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MECHANICAL EVALUATION OF A DEVICE FOR THE RESPIRATORY PHYSIOTHERAPY

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Abstract. *In this article it is shown a study on the mechanical behaviour of the Flutter VRP$_1$, a new device used by the respiratory physiotherapy. The device basically resembles a smoke-pipe with a conical cavity where a stainless steel sphere is located and which floats up and down due to the intermittent air flow of patients. The sphere maintains an oscillatory movement whose frequency is function of the air flow rate and orientation of the device. The oscillatoty frequency of the sphere inside the Flutter when matched with the natural frequency of the thoracic chest of the patient will produce the effect of resonance which by its turn will move the pulmonary secrections. In the present study an experimental setup was assembled in order to measure oscillatory frequency of the sphere, air flow rate and pressure inside the device. There were also manufactured spheres of different materials with specific weight lower than steel with the purpose of reducing respiratory efforts of children, old and recovering patients. Technical informations here highlighted will be very helpful to the professionals of the respiratory physiotherapy.*

Keywords: *Oscillatory Frequency, Floating Sphere, Respiratory Physiotherapy, Flutter VRP$_1$,*

1. INTRODUCTION

The VRP$_1$-Desitin device, also known as Flutter, is a small pocket device designated for the treatment of patients suffering from chronic mucus retention and bronchial collapse. Although being simple in its design, the Flutter has been showing encouraging performance when compared to the traditional respiratory physiotherapy such as, for example, autogenic drainage (Lindemann, 1992). It is based on oscillations of air in the respiratory tract during expiration. Pressure and flow variations depend on the position of the mouthpiece and effort of breathing or air flow rate executed by the patient.

As shown in Fig. 1, the Flutter is constituted of a mouthpiece (1), a hard material cone (2), a 28 grams high density stainless steel sphere (3), and a perforated and removable lid (4).

It works as follow. Before expiration the sphere closes the conical channel. During expiration, the instantaneous position of the sphere is resulted from the equilibrium states of its own weight, the cone angle and the pressure, the sphere starts to move, permitting air to flow through the variable area orifice (the expiratory flow in this state is under strong acceleration). After that, air pressure falls, the sphere rolls back to its initial position and it blocks the orifice, resulting again in the increase of the pressure. This process stimulates "bronchial percussion" easing the elimination of mucus and saliva and the frequency of this cycle can be adapted to each patient. The oscillation frequency, the air pressure and flow depend on the angle position of the mouthpiece and lid of the device as well on the expiration effort.

The objective of the present work is to experimental and analytically evaluate the Flutter VRP$_1$ under its original design and also to verify its behaviour when operating with spheres of different materials.

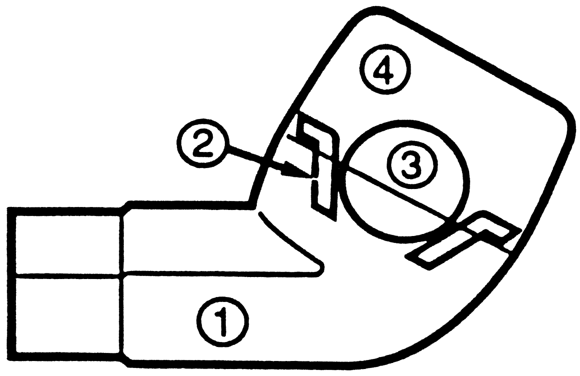

Figure 1. The Flutter VRP_1 device: (1) mouthpiece; (2) cone; (3) sphere; (4) removable lid.

2. EXPERIMENTAL SETUP AND PROCEDURE

The used experimental setup is shown in Fig. 2. A blower feeds air to the Flutter, two valves control air flow, an orifice plate measures air flow and piezoelectric transducer coupled to a 500 gain voltage amplifier was used for the measurement of air pressure inside the Flutter. For the measurement of sphere frequency an inductive proximity transducer was used.

Experiments were made with air flow rates ranging between 0.5 and 6 m^3/hr which is the range of air flow rate that a human being is usually able to produce. The entrance tubing in the Flutter makes a 30^o angle with respect to the horizontal direction. Considering the mouthpiece as reference all measurements were made in situations where the mouthpiece was in 0^o, $+30^o$ and -30^o orientations.

As can be seen in Fig. 3 there were manufactured spheres of aluminum, tecnew and teflon with nominal diameter of 20 mm which is basically the same as the diameter of the original sphere of stainless steel. The measured mass of stainless steel sphere was of 27.88 grams, 9.70 grams for the sphere of aluminum, 4.16 grams for the sphere of tecnew and 4.98 grams for the sphere of teflon.

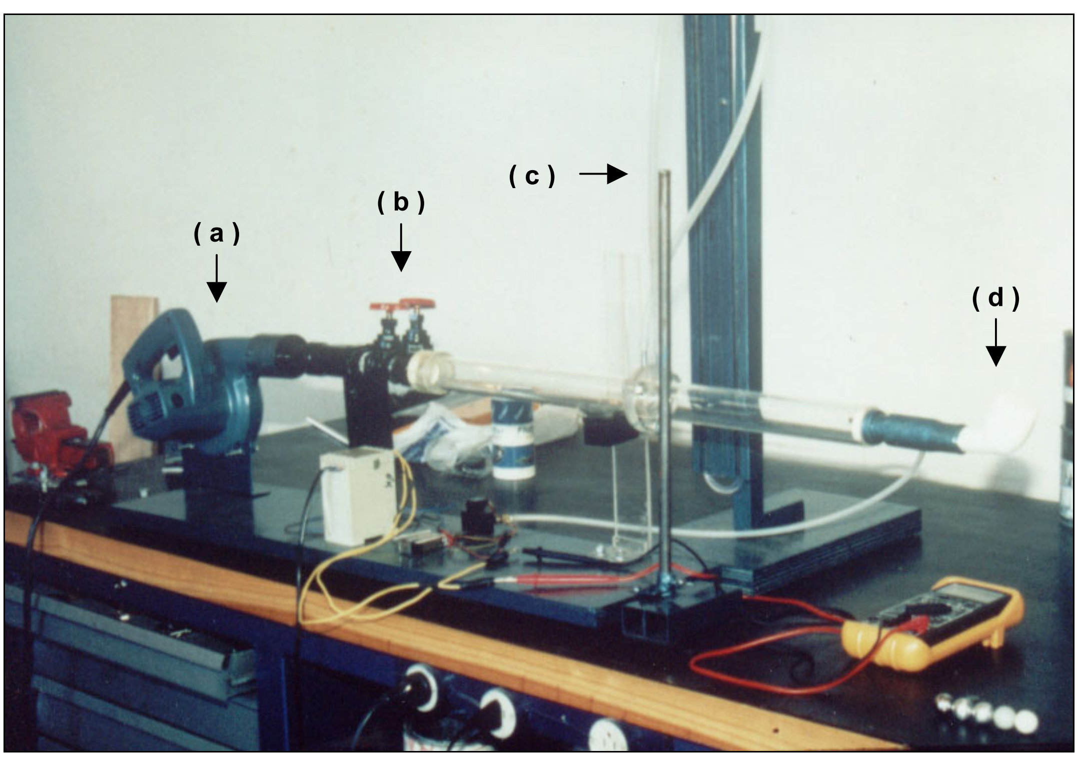

Figure 2. Experimental set-up and measurement system (a) air blower; (b) control valves; (c) "U" manometer; (d) Flutter device

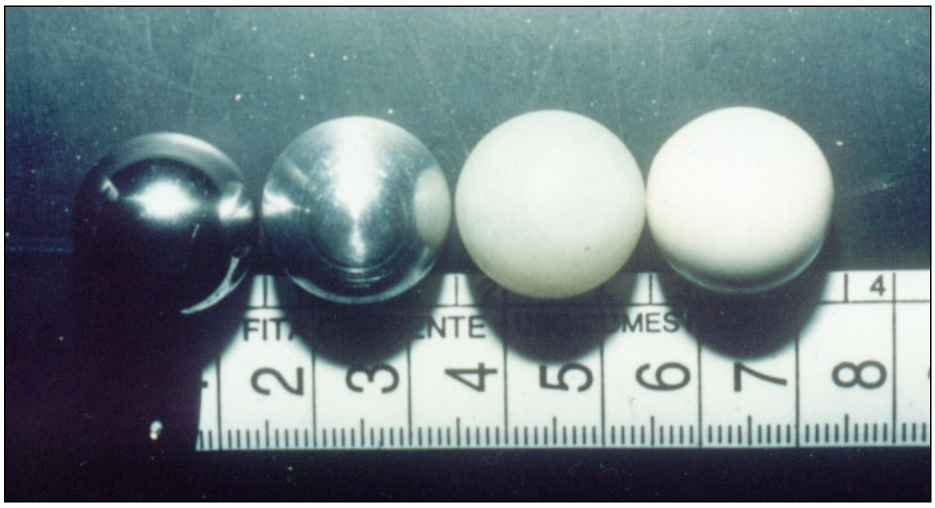

Figure 3. Spheres of stainless steel, aluminum, tecnew and teflon (respectively from left).

3. RESULTS

In Figure 4 it is shown adjusted curves of air flow rates against pressure inside the Flutter in the 0^o position. Every curve is derived from experimental measurements for each sphere. As can be observed, spheres of tecnew and teflon did show a level of pressure 25% lower than the level presented by the sphere of steel.

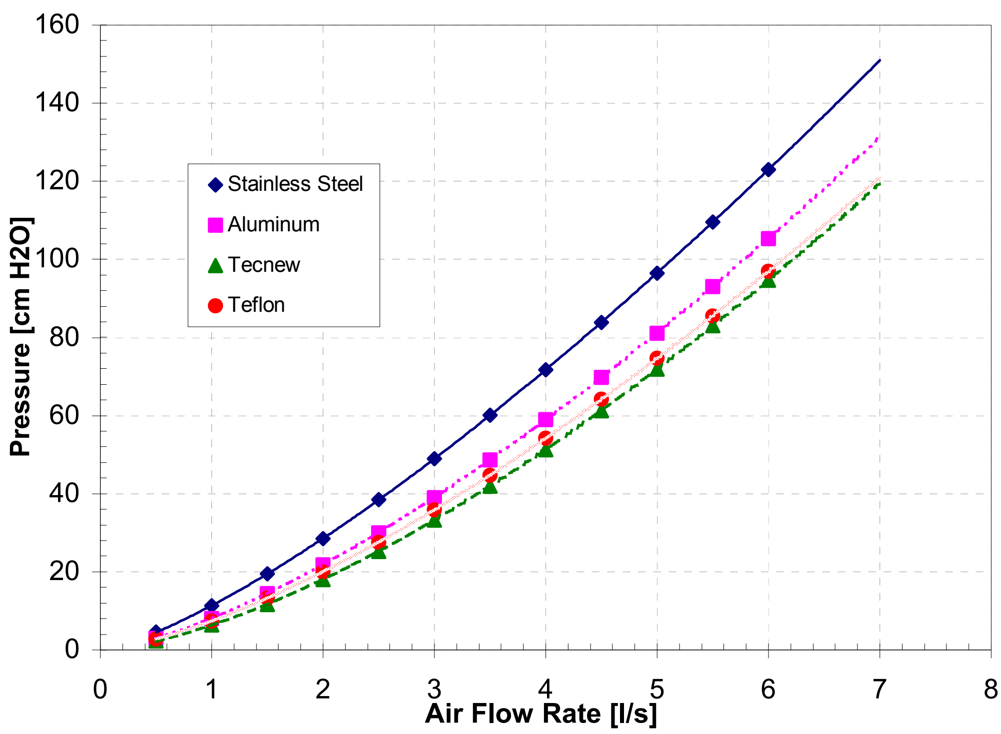

Figure 4. Adjusted curves of air flow rate x pressure for different spheres with Flutter in the 0^o position.

Figure 5 shows curves of air flow rate against pressure inside the Flutter in the $+30^o$ position. For this position, spheres of aluminum, tecnew and teflon presented the same level of pressure against the considered range of air flow rate. They presented basically a level of pressure 35% lower than the corresponding level of the original sphere.

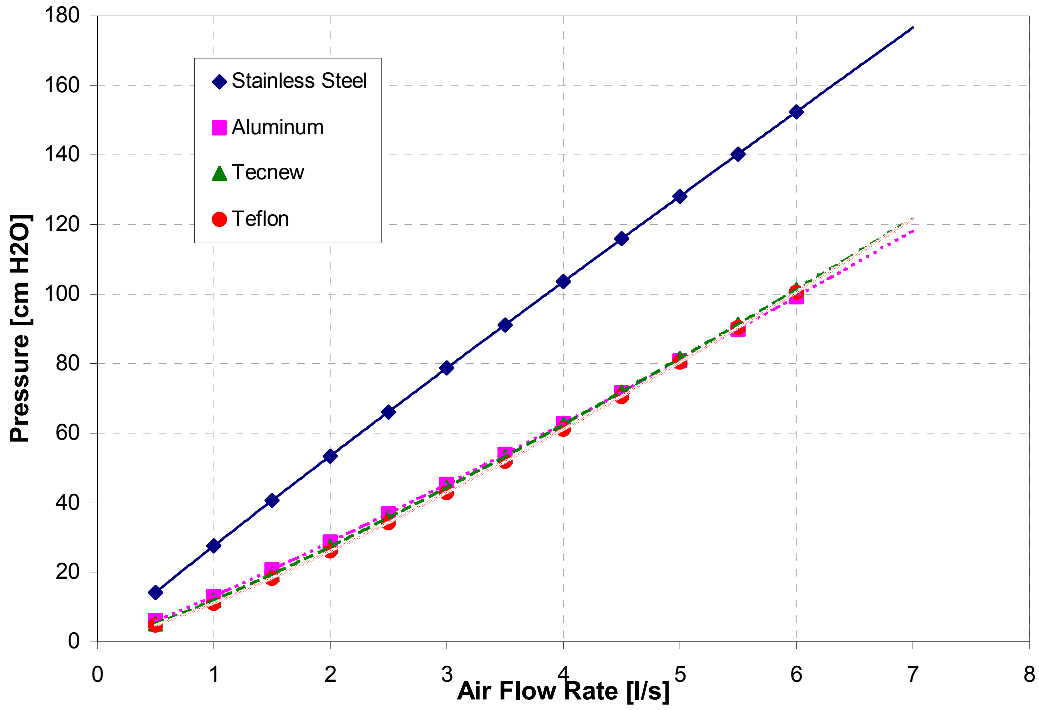

Figure 5. Adjusted curves of air flow rate x pressure for different spheres with Flutter in the +30^{o} position

Figure 6 shows curves of air flow rate against pressure inside the Flutter in the –30^{o} position. For this position every sphere presented practically the same level of pressure for the considered range of air flow rate.

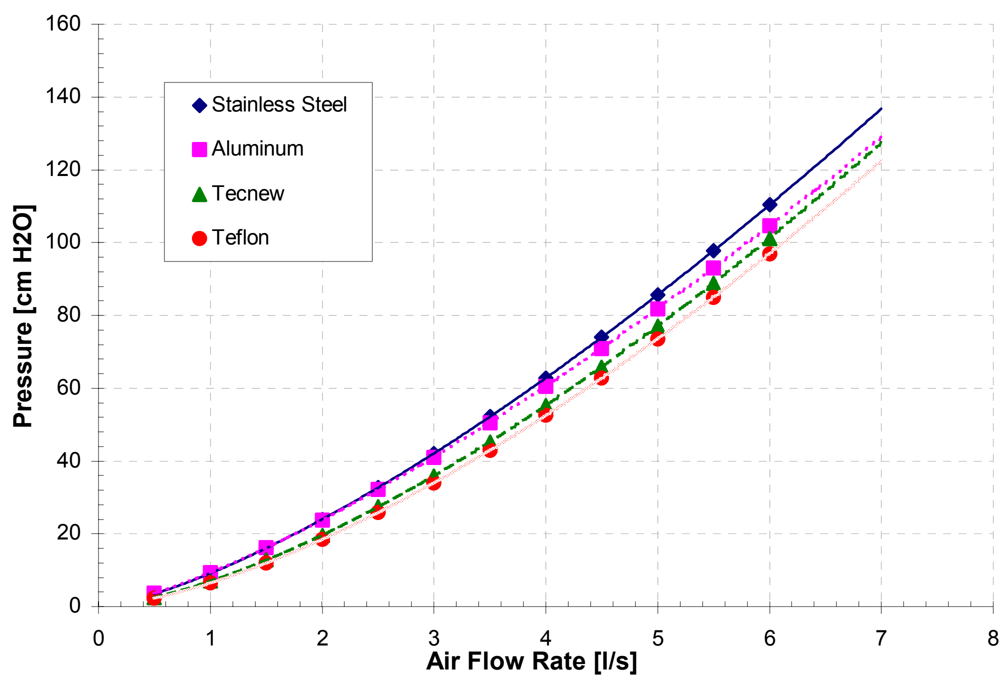

Figure 6. Adjusted curves of air flow rate x pressure for different spheres with Flutter in the -30^{o} position.

Figure 7 shows experimental data of the original sphere vertical vibration and corresponding frequency spectra for two air flow rates as measured by Lépore Neto et al. (2000). It noticeable that there exist peaks of frequency and harmonics for different level of air flow rate.

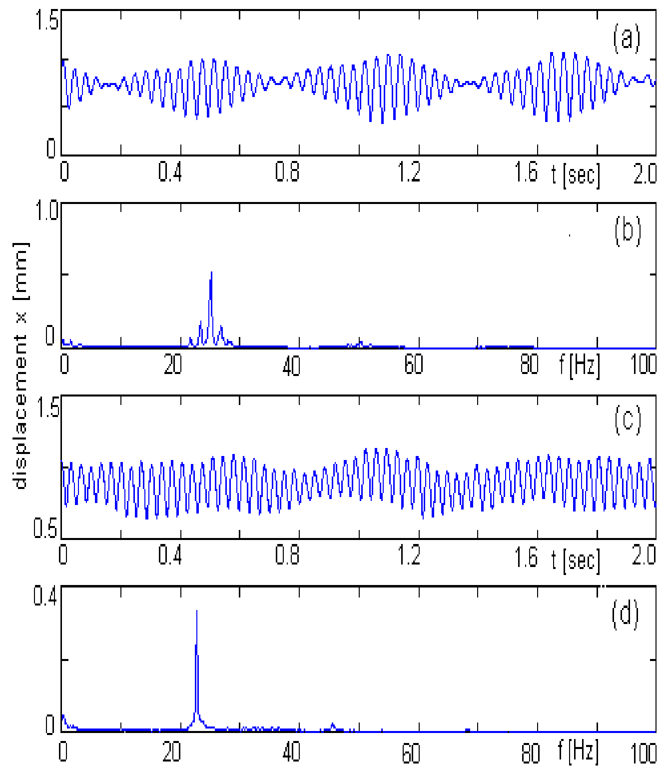

Figure 7. Comparison of displacement signals for two level of air flow rates (1.2 l/s in (a) and l.8 l/s in (b)).

4. DISCUSSION OF RESULTS

Although the Flutter has been used in almost every country of the world as a successful alternative for the traditional respiratory physiotherapies mainly due to its design, easy to use, efficiency and cost competitive, only Lindemann (1992) experimentally verified that the level of pressure inside that device can reach 75 cm H_2O if the patient is blowing it at the horizontal orientation of the mouthpiece in a expiration air flow rate of 5 l/s which is not very demanding for a usual patient. After King et al. (l983) the necessary requisite for an effective mucus transport to the cephalic direction during the high frequency thoracic compression manouvre is maintenance of limited range of air flow rate between l and 3 l/s. On the other hand the great majority of researchers (Chatam et al., 1993; Girardi and Terki, 1994; Hardy, 1994; Swift et al., 2000; Leru et al., 1994; Konstan et al., 1994; Newhouse et al., 1998; Bellone et al., 2000) on Flutter affirms that on that range of operation the Flutter shows level of pressure of 10 to 25 cm H_2O. The fact is that the recommended range of air flow rate can be easily surpassed but on the other hand the level of pressure can reach value which if continued would conduct the patient to adverse reaction such as dizziness or pneumothorax if the patient presents some kind of precondition. Considering the air flow rate of 3 l/s, as can be seen in Figure 4, the pressure inside the Flutter operating at the horizontal position and with the stainless steel sphere will reach the value of 50 cm H_2O and will reach 40 cm H_2O for aluminum and 35 cm H_2O for tecnew or teflon. The observed range of pressure of 10 to 25 cm H_2O affirmed by the above referenced authors as for the case of the original sphere will limit the air flow rate to about 2 l/s and this limitation can be influential on the respiratory physiotherapy.

As for the case of utilization of the Flutter on $+30^o$ position which is a normally used practice because sometimes the patient is stimulated to that orientation of the Flutter in order to provocate the resonance that will displace the mucus, the level of pressure inside the device will reach 80 cm H_2O for the case of the original sphere and 40 cm H_2O for the case of the others spheres, as can be seen in the Figure 5. Even being intermittent that level of pressure (80 cm H_2O) would be dangerous for some patients.

As for the case of utilization of the Flutter on the -30^o position as can be observed in the Figure 6 all spheres presented the same level of pressure (about 40 cm H_2O) for the considered range of air flow rate.

The time domain signals of displacement and frequency shown in the Figure 7 for two air flow rates present a periodic nature which is apparent by the existence of a fundamental frequency and its higher order harmonics for the case of air flow rate of l.2 l/s and only a peak of frequency for the case of 1.8 l/s. The highest peak represents the fundamental frequency of the sphere inside the Flutter and the lower ones represent harmonics that by its turn present a frequency spacing indicating modulation of the displacement of the sphere by the air flow. The presence of the modulation is the necessary factor for the existence of the beneficial resonance. As can be observed in Figure 7 the modulation effect is more present for air flow rate lower than 2 l/s and after that value it practically disappear indicating a transition on the behaviour of the dynamics of the Flutter.A study of the effects of shock and vibration on the human body presented by Harris (1988) shows that the natural frequencies of the mouth-chest system fall in the 5 to 11 Hz frequency band. These values were experimentally obtained by applying oscillating air pressure to the mouth and measuring the vibrations on the chest wall. The natural frequency values may vary and mainly depend on the seating or standing position of the human body. On the other hand, Cegla and Retzow (1993) reported that lung-chest natural frequencies might vary between 12 and 15 Hz. The comparison of the effects of high-frequency oral airway oscillations, high frequency chest wall oscillation and conventional chest physical therapy on weight of expectorated sputum in patients with stable cystic fibrosis was studied by Scherer et al. (1998). The tested frequencies in the airway method were 8 Hz and 14 Hz. The frequencies applied in the wall chest oscillations technique were 3 Hz and 16 Hz. For these two techniques the weight of expectorated sputum is higher for the low frequencies. When compared these informations with the behaviour of the present device it may be reasonable to stress that the effectiveness of the Flutter to improve sputum elimination in patients of the respiratory physiotherapy is eventually most present when the fundamental and the modulating frequencies of the inlet pressure have values close or multiple to some of the natural frequencies of the mouth-bronchi-lungs-thoracic cage system.

5. CONCLUSION

The present article studied the mechanical behaviour the Flutter VRP_1, a device used in the respiratory physiotherapy, and it may conclude that:

- the stainless steel original sphere inside the Flutter may produce high level of pressure (more than 80 cm H_2O) in the bronchi-lungs system of a patient if the air flow rate is higher than 3 l/s;
- spheres manufactured of materials lighter than steel, as for example aluminum, tecnew or teflon effectively reduces the level of pressure inside the Flutter and depending on its orientation the reduction can reach till 50%;
- the beneficial effect of resonance for the displacement of mucus is limited to the range of air flow rate, that is, up to about 3 l/s.

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