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DESIGN OF A MECHANICAL VENTILATION SYSTEM USING QUICK RETURN MOTION MECHANISM

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Abstract: The novel coronavirus disease has exposed critical supply shortages of various medical equipments in the medical field. This is the fact that many of the critically ill patients have required mechanical ventilation system as the part of their treatment. In this paper an artificial manual breathing unit bag (AMBU bag) based mechanical ventilator is designed to fulfil the void left by the scarcity of traditional ventilators during the pandemic situation. A Quick Return Motion Mechanism is used as the driving mechanism of this ventilation system. In this study, modifications of mechanical ventilator are made so that tidal volume, inhalation-exhalation ratio and breathing rates could be regulated and controlled as per a patient's clinical requirements. The ventilator is designed using CAD modelling software. The power needed to drive the system assembly is also calculated. Although the results shown are not completely full proof, this kind of ventilator can be operated on patients under external supervision.

Keywords: Mechanical Ventilator, Quick Return Motion Mechanism, AMBU bag, COVID-19.

1. INTRODUCTION

COVID-19 outbreak has become a global issue as this new pandemic has adversely affected the world. This virus has caused severe global health issues which has led to substantial and significant economic and social impact. Due to this adversity, patients are hospitalized to support their lung functions with mechanical ventilation, as it is the best medical treatment availed by doctors during the severe medical crisis. The medical equipment's making industries are also facing huge problems in delivering the huge numbers of ventilators demanded by the hospitals. Hence, many research teams have used their competence and knowledge to develop simple and sophisticated designed respirators manufactured in a large number within a short period. Among many ventilators, AMBU-bag-based mechanical ventilators are usefully preferred by medical professionals. A mechanical ventilator is a machine that helps a patient to breathe when they can't able to breathe on their own due to a critical illness or during undertaking any

surgery. Mechanical ventilator functions by pumping oxygen-rich air into the lungs for respiration.

From the literature review it is observed that many researchers have studied mechanical ventilation system. Among them, Norlander [1] has analysed a mechanical ventilators considering force and power. He has discussed physiological aspects of the various ventilators based on the power demands in patients. He has also discussed the physiological effects of the gas distribution for different force-power patterns. Rodriguez et al. [2] have reviewed mechanical ventilation for general aspects of functioning and limitations of traditional modes. During their review, they have mentioned different draw backs of traditional modes of mechanical ventilation also have discussed alternative developed modes for patient's ventilation demand. They have seen these new modes of ventilation are very promising to help to improve adaptation during assisted ventilation. Gould and Beer [3] have described in details the principle of artificial ventilation. In their study, they have mentioned volume controlled mechanical ventilation for constant inspiratory flow and pressure-controlled ventilation for decelerating inspiratory flow pattern. Esteban et al. [4] have performed a prospective utilization review on patients. These patients have received mechanical ventilation for at least 12 hours after admission. During their study, they have considered 349 participating ICUs patients within 23 participating countries. They have collected demographic and baseline data of a patient at ICU admission. They have recorded different ventilator data, gas exchange variables etc. Younes and Brochard [5] have studied the control of breathing with different ventilator modes considering mechanical ventilation. They have determined breathing pattern and the ventilatory demands. Lewith and Pandit [6] have analysed lung ventilation mechanism and control of breathing. They have discussed lung mechanics where normal lung compliance and dynamic lung compliance are measured during dieses states. They have studied artificial ventilation considering invasive mechanical ventilation and controlled mechanical ventilation. They have seen that respiratory system has a great reserve at rest, but it can fulfil increased demands during stress condition. El-Hadj et al. [7] have investigated a mechanical ventilators using ANSYS Workbench platform. In their design, they have considered two different mechanical ventilators, one is Ambu-bag based ventilator and another is piston- cylinder-based ventilator. They have obtained better and more satisfactory results in piston- cylinder-based ventilator in comparison with the Ambu-bag based ventilator. Alan et al. [8] have designed a cam and oscillating follower based low cost mechanical ventilation system. In their experimental setup they have used an airbag resuscitator. They have also developed a mathematical model. The mechanical ventilation model is evaluated with this mathematical model.

In the present investigation authors have designed an AMBU-bag-based mechanical ventilator. The manual process of mechanical ventilation system is planned to be automated using the popular Quick Return Motion Mechanism.

1.1. HUMAN RESPIRATORY PHYSIOLOGY

The respiratory system functions by providing O_2 for metabolism and removing waste CO_2.
Four core aspects of respiratory physiology are:

- Pulmonary ventilation: The process in which addition and removal of gases takes place from the lungs.
- Gas exchange: Oxygen and carbon dioxide exchange take place within the body. The process in which blood gets recharged with O_2, and CO_2 waste gets removed from the lungs.
- Transport of O_2 and CO_2: The transfer of O_2 and CO_2 occurs between the tissues and the lungs.
- Regulation of ventilation: The process by which bodily needs are converted into faster or slower ventilation.

2. CLINICAL SPECIFICATIONS AND PARAMETERS

2.1. KEY PARAMETERS IN MECHANICAL VENTILATION

Of several parameters controlling the design and manufacturing of Mechanical Ventilator, three parameters are the most important:

- Tidal Volume (amount of air delivered to patient)
- Start of Inspiration Phase (known as triggering)
- Start of Expiration Phase (known as cycling)

2.2. TIDAL VOLUME: VOLUME-CONTROL VS. PRESSURE-CONTROL MODE

Tidal Volume can be defined as the amount of air in millilitres which moves in and out of the lungs in each respiratory cycle. In a healthy male it is 500 ml on average whereas in a healthy female average tidal volume is 400 ml. In volume control mode, a clinical operator preferably a doctor or a respiratory therapist defines tidal volume based on the patient's condition. Here, pressure is variable depending upon the compliance of the lung.

In pressure control mode, tidal volume depends on the patient's lung compliance and inspiratory time. In patients suffering from ARDS a baseline positive pressure needs to be maintained in order to keep alveoli open. This pressure is called positive end-expiratory pressure also known as PEEP in short.

Inspiratory Phase Start (Triggering) can be initiated at a regular interval which depends on respiratory rate, generally in range of 1:2 to 1:4. This is called time triggering. In another mode, ventilator can sense patient's effort of breathing using various pressure and flow sensors present in the circuit and start inspiration based on that. Expiratory Phase Start (cycling) is depending on several parameters namely time, flow, volume and pressure. In volume cycling, when the target volume is delivered to the lungs, expiratory phase starts.

If a specific rate of respiration is set in breaths per minute (bpm), the duration of inspiratory and expiratory phase can be determined using inspiratory to expiratory ratio known as IE ratio. These values can be manually adjusted. The duration of each phase is very important to consider in order for preventing over-inflation of lungs. Expiratory phase is longer than inspiratory phase.

Depending on the patient's condition or what machine determines, different modes of ventilation can be created by adjusting these parameters. Some of the most common examples of ventilation modes are volume control, assist control, pressure support, SIMV, etc. ICU ventilators have several modes that are available to serve the patient's needs.

2.3. OPERATING MODALITY

I Patient should be intubated or have a tracheostomy. (As per medical guidance).

ii. PEEP pressure must be adjusted as per judgement of clinician.

iii. Respiratory rate can also be adjusted; in our case it is mechanically adjusted.

iv. I/E ratio can also be adjusted mechanically.

v. Tidal volume is adjusted manually by detecting the compression of bag as per judgement of doctors. .

vi. The mechanical ventilation cannot work according to the breath sensing. Because it works only by the principle of proper controlling of volume. This is the main limitation of the mechanical ventilator.

vii. Components of breathing circuit and their optimization in order to give patient proper ventilation will require medical expertise.

2.4. PARAMETER SET

A mechanical ventilator should operate in volume control mode at an initial rate that can be adjusted based on patient's condition. In volume control mode airway pressure should be sensed in order to avoid barotrauma and other complications. As far as implementation is concerned this ventilator must be used only as a bridge to advanced ventilators. Prolon-ged use may cause damage to patient's lungs. Based on all the arguments made, three important parame-ters namely tidal volume, IE ratio and number of breaths per minute (bpm) is selected. The fixed values of all these have been defined in the table given below.

Table 1. List of specifications

Specifications	Standard or Range
Working principle	*Volumatic Adjustment.*
Volume range	*200 – 800 ml. 6 ml or less / kg (ideal patient weight) as start point*
Range	*8 – 40 or 10 – 40 breaths per minute*
I/E (inspiratory/ expiratory)	*1:2; range of 1:1 – 1:4 (COVID-19 patients are frequently requiring 1:3 and higher)*
Assist Control (breath detection or trigger sensitivity)	*Sensing pressure of -1 to -5 cm H_20*
Peak inspiratory pressure (PIP) (normally greater than 50 cm H_2O)	*Will be set by pop off valve threshold in initial product. If pressure transducer is used to continuously measure airway pressure, can program to limit PIP*

3. MECHANISM USED

3.1. QUICK RETURN MOTION MECHANISM

A quick return motion mechanism is a mechanism which converts rotary input into reciprocating output while having different acceleration and velocities in the two directions i.e. forward and backward movement. It is an accelerated return mechanism that produces a reciprocal effect so that the system takes less time for the return stroke when compared with the forward stroke. The backward stroke is much faster compared to the forward stroke and thus the motion is known as the Quick Return Motion Mechanism. This process is used in many applications. Shaper, slotting machine, screw-press, mechanicai drives are some of them. The main purpose of a quick accelerating mechanism is to reduce the time required for cutting.

Quick return mechanisms can be achieved using:

- Hydraulic Drive
- Whitworth Mechanism
- Crank and Slotted Lever Mechanism (Fig.1)

Hydraulic drives are mainly utilised in shaping machines. There is a piston inside the hydraulic cylinder in a hydraulic drive, which reciprocates. Ram and piston are connected with the help of the piston rod. Therefore, ram moves with the piston. This machine always requires continuous discharge oil pump, a valve chamber, a piston and a cylinder for smooth movement. The ram should be fastened with the piston. In the hydraulic quick return mechanism Hydraulic fluid is used to speed the ram. Implementing hydraulic drive will led to design compiications as it is difficult to execute it in a small model with simple operating methods.

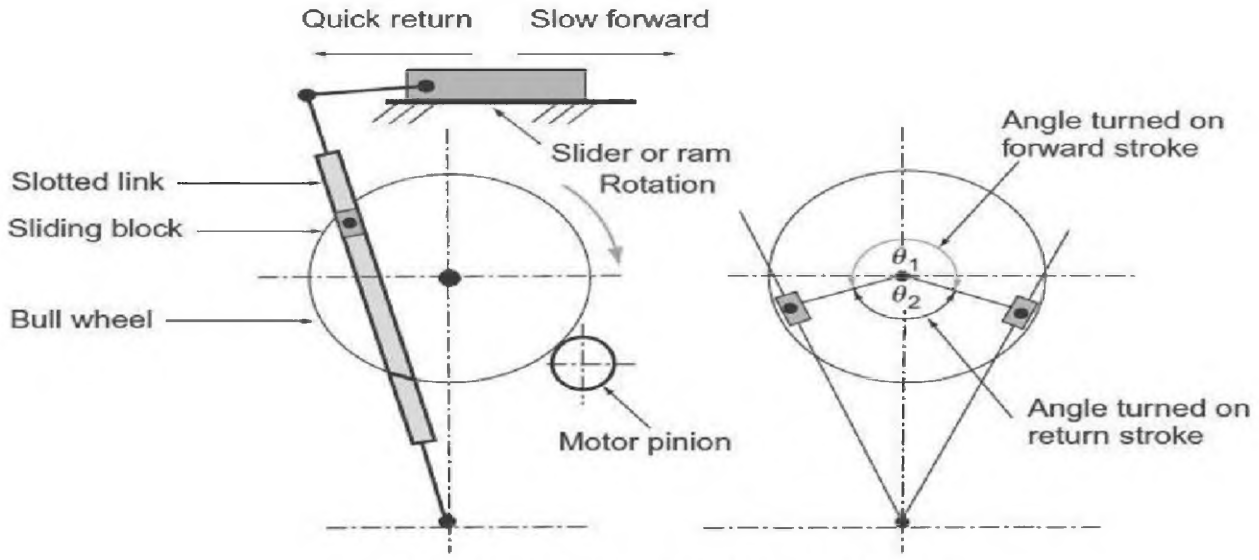


Fig. 1. Crank and Slotted Lever Mechanism

After looking at the remaining mechanisms and their respective possibilities, the slotted lever and crank quick return motion mechanism seemed like the better mechanism that served the required needs. This mechanism is considered a better version of the Whitworth Mechanism as it helps to vary a number of parameters as per requirements. Implementing the slotted lever and crank mechanism in the mechanical ventilator allows the control over the tidal volume supplied to the patient alongside maintaining a healthy breathing rate. This mechanism is the third inversion of the single slider crank chain which is a four-bar mechanism with degree of freedom as 1. A four-bar mechanism by trade, it consists of a rotating disc moving at uniform speed attached to an arm. The connecting rod is fixed in this inversion. It consists of one sliding pair and three turning pairs. The arm however, moves at a different speed than that of the rotating disc or in deeper terms, the forward stroke is slower than that of the return stroke, based upon which it is named. Implementing this mechanism in the mechanical ventilator allows the control over the inspiration and expiration stroke so that it follows the specified I/E ratio.

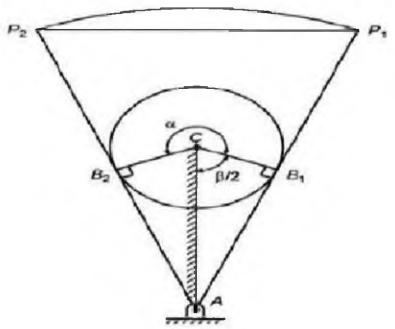


Fig. 2. Angles in Crank and Slotted Lever Mechanism

Quick Return Ratio = *Forward Stroke Angle/ Return Stroke Angle*
= *Forward Stroke time/ Return Stroke Time*
= α/β *(Fig.2)*

Tidal volume can be controlled by changing the length of stroke : ***Length of stroke = 2*L*R/CR***

Where, L = length of slotted lever
R = crank length
CR = connecting rod length

4. DESIGN CHALLENGES AND OBSERVATIONS

4.1. RESPIRATORY RATE ADJUSTMENT

As encountered by previous researches, the primary challenge is to be able to control the tidal volume based on patient requirements. The goal is not only to automate tidal volume control based on patient breathing patterns but to enable the corresponding physician to regulate the same just with a manual action as per the physician's wish. It has been previously stated that adjusting the Respiratory rate and the IE ratio is also of paramount importance.

Decision of using a plain DC motor with high precision having encoder support can help in adjusting the respiratory rate. If it is possible to equate one breathe cycle to one shaft rotation, simply changing the encoder motor velocity will allow adjusting respiration rates.

4.2. TIDAL VOLUME CONTROL

As stated previously, the QRMM consists of four key parts, the crank, the connecting rod, the bull gear and the slider/ram. Since varying the stroke width will affect the tidal volume, the goal is to vary the stroke width without deprecating the mechanism.

This implied that of among all three parameters, the stroke width is dependent upon, i.e. Slotted Lever Length (L), Crank Length (R) and Connecting Rod length (CR), changing any one would do the job. It may be mention that varying the Crank Radius will be the most viable and efficient option for varying the stroke length. The crank remains at a certain distance from the centre of the bull gear and the connecting rod remain attached to it as a pin. If it is possible to adjust the crank extension to move along the surface of the bull gear, tidal volume can be regulated.

Why not adjust the Connecting Rod length?

1. IE ratio depends upon the Connecting Rod length, and changing the Connecting Rod length would mean compromising with the IE ratio.
2. Velocity of the ram will get changed, and since the connecting rod component is of fixed length, there are chances that the assembly gets out of place. Hence, it will not be feasible.

4.3. INHALATION-EXHALATION RATIO REGULATION

Three different IE ratios are considered during the study. These are 1:2, 1:3 and 1:4. While considering QRMM, this I/E ratio is nothing but the inverse ratio between the Forward Stroke and Return Stroke time as inhalation occurs during backward stroke and exhalation occurs during the forward stroke. The rate of strokes depends upon angles turned during the respective strokes. It can be expressed as:

Time needed for Forward Stroke/ Time needed for Return Stroke = Forward Stroke Angle/Return Stroke Angle = α/β

5. DESIGN AND MODELLING OF MECHANICAL VENTILATOR

Based on the previously discussed points about specifications and needs regarding mechanical ventilation, the team decided upon designing a mechanical ventilator based on standard mechanical driving mechanisms. This will not only reduce design complexity (beneficial for mass production) but will also help to tackle key challenges faced by researchers in this field such as –

1. Tidal Volume Control
2. Respiratory rate adjustment
3. I/E ratio adjustment

Since the ventilator is an AMBU based machinery, the core component is the AMBU bag assembly. The AMBU bag assembly allows a clinically trained professional to manually pump in oxygen or air to a patient's lungs, in order to overcome the patient's breathing difficulties at the time of emergency. To automate this tedious process, the aim is to replicate this manual breathing process using a simple yet effective driving mechanism. Before moving onto that, it is imperative to have an academic understanding of the underlying principles in an Ambulatory Manual Breathing Unit or in short- AMBU. The components that are part of the AMBU are described in the following.

5.1. THE BAG

The Bag Valve Mask (BVM), mostly known by

Table 2. Different AMBU bags and their measurements

AMBU-BAG (Market name)	A (DISTANCE) (cm)	B (BOTTOM) Φ (mm)	C (TOP) Φ (mm)	D (CENTER) Φ (mm)
Adult Silicon	*21*	*61*	*29*	*129*
Care Fusion	*21*	*54.5*	*50*	*134*
Laerdal The Bag	*21*	*Na*	*40*	*139*
Portex	*20.5*	*61.5*	*37*	*131*

For this purpose, the Adult Silicon version of the AMBU bag is decided.

its proprietary name, the AMBU bag is perhaps the most important component of any AMBU based ventilator. The main body is a cylindrically shaped self-inflating bag primarily made up of silicon (as shown in Figure 1) and its conceptual development was done by German engineer Holger Hesse and his partner, Danish anaesthetist Henning Ruben in 1953.

The bag receives fresh oxygen from the inlet unit, stores it within its chamber and allows unidirectional flow to the patient unit. To make the design adjustable for any bag size, different types of bags available in the current market were accounted for and the study was adapted according to that. The dimensions of the various contact points and centre of the bag is given in Table 2.

5.2. THE INLET UNIT

The Inlet Unit is connected towards the side with larger opening and it is responsible for unidirectional flow of oxygen supply. This consists of two openings, the smaller one is attached to liquid oxygen supply while the other one is attached to a reservoir. The reservoir can be of two types– 1. Corrugated tube type, and 2. Bag type. Apart from the openings, there is also an inlet valve which promotes unidirectional flow of air and oxygen within the bag.

Once the Bag gets squeezed, the valve is closed and the oxygen and air mixture within it cannot move back to the reservoir. If neither opening is connected with oxygen supply nor reservoir, patient can still receive ventilation in the form of atmospheric air mixture, which roughly contains 21% oxygen; On the other hand, if only oxygen supply is attached without the reservoir, the patient can receive a mixture containing around 40% oxygen. 100% oxygen mixture can only be supplied if both reservoir and oxygen supply is attached to the inlet unit.

5.3. THE PATIENT UNIT

The Patient Unit is connected with the bag on the opposite side of the inlet unit. This remains directly connected to the patient and regulates inhalation and exhalation through careful usage of mechanical valves. It primarily consists of three valves-

A. The Pop-Up Valve: The Pop-Up/Safety /Pressure Release valve remains at the top of the patient unit and it stops air from entering the patient if the pressure exceeds a certain threshold. This is mainly used for patient's

safety and it can be disabled if required.

B. The Fish Mouth Valve: The Fish Mouth valve allows unidirectional flow of fresh air to move into the patient's lungs. This valve opens when the patient during inhalation and is closed during exhalation.

C. The Expiratory Valve: The Expiratory valve releases the exhaled air from the patient. A PEEP valve can be introduced after the expiratory valve in order to maintain back pressure. The entire patient unit is shown in Figure 3.It is noted that the necessary plumbing required for the assembly should be done according to an appropriate breathing circuit manually by a trained professional as manual resuscitator bags are not FDA approved as long-term ventilation solutions..

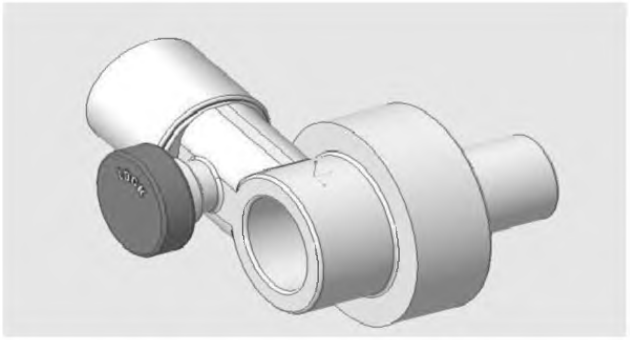


Fig. 3. he patient unit valve mechanism

After deciding upon the ways in which the design challenges can be tackled, the team started designing the mechanical ventilator using PTC Creo Parametric 8.0, a Computer Aided Modelling Software. The AMBU assembly previously mentioned are commercially available thereby eliminating the need to design the customised assembly of the ventilator.

5.4. ADJUSTING THE TIDAL VOLUME

In order to solve the design challenge mentioned in section 4.2, we took reference from a simple box cutter and the way it allows us to adjust the knife length through manual adjustment. In the same manner, well defined groove within the bull gear was developed and the crank extension was turned into a slider component. This allowed manual adjustment of the Crank Radius (R), which in turn affected the stroke length.

As the stroke length was inversely proportional to the amount of air the AMBU bag can pump at a time, tidal volume could be adjusted by simply moving the crank extension manually

5.5. DESIGNING THE AMBU MOUNTS

Most commercially available AMBU bags have a distance of 21 cm. This meant that the mounts can be spaced 21 cm apart with some kind of vertical adjustability considering that the necessary valves and sections are extended.

5.6. DESIGNING OF THE BULL AND PINION GEAR

The Pinion gear is designed in such a manner that the Gear ratio between the Pinion and the Bull would be 1:3. In that way, the high rpm of motor can be off set into workable speed.

The bull gear would have another extension attached in front of it. The distance between the centres of the extension and the gear would be the Crank Radius (R) which would be varied during Stroke length calculation.

Table 3. Observation of Crank Radius for different stroke widths

Slotted Lever Length L (mm)	Connecting Rod Length CR (mm)	Stroke Length = 2*R*L/CR	Crank Radius R (mm)
50	*20*	*60*	*12*
50	*20*	*55*	*11*
50	*20*	*50*	*10*
50	*20*	*45*	*9*
50	*20*	*40*	*8*

For this, box cutter like grooves are made on the bull gear's front surface.

5.7. DESIGNING THE CONNECTING ROD

The slotted lever is designed after referencing the bull gear and the stroke length. For maximum tidal volume push, the optimum stroke length will be around 40mm, and if Crank Radius is 8mm, then the slotted lever should be 50mm in length.

5.8. DESIGNING THE SLIDER RAM

After designing the connecting rod, the slider ram is designed. It is made in such a way that its dimensions would have minimum effect on the stroke length.

5.9. DESIGNING THE COMPRESSORS

The compressor is designed and connected to the ram, fixated with a connecting screw, so that it would not have any degree of freedom. The compressors are made convex shaped instead of concave for uniform distribution of force upon the AMBU bag.

6. RESULTS AND DISCUSSIONS

All components are designed first. Then the stroke lengths of the current dimensions are calculated. It is ensured that each and every connection has sufficient tolerance on pre-assembling. Since, the interior volume of the compressed AMBU bag has not been calculated for different stroke widths, manual readings of crank radius for different stroke lengths are taken and grooves on the bull gear are made accordingly.

6.1 RETIRED MECHANISM: THE RACK AND PINION MODEL

The Rack and Pinion is a kind of linear actuator which comprises of a circular and a linear gear. The circular gear is called as Pinion, while the linear gear is called rack. This gear engagement translates rotational motion into linear motion as rotating the pinion makes the rack move linearly and vice-versa as shown in Figure. The rack and pinion is chosen as a driving mechanism because it would allow converting the rotating motion of motor shaft to the linear motion one needed for compressing the AMBU unit. If one can change the rotating direction of the motor, then one can also tackle adjusting the tidal volume and the IE ratio, since encoder motor velocity can be regulated. However, this model has major drawbacks and eventually it should be retired for the following reasons–

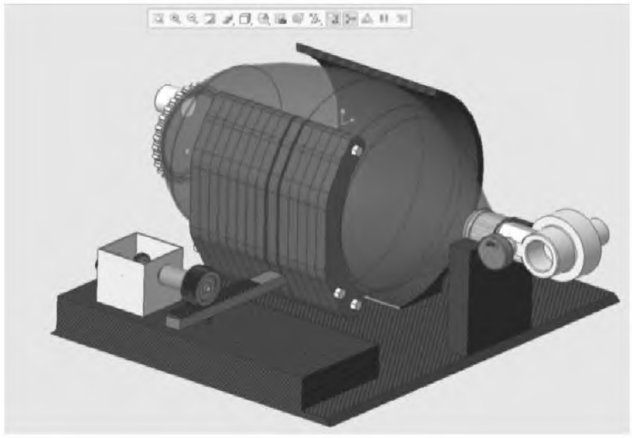


Fig. 4. Retired Mechanism: Rack and Pinion Model

1. For achieving the to and fro motion of the mechanism, either two motors rotating in opposite directions or a single motor subjected to polarity reversal after specific intervals would have been required. This is simply impractical and cannot be improved upon.
2. Even if to and fro motion is achieved by careful monitoring, the motion can never be smooth and can break down while in emergency. The patient can be at life risk in that case.

6.2. RETIRED MECHANISM: THE SLIDER CRANK MODEL

The slider crank is a typical arrangement of mechanical components which convert rotary motion to linear motion and vice-versa. It is primarily used in reciprocating piston engines in automobiles across the world. The mechanism can be seen in Figure 5. The crank performs a rotary motion along its central axis, while the connecting rod is connected with it through pins which are not located at the absolute centre of the pin. This allows the connecting rod to not remain static but perform a helical movement. The connecting rod transforms the motion to the slider which is capable of moving linearly, thus converting the rotary motion of the crank to the linear motion of the slider.

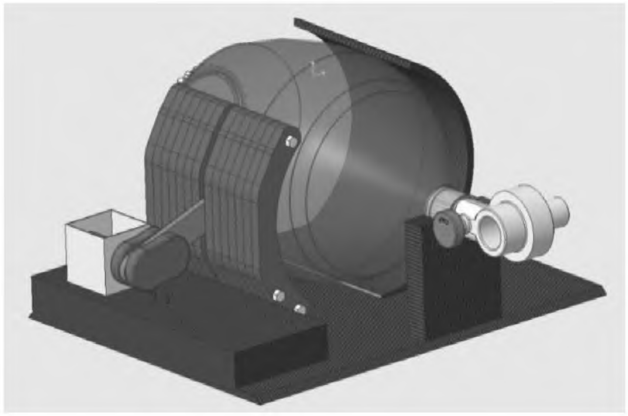


Fig. 5. Retired Mechanism- Slider Crank Model

1. As stated previously, Tidal Volume Control is of prime importance for any ventilator, and unfortunately this model did not provide any solutions regarding that.
2. The IE ratio for this model would remain constant at 1:1, which is impractical.

6.3. MATERIAL SELECTION

1. Three materials are selected primarily for the design after carefully studying all the available options.

2. The compressing hand is made up of ABS Plastic.

3. Structural steel is chosen for rest of the assembly. Other materials can also be considered based on the design need.

Table 4. Properties of Materials

Properties	PVC Plastic	ABS Plastic	Structural Steel
Density	*1330 kg/m^3*	*1040 kg/m^3*	*7850 kg/m^3*
Young's Modulus	*32.4 MPa*	*2.39 GPa*	*207 MPa*
Poisson's Ratio	*0.475*	*0.399*	*0.3*
Shear Modulus	*10.983 MPa*	*854 MPa*	*7.91e+10 Pa*
Tensile Yield Strength	*1.95 MPa*	*41.4 MPa*	*2.5e+08 Pa*
Tensile Ultimate Strength	*1.95 MPa*	*41.4 MPa*	*2.5e+08 Pa*

6.4. SYSTEM ASSEMBLY

All the components of mechanical ventilator are designed and assembled in CREO Ptc software.

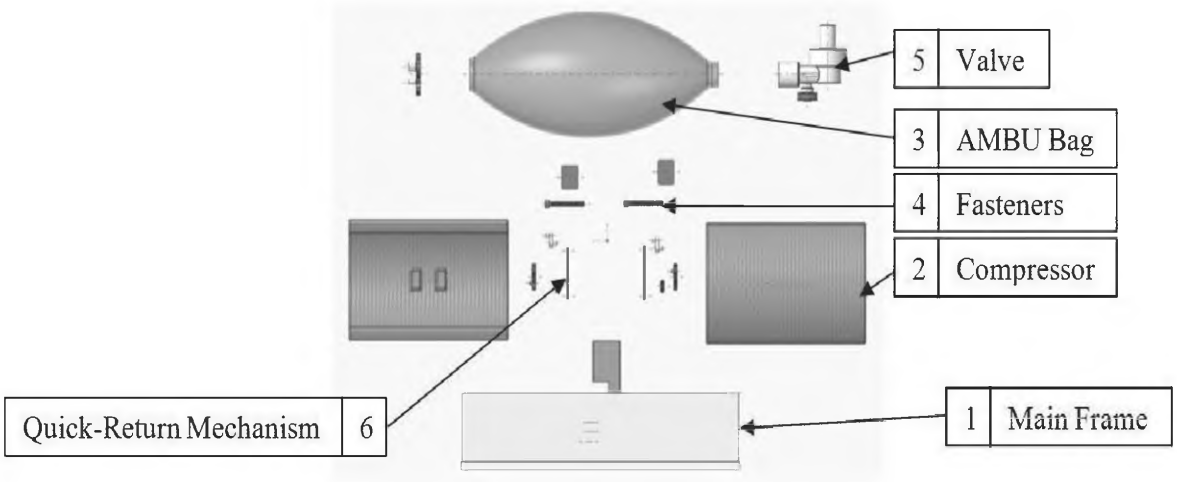


Fig. 6. Side Exploded view of Assembly

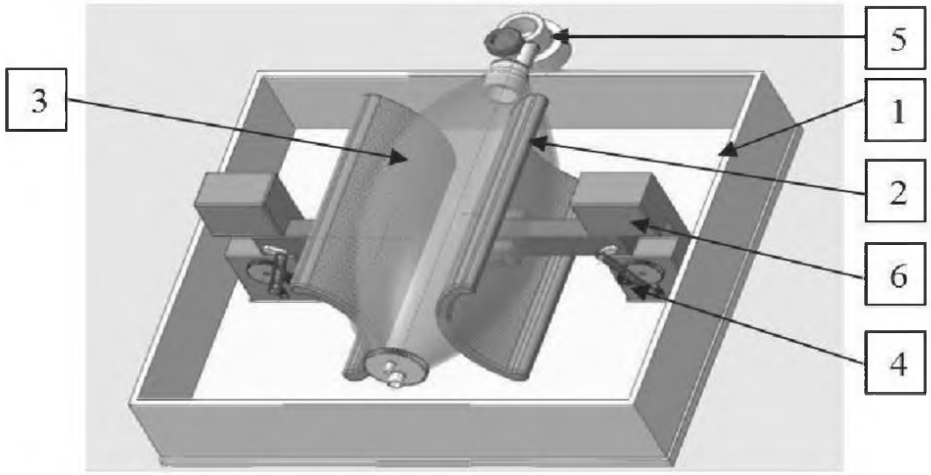


Fig. 7. Final assembly

Table 5. Inhale and Exhale rate for different values of angles

I/E RATIO	α (degree)	β (degree)	Driven Gear speed (rpm) = breathes/minute	Time for inhalation (s)	Time for exhalation (s)
1:2	*240*	*120*	*10*	*2*	*4*
1:2	*240*	*120*	*20*	*1*	*2*
1:2	*240*	*120*	*30*	*0.667*	*1.33*
1:2	*240*	*120*	*40*	*0.5*	*1*
1:3	*270*	*90*	*10*	*1.5*	*4.5*
1:3	*270*	*90*	*20*	*0.75*	*2.25*
1:3	*270*	*90*	*30*	*0.5*	*1.5*
1:3	*270*	*90*	*40*	*0.375*	*1.125*
1:4	*288*	*90*	*10*	*1.2*	*4.8*
1:4	*288*	*90*	*20*	*0.6*	*2.4*
1:4	*288*	*90*	*30*	*0.4*	*1.6*
1:4	*288*	*90*	*40*	*0.3*	*1.2*

The observations for standard breathing rates are given in table 5.For the purposes, the mechanism is fixated on a 1:2 IE ratio as it is globally recognised to be healthy breathing rate.

6.5. CALCULATION FOR INHALATION AND EXHALATION TIME

A speed variable control motor (generally have higher rpm than required in the model for healthy breathing rate) is used in the model through a gear and pinion arrangement so as to reduce the speed of compressing arms. In the gear arrangement, the motor is connected to the gear and the arms of the compressor to the pinion. For every rotation of the driven gear (pinion), a breathing cycle takes place.

Here, w1/w2 = r2/r1. (w = angular velocity; r = radius of gear)

As compression of ambu-bag takes places in the return stroke;

Time for inhalation = Time taken for return stroke

Time for exhalation = Time taken for forward stroke

Time for a breathing cycle in seconds; T_{cycle} *= 60 s / rpm of driven gear = 60 s / Respiration rate*

$T_{inhale} = 60 / RR / (1 + I_{Eratio})$ s

$T_{exhale} = T_{cycle} - T_{inhale}$

Where, RR = Respiration rate

6.6. POWER CALCULATION

The power requirement for the compressor is calculated below, but not considering the internal design of compressor. The following parameters with values are considered during the finding out of power calculation:

Assuming the maximum Airway pressure will be; $S_{airway, max}$ = 40 cm H_2O (depending the patient condition).

Maximum Breathing count per minute; Bmax = 40 $_{bpm}$ (This value is equal to 0.04 bar).

Where, bpm= breathes per minute

Taken, the ratio between inhale/exhale ratio of 1:2, the minimum value is considered from the table no. 5; $IE_{ratio, min} = 2$

The Maximum output volume through compressor; $CV_{max} = 800\ cm^3 = .0008\ m^3$

The AMBU bag should be provided minimum air at a pressure of 40 cm of H_2O, during any time of the operation.

S0, the inhaling time will be $T = 60 / B_{max} / (1 + IE_{ratio,min})$

i.e. T = 60/40/ (1+2) s = 0.5 s. (Considering the values of B_{max} & $IE_{ratio,min}$)

For the critical condition, the maximum volume flow rate at airway will be,

$Q_{max} = CV_{max} / T = 800/500000\ m^3/s = 0.0016\ m^3/s$

The power required as per above calculation

$P = S_{airway,maxx} Q_{max} = 4000*/0.0016\ W = 6.4\ W$

Moreover, there may be some amount of power loss in compressor due to bag deformation, friction, etc. Here 50% power is considered for maintaining the critical flow rate. So, the power required at the compressor as per mentioned consideration will be:

$Power_{compressor} = 2*P = 12.4W$

The motor efficiency is not considered in above calculation. The actual motor power requirement will be more. This extra power depends on the design criteria of mechanical and electrical guidelines. There is power loss of motor due to mechanical and electrical design (gears, thermal dissipation, etc.). So, considering the motor efficiency is 50%. Then, the actual motor power requirement will be:

$P_{motor}(Actual) = 2Power_{compressor} = 24.8W$

Thus, two motors of 25 W each on the two sides are needed. Motors of 25 W powers are standard and these are easily available. In this model, motor does not drive the arms directly, instead it drives the driving pinion. So, torque of the motor must be selected by keeping that in mind. This is theoretical power requirement. The actual power required may vary based on design.

7. CONCLUSION

An AMBU bag based mechanical ventilator is designed using the Quick Return Motion Mechanism. During modeling, several key challenges are faced while automating the process of mechanical ventilation. In this design, encoded DC motors are used for varying the breathing rates. A slight adjustment is made in the QRMM assembly design so that the length of the connecting rod could be varied, and in turn the tidal volume can be controlled. Although regulating the Inhalation-Exhalation ratio would have made the ventilator more robust, the design team recommends for the globally recognized healthy IE ratio of 1:2 with scope for future modifications. The implications of this project are far and wide because not only it would be a viable stopgap for lack of traditional ventilators during pandemics but also can be a good alternative in clinical centers which cannot afford traditional expensive ventilators.

REFERENCE

[1] Norlander, O. P., Functional Analysis of Forge and Power of Mechanical Ventilators, Acta anacsth. Scandinau, Vol.8, pp. 57-77, 1964

[2] Rodriguez, P., Dojat, M. and Brochard, L., Mechanical Ventilation: changing concepts– Review Article, Indian Journal of Critical Care Medicine, Vol.9, No.4, pp. 235-243, 2005

[3] Gould, T. and Beer, J. M. A. de, Principles of artificial ventilation, Anaesthesia & Intensive Care Medicine, Vol 8.3, pp. 91-101, 2007.

[4] Esteban, A., Ferguson, N. D., Meade, M. O., Vivar, F. F., Apezteguia, C., Brochard, L., Raymondos, K., Nin, N., Hurtado, J., Tomicic, V., Gonza´lez, M., Elizalde, J., Nightingale, P., Abroug, F., Pelosi, P., Arabi, Y., Moreno, R., Jibaja, M., D'Empaire, G., Sandi, F., Matamis, D., Montan˜ez, A. M. and Anzueto, A., Evolution of Mechanical Ventilation in Response to Clinical Research, American Journal of Respiratory And Critical Care Medicine, Vol. 177, pp. 170-177, 2008.

[5] Younes, M. and Brochard. L., The Control of Breathing during Mechanical Ventilation. Clinics in Chest Medicine, Vol. 40, pp.259-267, 2019.

[6] Lewith, H. and Pandit, J. J., Lung ventilation and the physiology of breathing, Surgery (Oxford) Vol. 38, Issue 5, pp. 233-239, 2020.

[7] El-Hadj, A., Kezrane M., Ahmad , H., Ameur, H., Rahim S. Z. B. A., Younsi, A. and Abu-Zinadah, H., Design and simulation of mechanical ventilators, Chaos, Solitons and Fractals Nonlinear Science, and Non equilibrium and Complex Phenomena, Vol.150, 2021.

[8.] Alan Calderon Ch, J., Rincon, C., Agreda, M. and Cisneros, J. J. J. de., Design and analysis of a mechanical ventilation system based on cams, Heliyon, Vol.7, 2021.