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DEVELOPMENT OF AN ARTIFICIAL RESPIRATORY DEVICE FOR EMERGENCY VENTILATION

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Abstract :This paper elaborates a novel research approach of an artificial respiratory device used for supplying artificial breath in respiratory failure condition by compression and controlling the function of Bag valve mask (BVM) using electro mechanical actuator and controlled by Arduino microcontroller. Two main parameters, Tidal volume and breaths per minute are considered as input variables. Paper also describes results of volumetric output of the device.

***IndexTerms*–Bag valve mask, Ambu bag, BVM, Artificial respiration, Stroke length, Tidal Volume.**

I. INTRODUCTION

Artificial respiration refers to initiating and supporting one's breath by manual or mechanical methods in respiratory failure condition [1]. Such conditions induce due to illness, accidents, infections like COVID-19, etc. Several methods are carried out by medical professionals to provide artificial breath such as manually compressible ambu bag or bag valve mask (BVM), ventilators, continuous positive airway pressure (CPAP) and Bilevel positive airway pressure (BiPAP) amongst which automating the manual function of BVM is main objective of this research [4]. Need of such emergency respiratory devices is observed in recent COVID-19 pandemic [2,3]. The objective of this research is to design portable and cost efficient artificial respiratory device which will turn out to be lifesaving.

Literature study indicates that the manual operation of BVM may have some drawbacks such as, synchronizing the respiratory rate with breathing pattern of patient is difficult task and subject to experience and expertise of medical professional conducting it [1]. A higher respiratory rate (known as hyper-ventilation) or lower rate (known as hypo-ventilation) are the common problems for manual operation of BVM. Manual operation of BVM also requires precise skills and human efforts. Considering all these drawbacks, the research is aimed for automating the function of BVM to reduce human efforts and gain consistency and accuracy in respiratory rate pattern while performing artificial respiration.

This paper includes novel approach towards development of the device in section II. The operating mechanism of the said device is elaborated in section III. Volumetric output of this device is discussed in section IV and further the paper is concluded.

1.1 Literature Review

The prior art for portable and emergency ventilators can be categorized as pneumatic and electric [1]. Mechanical ventilators are categorized by type of mechanical actuator used in them, such as cam and follower, scotch yoke mechanism and crank shaft mechanism. Respiratory systems such as CPAPs and BiPAPs are also portable but not cost efficient. CPAPs and BiPAPs are intended to use for treatment of obstructive sleep apnea.

Literature study also shows mechanical ventilator designs includes pliers or crab type of mechanism for compression of ambu bag [7]. Such mechanisms may possess complex operating systems and hence greater maintenance costs. As the market is lacking of portable, low cost, low maintenance and user-friendly ventilator system, there is need of one such device and it can be manufactured as per demand.

1.2 Objectives of The Research

The main objective of this research to automate the functioning of ambu bag to reduce human efforts and to gain consistency over each breath delivery. Another objective is to make it affordable to ambulances, small clinics and for individual ones. Such devices are useful not only for treatment of respiratory failure but also for treatment of Asthma, Tuberculosis and other respiratory

diseases. Another objective of this research is to make the device light in weight and portable, it may help hikers who do hiking at high altitude areas where air does not have sufficient amount of oxygen.

II. RESEARCH METHODOLOGY

2.1 Ambu bag

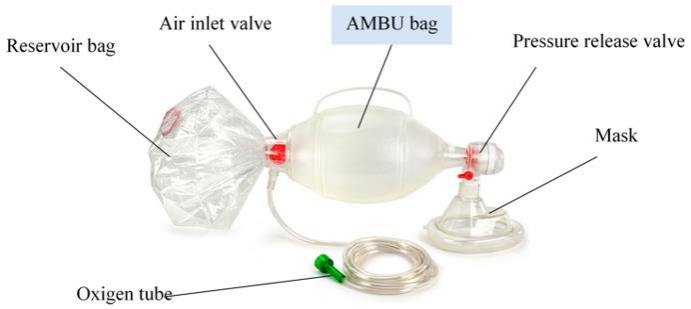

Figure 1. Ambu bag with part nomenclature.

As said above, Ambu bag also known as bag valve mask (BVM) is manual artificial respiratory device consists of main self-inflating bag made up of silicon material, a face mask, oxygen reservoir bag, tubing and valves. The main bag self inflates to gather air from air inlet valve. Further the air is delivered from outlet consisting of non-return valve. A pressure release valve is provided to avoid high pressure to entre in patient's lungs. Some ambu bags may have a PEEP (Positive end expiratory pressure) valve to avoid collapsing of alveoli during expiration. While operating this device, face mask is held tight on face of the patient and bag is compressed to provide amount of air to the lungs of the patient. The bag may operate at ambient air or it may be connected to oxygen supply as per condition of the patient. In this research compressing mechanism is made such that it can compress the ambu bag as per set respiratory rate by use of mechanical actuator, servo motor and microcontroller.

2.2 Electro-mechanical actuator

To compress the bag, a mechanical actuator is used with a semi-cylindrical plunger arm made up of nylon. Nylon material is selected to avoid puncturing and harm to the soft silicon material of BVM during its compression.

Figure 2 (a). Prototype of the device.

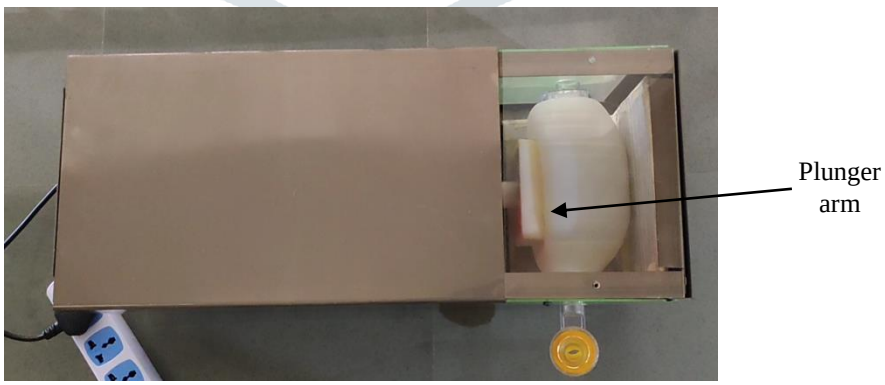

Figure 2 (b). Ambu bag in compressed position.

The actuator and plunger arm are connected to servo motor which provides necessary torque and operating to the actuator. The motor is controlled by Arduino micro-controller with suitable motor driver. The prototype consists of 12V DC geared servo motor. The servo motor operates at 'position control mode' wherein value of position control is assigned by use of Arduino program.

The servo motor is selected according to load estimated for compression of ambu bag. Hence ambu bag is made up of soft material, it is observed that motor runs at negligible load.

2.3 Electronics and control unit

As said above, the device has Arduino microcontroller as central controlling unit. Along with it, a customized'through beam optical proximity sensor' or opto-coupler is provided to determine position of the plunger arm. At starting, the plunger arm should be at its zeroth or inner dead center (IDC) position also called as 'Home position'. To determine whether the plunger arm is at IDC

or not the opto-coupler plays important role.A cooling fan is provided near the electronic unit and motor to dissipate heat generated during operation.

2.4 Power supply

The prime mover or the motor of the device runs of 12V DC supply for which a 12V SMPS is used as power source. The device has provision to run on 12V battery supply also. An IC 7805 is provided inside the device to convert 12V DC to 5V DC to run the Arduino.

III. OPERATING MECHANISM

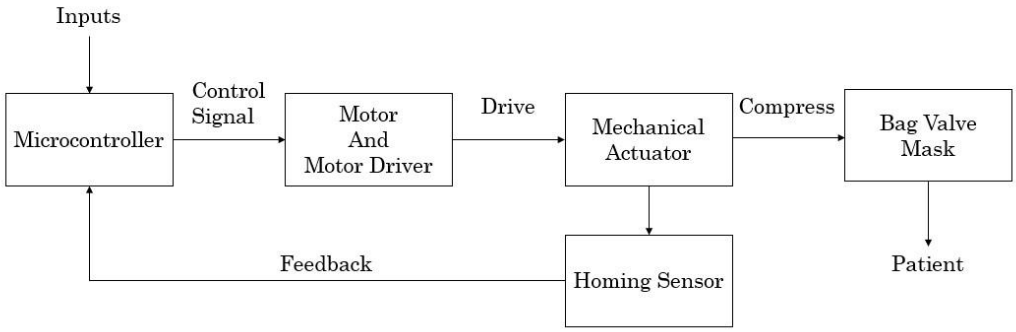

Figure 3. Process Block diagram.

When the device is started, the sensor sends feedback of plunger arm position to the controller. When arm is at 'home' position, the servo motor is rotated in anticlockwise direction and plunger arm is moved in forward direction to compress the bag. The amount of compression is dependent on position control value of the motor. After compression, motor starts rotating in anticlockwise direction results is reverse motion of plunger arm. Velocity and acceleration of motion is set inside the program.

Figure 2 (a) shows plunger arm at rest of home position, Fig. 2 (b) shows how bag is compressed by the plunger arm. Figure 3 is process block diagram elaborating whole process of the device.

3.1 Tidal Volume

As artificial or emergency respiration is considered, several medical parameters need to be controlled such as Tidal volume, breaths per minute and I:E ratio, etc. amongst which tidal volume and breaths per minute are the main two parameters to be considered during operation of BVM. The amount of air or oxygen provided to the patient by compression of ambu bag is called as tidal volume. The tidal amount may vary according to patient's condition. The device is made such that amount of tidal volume can be varied easily.

3.2 Breaths per minute

The second most important parameter for emergency breathing is breaths per minute i.e. BPM, Value of BPM can be controlled through the micro-controller by adjusting values of velocity and acceleration of motion. Normal range of BPM for human is 8 to 12 breaths per minute. It may vary upto 15 BPM as per patient's condition.

IV. RESULTS AND DISCUSSION

The device is still under experiment and theoretical calculations suggests that, Tidal volume of the device is directly proportional to the stroke length of compression, while stroke length of plunger arm is proportionate to 'position control values' of the motor. Table 1 shows variation of volumetric output from ambu bag with position control values.

One set of compression and returning to home position by plunger arm results in production of one breath delivery. Number of such sets performed in one minute decides value of BPM. Timing of strokes is maintained as follows, forward stroke of 1sec and return stroke of 1sec this results I:E ratio equals to be 1:1. Standard breathing pattern follows 1:2 or 1:3 I:E ratio. I:E ratio can be changed by applying delay in forward-backward loop in programming.

Table 1. Volumetric output of the device.

Sr. No.	Position control value	Flow rate (Nl/min)
1.	1,50,000	2
2.	2,00,000	5
3.	2,50,000	9
4.	3,00,000	13

V. CONCLUSION

It is observed that such artificial respiratory devices can turn out to be life saving in emergency situations. Lack of emergency medical apparatus in rural and recourse poor areas is a major problem in less developed countries. In COVID-19 pandemic need of small, portable and cost-efficient respiratory devices was addressed in India. The research is oriented at developing cost efficient and portable device. The device developed is almost size of a suitcase and weighs about 5kgs. The material and parts used are easily available through the market and are cheaper. Medical tests of the device are yet to be performed but the mechanism and electronics control unit provides technical flexibility to adopt the changes needed to be done after medical test performance.

The cost of the device is made affordable to primary health care centers as well as for small clinics. Portability of device made it useful for patients who are home quarantined as well as for ambulances, etc. So it is fair to say that main objectives behind conducting this research are fulfilled.

VI. FUTURE WORK

As said above, medical tests are yet to be performed, along with that several technical features are under development. Future iterations of this device will have all the technical key features which are most essentials.

5.1 User interface – Selector switch

A multi way selector switch will be included in the device for selection of tidal volume and BPM values. Multi-way selector switches are observed as cost efficient, easy to use and ergonomically superior user interface considering use of the device.

5.2 Weight reduction

Currently the device weighs about 5 kgs. All metallic parts are made up of aluminium. Future iterations of device will include use of acrylic or Nylon type of material instead of metal to reduce weight. Currently the undergoing research also includes reduction in the size of the device to make it more transportable and user friendly.

VII. ACKNOWLEDGMENT

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