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Jefferson Luiz Brum Marques
Cesar Ramos Rodrigues
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José Marino Neto
Renato García Ojeda *Editors*

IX Latin American Congress on Biomedical Engineering and XXVIII Brazilian Congress on Biomedical Engineering

Proceedings of CLAIB and CBEB 2022, October 24–28, 2022, Florianópolis, Brazil—Volume 1: Bioengineering and Biomaterials

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Preface

The IX Latin American Congress on Biomedical Engineering and XXVIII Brazilian Congress on Biomedical Engineering (CLAIB&CBEB 2022) took place simultaneously on October 24–28, 2022, in Florianópolis-SC, Brazil, and were organised by the Institute of Biomedical Engineering of The Federal University of Santa Catarina (IEB-UFSC), the Regional Council of Biomedical Engineering for Latin America (CORAL) and the Brazilian Biomedical Engineering Society (SBEB). These events were held remotely for the most part, with a small set of conferences taking place in person on the premises of IEB-UFSC (Florianópolis, Brazil). They included 11 hands-on technical workshops for students, 26 keynote speakers and symposia, and 40 oral and poster presentation sessions attended by about a thousand participants, including undergraduate and graduate students, academic researchers, and public and private sector agents.

We are proud to present in this book a selection of papers presented at this event by researchers from all over the world, reporting recent and innovative findings and technological outcomes in the many areas of interest of biomedical engineering. These papers represent nearly 50% of those original contributions presented at the CLAIB&CBEB 2022. Their academic quality has been warranted by careful peer review coordinated by an expert scientific committee of leading Latin American senior researchers in biomedical engineering. The content is organised into four volumes and eleven chapters, covering the most relevant areas of scientific and technological developments within the broad spectrum of biomedical engineering interests. We are sure that the contributions presented in this book give a deep overview of the leading edge in your expertise and other areas.

On behalf of Scientific and Organising Committees, we thank authors, academic reviewers and sponsoring societies such as CORAL, SBEB, UFSC, FAPESC and IEB-UFSC for their contributions. Moreover, we encourage readers to enjoy this amazing piece of scientific literature as a breadth of knowledge in the biomedical engineering field.

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CLAIB&CBEB 2022 was organised by the Regional Council of Biomedical Engineering for Latin America (CORAL) and the Brazilian Biomedical Engineering Society (SBEB) in cooperation with the International Federation for Medical and Biological Engineering (IFMBE).

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Contents

Bioengineering, Modelling and Simulation, Bioinformatics and Computational Biology

Mechanical Design and Modeling of COMBIOVENT Pulmonary Ventilator

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Abstract. This paper presents the mechanical design of a Pulmonary Ventilator that allows the control, selection and monitoring of parameters necessary to provide life support to patients with acute respiratory failure. 3D models of the ventilation block are described. The sequence of iterations of modeling allowed perfecting the pieces before their manufacture. The simulation of the injection process of the front plastic piece of the equipment is analyzed. Finally, the design of the trolley and the tests to which they were subjected according to the IEC standards are examined. As a final conclusion, the equipment complies with the general safety requirements demanded in the standards for medical equipment.

Keywords: Ventilator · Mechanical Design · Simulation in 3D Models · Medical Equipment · Testing for Medical Trolleys

1 Introduction

COMBIOVENT is a pulmonary ventilator used in intensive care of adults, is medical equipment intended to treat patients who have difficulty or are unable to breathe on their own [1]. The patient receives air through a mask or a hose inserted into the trachea. Its operation is based on supplying an air flow that may or may not be enriched with oxygen, with a normalized frequency and volume, which is inhaled by the lungs and then exhaled.

This assisted breathing is controlled internally by means of an electro-pneumatic circuit that works according to defined parameters. The intensive care physician selects different breathing modes through a user interface with a friendly and intuitive design for easy communication. Likewise, other breathing modes can be established by the doctor with various parameters that respond to the patient's condition. Finally, the alarms are set to notify the medical group in case the patient registers parameters outside the permissible ranges [2].

The aim of this article is to show the final results of iterations to the mechanical design according to the industrial design guidelines, in order to achieved an equipment in the state of the art, aesthetically and as compact as possible, with easy access to its internal components and with technological feasibility [3].

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It is analyzed the simulating of the filling time and the formation of sink marks, during the injection of the plastic piece that is located in front of the equipment.

Finally, the results of different tests to the ventilator trolley according to the international standards of the IEC related to medical equipment are exposed [4].

2 Materials and Methods

2.1 Theoretical Background

COMBIOVENT's design has the most common ventilation modes (assisted, controlled and pressure support modes); automatic control of the oxygen concentration and its visualization; capnography and oximetry monitoring. It also provides the option of using proximal and expiratory flow sensors for greater ventilation precision, as well as proximal pressure measurement.

Two circuits (inspiration and expiration) were located, separated from each other and both controlled by electronic boards that measure and regulate the flow and pressure parameters.

The inspiration circuit (Fig. 1) is composed by an inlet for high-pressure compressed oxygen that passes through a filter and a regulator. An air blower generates a flow which is mixed with this oxygen. This mixture passes through pressure and flow sensors and later for a distributor where hoses are connected carrying the mixture to the electronic boards sensors. At the end of the circuit, the hoses to the patient are connected [5].

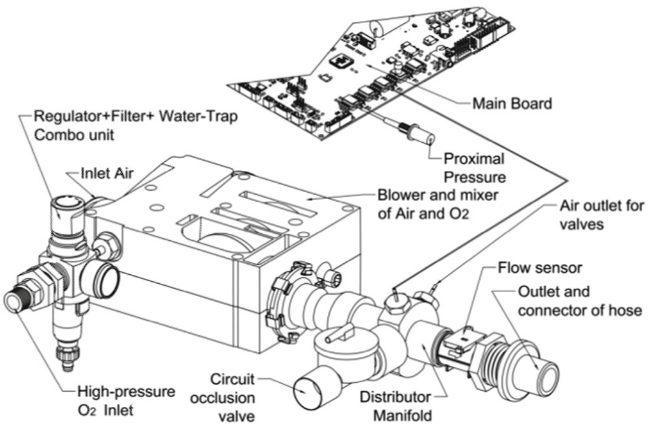

Fig. 1. Inspiration Circuit and its connection with main board.

The expiratory circuit handles residual carbon monoxide that has returned from the patient's expanded lung tissues. The flow of this air is also monitored by the equipment. A set of mechanical pieces was built with the aim of being able to easily decouple this entire circuit from the ventilator and to sanitize it. This assembly allows the attachment of an expiratory valve to control expiratory flow and positive end-expiratory pressure (PEEP) of the patient.

2.2 Mechanical Design Methodology

The mechanical design of the ventilator had several stages. In the first, conceptualization, it was decided to divide its elements into three blocks. The ventilation block contains the electronic boards and the electro-pneumatic controls where the oxygen inspiration circuit hoses and CO_2 expiration circuit hoses are connected to the patient. The other block is a touch screen used to operate the equipment. The decision to separate the screen and the electro-pneumatic system allows using any standard touch screen model. The last block is the trolley for the ventilator movement and where the two previous blocks are supported.

The second stage of the mechanical design was carried out based on the electro-pneumatic circuit proposed by the entire design team. The valves, sensors, regulators, with their mechanical and electrical parameters, were defined. Finally, their entire mechanical assembly was simulated, performing several iterations that ultimately led to a compact and technologically feasible design to manufacture.

2.3 Materials and Devices Used

All mechanical pieces were manufactured using 3000 Series Aluminum Alloy. This alloy has moderate strength, good workability, and good corrosion resistance. Sheets metals were manufactured with Aluminum 3105 and machined pieces with Aluminum 3005. Internal pieces were subjected to an anodizing process in order to increase resistance to corrosion, maintain its metallic appearance and create an external surface three times harder. External sheet metals pieces were covered with White Electrostatic Paint for its easy sanitization.

Pneumatic and the electrical modules were integrated into the mechanical assembling to achieve a functional system. The main modules or devices used were the following:

- Electronic Boards
- Touch screen
- Blower and Mixer of O_2 and Air
- Hoses and Couplings
- Flow sensors
- Valves ON/OFF and Proportional Solenoid Valves
- Pressure Regulators and Filters.
- Fastenal elements
- Manifold.

2.4 Modeling of the Mechanical Design of the Ventilation Block

Inside the inspiration circuit, there is one element with custom mechanical design: the distributor manifold. Initially, it had one inlet and four outlets for the air that come from the blower. The inlet is attached to the blower by means of clips. One of the outputs had a conical shape, to get a quick adjustment of the elements that are connected to it. The other three are threaded radial outlets. In the initial design (Fig. 2) the threaded outlets are in a fairly large thickness area. During the initial operation tests, reduction of total

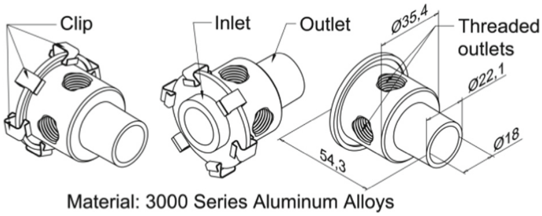

Fig. 2. Distributor manifold initial design

space of the piece was needed to add one outlet and also to change the way the piece is fastened to the circuit.

After doing several iterations of this design, the final result (Fig. 3) was reached eliminating the fastening clips, giving to the inlet the same shape as the conical outlet. The angle between the threaded radial outlets was reduced to 72 degrees (before was 90 degrees). A new outlet and a new piece were added, joining them by means of an interference fit and achieving a larger internal diameter of the outlet that allows a greater air flow inner. As a result, in a smaller space, six holes of different diameters were concentrated through which the air flows in different directions [6].

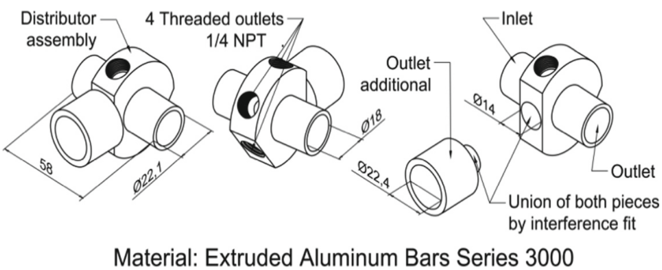

Fig. 3. Distributor manifold final design.

The mechanical element of the expiration circuit that had to be designed was the expiration elbow with an angle between both outlets of 90 degrees (Fig. 4). It connects the hoses coming from the patient with the expiratory pneumatic valve.

In the initial design, it was made up of two pieces with angles at their ends milled at 45 degrees and joined both pieces by welding. As the pieces are made of aluminum, the welding process becomes very expensive and productivity is very low. Under these circumstances it was necessary to make a new iteration of the design and change the way of the joint in both pieces.

This was solved by milling holes at 90 degrees and inserting one part into the cavity of the other with an interference fit joint.

The easy coupling and uncoupling of the elbow to the furniture plate was obtained with a nut that can be easily manipulated by hand. Finally, once the set is assembled, it is positioned in the equipment by means of a threaded knob.

Both pneumatic systems (inspiration and expiration) are controlled by a set of electronic boards (Fig. 5). The main board is where all the pressure sensors are located,