UNITECH SELECTED PAPERS

International Scientific Conference
UNITECH`2024

DESIGN AND PROTOTYPE OF A MICROCONTROLLER-CONTROLLED ELECTRO-PNEUMATIC REHABILITATION DEVICE

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Abstract

In this study, a portable prototype device was designed and developed for physiotherapy applications in diseases that cause respiratory problems, such as COPD, Chronic Bronchitis, Emphysema, Bronchiectasis, Chronic Asthma, and Cystic Fibrosis. This programmable device is intended to be used for respiratory rehabilitation in the aforementioned diseases. The device controls the operation of an electro-pneumatic system through a microcontroller. The microcontroller processes parameters provided by the user and various data from sensors to generate the necessary commands and appropriate responses. In this way, the physician or rehabilitation specialist can manually or automatically optimize the adjustable device parameters based on the patient's condition, thereby accelerating the treatment process and increasing its effectiveness.

Keywords: Pneumatic Valve Control, Flutter, Respiratory Rehabilitation Device

INTRODUCTION

Respiratory rehabilitation is an evidence-based, multidisciplinary, and comprehensive intervention designed for chronic respiratory patients who experience respiratory complaints and have limitations in daily life activities. The multidisciplinary team typically includes a physician, physical therapist, respiratory therapist, nurse, psychologist, dietitian, and/or other relevant specialists. Respiratory rehabilitation contributes to standard treatment by helping alleviate and control symptoms, improving functional capacity, and reducing the medical and economic burden caused by lung disease (1). The Flutter device is an alternative method to traditional physiotherapy, and its use has increased in recent years for respiratory diseases characterized by chronic sputum production (Üzmezoğlu 2010). The Flutter is a simple handheld device that aids in clearing mucus from the airways through positive expiratory pressure oscillation (Thompson et al., 2002). It consists of a mouthpiece made of hardened plastic at one end, and a steel ball housed inside a perforated section at the other end. The appearance of such a device is shown in Figure 1, and its internal structure is displayed in Figure 2 (4). The components of Figure 2 are as follows: 1- Mouthpiece, 2-Conical channel, 3-Steel ball, 4-Perforated cap.

Fig. 1.
General appearance

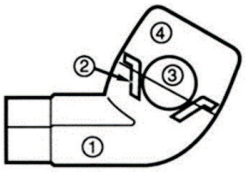

Fig. 2.
Internal structure of the mechanical Flutter

EXPOSITION

The external appearance of the device is shown in Figure 3, while the internal structure is shown in Figure 4. The device can operate using mains voltage or independently for several days, thanks to its built-in 14.4V/5000mAh LiPo rechargeable battery and a “step-up” DC-DC converter.

doi: www.doi.org/10.70456/.....

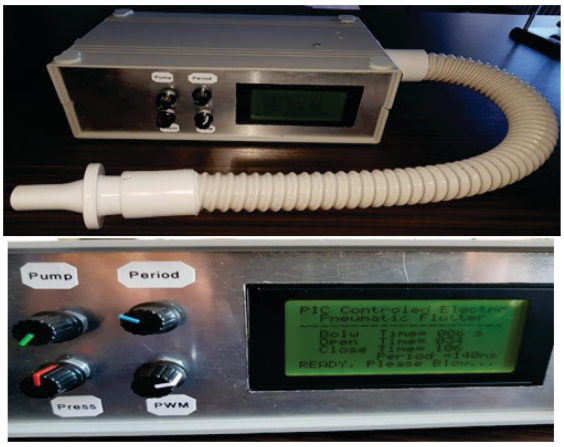

Fig. 3. *External appearance of the device*

Fig. 4. *Internal appearance of the device*

In the designed device, a high-precision and sensitive analog pressure transducer is used to adjust the blowing pressure to the desired value via the associated potentiometer (5). A single-piston, suction-blowing valve-type mini compressor powered by a 24V DC motor is employed to deliver positive pressure to the patient. The compressor's motor speed is controlled using the associated potentiometer, allowing for precise adjustment of airflow. During exhalation, the lungs are made to vibrate (oscillate) by the appropriate periodic opening and closing of a 12V electro-pneumatic valve with three paths and two positions. By modifying the valve's working period with the related potentiometer, the alveoli in the lungs can be resonated, facilitating the easier expulsion of accumulated secretions. Additionally, by using another adjustment potentiometer while maintaining the related frequency, the opening and closing durations of the valve can be altered through pulse-width modulation (PWM), thereby increasing or decreasing the expiratory resistance. This will contribute to both oxygenation and strengthening the respiratory muscles with the resultant positive airway pressure generated during expiration. The adjusted parameters are displayed on a backlit 4x128 pixel graphical LCD screen. Control of all these processes is achieved by uploading software written in an open-source Arduino IDE interface to the ATmega 2560 (Arduino Mega) microcontroller, as shown in Figure 5. Since each patient's lung measurements and lung conditions vary, the resonance frequencies required for expelling secretions will also differ. During exhalation, the data from the precise pressure sensor is analyzed by the software to automatically detect and apply the optimum resonance frequency to the patient.

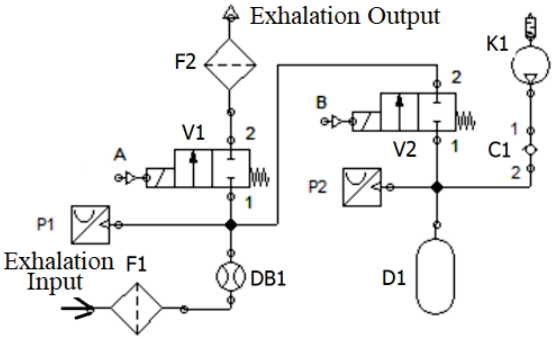

Fig. 4. *Schematic Diagram of the Device*

The patient exhales through the exhalation input. The volume of exhaled air is measured by the DB1 flowmeter and transmitted to the microcontroller for calculating lung capacity. When the exhalation pressure reaches the defined pressure value indicated by the P1 precision analog pressure sensor, the waiting device activates, causing the normally closed 2-position, 2-way valve to start opening and closing at specific intervals as controlled by the microcontroller. The pressure variations detected by the P1 sensor are analyzed by the controller, which automatically adjusts the opening and closing intervals of the valve using pulse-width modulation, ensuring that the patient's lungs resonate at the appropriate frequency. To facilitate the expulsion of the sections to be removed from the lungs, while the V1 valve is in the

closed position, the V2 valve opens for a predetermined duration, applying the compressed air from the D1 pressure balloon to the patient's lungs in brief pulses, increasing resonance. This also helps fill the lung walls, which might be stuck due to muscle weakness during exhalation, preventing the patient from choking and enhancing the effectiveness of secretion removal. The operation of the K1 compressor, which pressurizes the D1 balloon, is automatically controlled by the microcontroller using the values read from the P2 pressure sensor. The exhaled air from the patient passes through the V1 valve and is released into the atmosphere through the F2 filter. The opening and closing intervals of the V1 valve can be adjusted manually via the potentiometers on the device or automatically processed from the P1 sensor data to resonate the lungs. The C1 check valve prevents the escape of compressed air from the pressure balloon into the atmosphere when the compressor stops. The intensity and frequency of the pressure pulses applied to the patient are managed by processing the values from the P2 pressure sensor to control the V2 valve.

CONCLUSION

With this designed and prototyped device, patient-specific parameters will be identified, allowing the patient to enhance the mobilization of mucus by exhaling multiple times through the device. Since the device will automatically find the resonance frequency of the lungs, it will induce vibrations in the airways, facilitating the loosening of mucus from the airway walls, promoting its upward flow, and enabling its expulsion. This will help to ease the removal of secretions that are difficult to expel through normal means, thereby accelerating the related treatment.

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