.

For these peak frequencies, the corresponding peak values of the sound pressure spectrum and vibration spectra were also recorded. Figure 4 shows the relationship between the SPL and rotational speed of the blower at different harmonics.

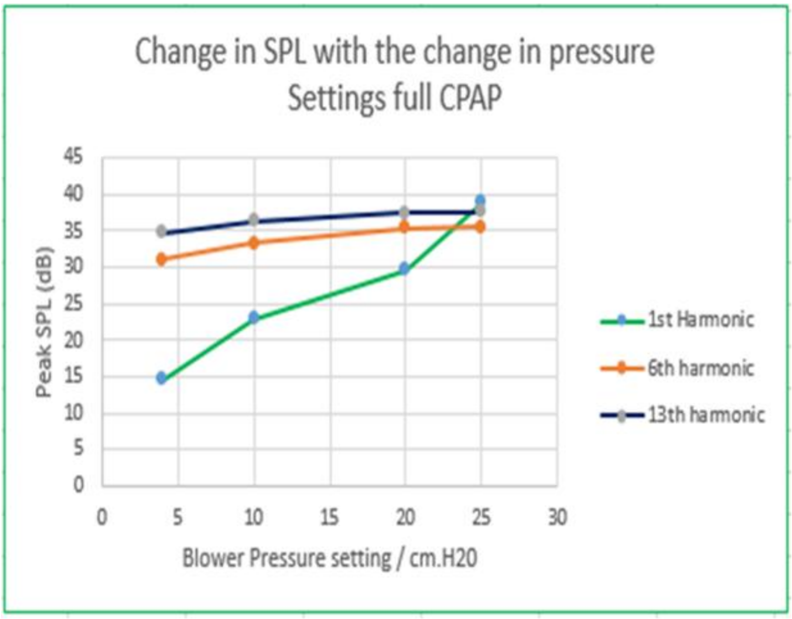

Figure 4: The SPL values versus the blower pressure settings at different harmonics with the cover.

When the speed of the blower increases, the blower generates larger air flow pressure, the change of sound pressure level for the 1st harmonic is dramatic. For the 6th and 13th harmonic, the change of SPL is quite small. This indicates the 1st harmonic had the dominate influence on the sound pressure level. The noise was mainly caused by the vibration of the blower which was caused by imbalance mass.

5.2 The test of the device without outside cover

The similar results can be found from testing of the device without the cover.

Table 4: The results from testing of the device without the cover.

The air pressure	Peak frequency (Hz)	Sound pressure spectrum peaks (dB)	Vibration spectrum peak (dB)
4cm of H_2O	1090	31.8	-7.09
10cm of H_2O	290.1	20.7	-14
20cm of H_2O	409.7	29.2	-0.675
25cm of H_2O	459.7	30.9	-0.137

Table 5: The calculated SPL and vibration level sums and measured total SPL and vibration levels

The air pressure	The measured total SPL(dB)	The calculated SPL(dB) sum of the peaks	The measured total vibration(dB)	The calculated vibration level (dB) sum of the peaks
4cm of H_2O	52.8	37.65	-6.45	-6.87
10cm of H_2O	52.8	40.34	-10.3	-12.25
20cm of H_2O	55.2	43.31	-0.32	-0.63
25cm of H_2O	53.3	43.4	0.3	0.08

Tables 4 and 5 also show that the most outstanding frequency peaks and their calculated sound pressure and vibration level sums. The second test results also show that the major noise source is the structure borne.

Table 6: The peak frequencies and harmonic numbers

Pressure settings	Rotational speed (Hz)	Vibration spectrum peak frequency (Hz)	Harmonic numbers
4 cm H_2O	185	183, 1090 (outstanding), 2441	1, 6 (outstanding), 13
10 cm H_2O	291	290.1 (outstanding), 1728, 3652	1 (outstanding), 6, 13
20 cm H_2O	410	409.7 (outstanding), 2441, 5464	1 (outstanding), 6, 13
25 cm H_2O	455	459.7 (outstanding), 2738,5788	1 (outstanding), 6, 13

Table 6 also shows the peak frequencies and the harmonic numbers. The peak frequencies are almost the same as those of the first test. The most outstanding frequency peaks were at first harmonic except when the blower was operated under the air flow pressure of 4cm H_2O.

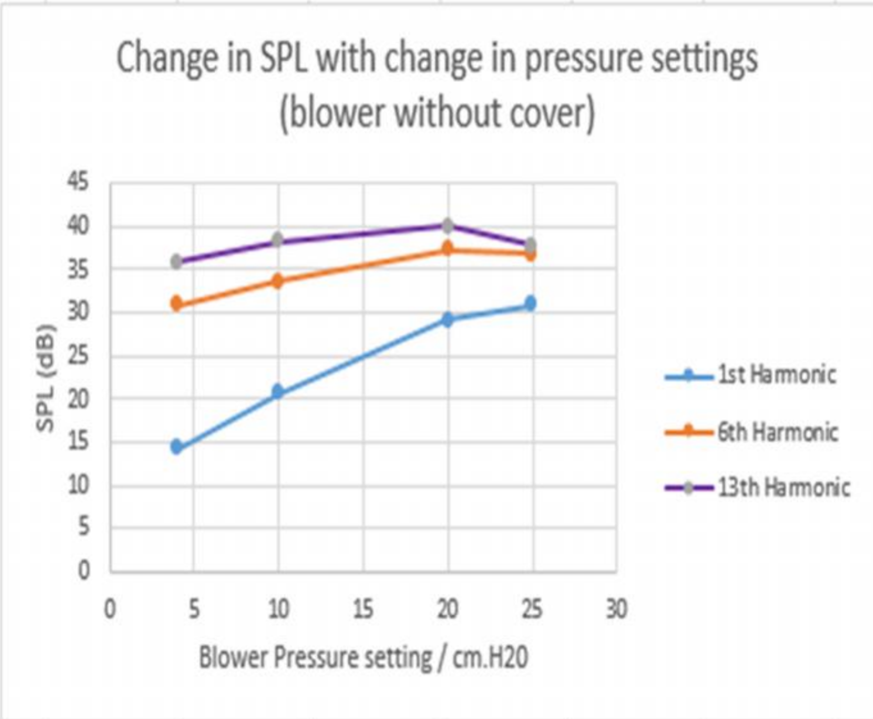

Figure 5: The SPL values versus the blower pressure settings at different harmonics without the cover

Figure 5 indicates that the 1st harmonic has the most effect on the SPL as the SPL changes for the 1st is much greater than that of the 6th and 13th harmonic.

6. Conclusion

The primary objective was to identify the noise source from experiments. Experimental results have validated the test method where a microphone was placed in a far field from the test device. The background noise was measured to eliminate its contribution to the generated device noise. From the results discussed it can be seen that the first harmonic was clearly the major contributor of the device noise. The first harmonic noise level increased significantly with the air flow pressure levels. The first harmonic noise were generated due to the rotational imbalance of the blower rotor. This could induce whirling, where the unbalanced mass causes the shaft to deflect from its center line and the blade vibration generating an unwanted noise due to the heavy vibration at the 1st harmonic. The solution to the overall problem could be prescribed as balancing the rotor and retesting the prototype CPAP device. The 6th and the 13th harmonic frequency peaks were also caused by Structure Borne vibration. The 6th harmonic frequency peak SPL could be caused by the assembly errors which may include gaps or loosely fixed screws in the blade structure. The 13th harmonic was caused by one sweep of the 13 blades in one revolution which could be either structure borne or air borne noise which is hard to be eliminated. The major noise contributor is the 1st harmonic vibration. As a result, insertion of a mounting isolators inside the blower is recommended as a solution.

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