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Design of an Emergency 3D Printed Electro-Mechanical Ventilator with Bag-Valve–Mask (BVM)

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***Abstract*: As a result of the COVID-19 epidemic, there are severe shortages of ventilators caused all across the world. To overcome this problem a 3D printed manual ventilator is a simple type of ventilator that is manually operated and relies on a bag and mask to open the airway and provide enough ventilation. (Bag-Valve-Mask) is an important aspect of manual ventilation since it enhances airflow as well as respiration these bags are return to their original shape spontaneously after being compressed. In this work a simplified mechanism of a 3D printed mechanical ventilator with a BVM is proposed and designed for ventilation. The BVM is operated by a battery and a DC motor driven by a 3D printed rack and pinion mechanism. The rack and pinion mechanism compress and decompress the bag in response to signal. The main advantage of this project is it can be sent to hospitals in rural areas for quick treatment at a low cost and with minimal risk. It can be operated by anyone because it does not require the study or training of ventilation rules like an ICU ventilator. The proposed system is risk-free, safe, and repairable. The accuracy of the angle, volume, and respiratory measurements were absolutely close to traditional one. This portable ventilator equipment can be used in rural or general hospitals, as well as ambulances, to provide rapid care.**

***Keywords*: BVM (Bag-Valve-Mask), Battery, BLDC Motor, Covid -19, 3D Printed rack and pinion, Low-cost.**

1. Introduction

1) 3D printing

The production of a three - dimensional object from a CAD model or a digital 3D model is known as 3D printing or additive manufacturing. The term 3D printing can refer to a variety of methods in which material is deposited, connected, or solidified under computer control to make a three – dimensional object, with material being placed together (such as polymers, liquids, or powders grains that are fused), typically layer by layer. Rapid prototyping is another term for it. It's a mechanized process in which 3D items are swiftly created to the desired size using a machine connected to a computer that contains blueprints for any object. The subtractive method, in which material is removed from a block by sculpting or drilling, may differ from the additive method. The primary objective for using a 3D printer is to maximize resource consumption, extend product life, and make products lighter and stronger. 3D printing is widely used in a variety of industries, including aerospace, automotive, medical, construction, and the manufacture of a wide range of consumer goods.

2) Basic steps involved in additive manufacturing (AM)

- Create a cad model of the design
- Convert the CAD model to STL format
- Slice the STL file into thin cross – sectional layers
- Construct the object through layer by layer
- Clean and finish the object if may required

2. Principle

1) Modelling

The object or model that will be printed must first be designed or modelled using a CAD (computer-aided design) program such as Solid Works. By using a 3D scanner or a digital camera with specialized photogrammetry software. These 3D printed models were produced with the use of CAD, which resulted in fewer faults being discovered and addressed before printing. The method of manually modelling geometric data for 3D computer graphics is analogous to plastic arts such as sculpture. 3-Dimensional models of the scanned object can be created using this information.

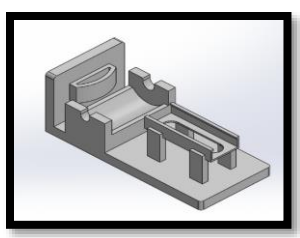

Fig. 1. CAD Modelling

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After creating a model in a CAD program (in.skp, dae,.3ds, or another format), it must be converted to a STL or.OBJ format so that printing software can read it.

2) Printing

After the model has been converted to STL, it must be checked for "errors," a process known as "fix up." Most cad applications cause problems in STL files that must be addressed, such as self-intersection, incorrect holes, and face normal. After the file has been converted to STL, it must be processed by a program called "slicer," which divides the model into layers and generates a G-code file with instructions for a certain type of 3D printer. The 3D client software (which loads the G-code and uses it to command the 3D printer during printing) may print this G-code file. Client software and slicer applications like as Cura, Slic3r, Repetier-host, Pronterface, and skein forge, as well as closed source programs like simplify 3D and KISSlicer, are available in practice.

To create a model from a succession of cross sections, a 3D printer uses G-code instructions to lay down consecutive layers of liquid, powder, paper, or sheet material. Plastic, sand, metal, and other materials can be utilized with a print nozzle. To construct the final shape, these layers, which correspond to the virtual cross sections from the CAD model, are linked or automatically fused. The process could take minutes or hours, depending on the printer's output. The layer thickness and X-Y resolution of a printer are measured in dots per inch (dpi) or micrometers (m). The layer thickness that can be found is typically approximately 100gm, while some of these machines, such as the object connex series and the 3D Systems ProJet series, can print as thin as 16m layers. These X-Y resolutions are comparable to laser printers. The particles (3D dots) range in size from 50 to 500m (510 to 250 Dpi) in diameter. The procedure for Model construction can take anything from a few hours to several days, depending on the size of the model, the technology utilized, the printing speed, and the model's intricacy. Depending on the type of machine and its size, the time can usually be reduced to a few hours. Designers and concept models can be printed on a desktop with 3D printers.

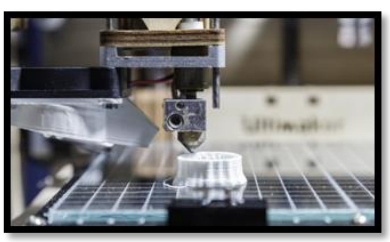


Fig. 2. Printing of models

3) Finishing

For many applications, the printer's resolution is sufficient, but the printing will be a slightly bigger version of the desired object, which can be the standard resolution, and then the process of eliminating material can provide more precision. Chemical vapor methods can smooth out and increase the surface finish of some printed polymers. Some additive manufacturing processes are capable of using various materials in the construction of parts. These techniques can print in a variety of colors and color combinations at the same time. Internal supports for overhanging parts are required for several printing processes during fabrication. After the printing is finished, these supports must be mechanically removed or dissolved. Metal 3D printers that have been commercialized are extremely likely to include cutting the metal component of the metal substrate after deposition. The extremely innovative GMAW 3D printing technology, which will enable for substrate surface adjustments and the manual removal of many aluminum components with a hammer.

3. Applications of 3D Printing

1) Education

New learning materials you may desire new teaching resources, but you may not be able to buy them. Their resources can now be printed utilizing a 3D printer, saving your department money. When we print our own learning, materials are not only less expensive, but they are nearly always faster as well. Despite the fact that kinesthetic learners prefer to learn through the use of aids and objects, they are generally taught through books and theory. 3D printing allows you to bring any subject matter to life as a tangible assistance to engage all of your pupils for an extended amount of time, strengthening their learning and problem-solving and critical thinking capabilities.

Fig. 3. Planetary gear

2) Apparel

Fashion designers are experimenting with 3D-printed shoes, and gowns as a result of 3D printing's growth into the realm of clothes. When it comes to commercial production, Nike uses 3D printing to develop and manufacture the same football shoe for American football players, whereas New Balance uses 3D printing to create custom fit shoes for all sportsmen. Companies are already generating consumer-grade eyewear with on-demand personalized fit and styling using 3D printing (although they cannot print the lenses). Rapid prototyping allows for on-demand customization of spectacles.

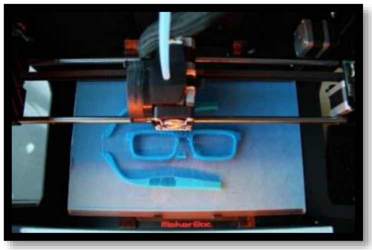


Fig. 4. 3D printed shoe and Spectacle

3) Construction

We may use 3D printers to create civil models such as building prototypes and plan constructions so that buyers can visualize the models simply.

Fig. 5. Prototype building constructing

4) Dental

We can print jaws with the help of 3D printers. It could be a prototype or a jaw bone that can be transplanted depending on the situation. An 83-year-old British woman just had the world's first 3D-printed personalized lower jaw transplant.

Fig. 6. 3D Printed Digital Dentures

5) Medical

3D printing's medical applications are fast developing, and it is expected to improve health care. Tissue and organ fabrication; construction of customized prosthetics, implants, and anatomical models; and pharmaceutical research regarding drug dosage forms, transport, and discovery are just a few of the current and potential medical applications for 3D printing. The use of 3D printing in medicine has a number of advantages, including the ability to customize and personalize medical items, medications, and equipment, as well as cost-effectiveness, higher productivity, democratization of design and manufacturing, and improved cooperation. However, despite recent substantial and exciting medical discoveries involving 3D printing, considerable scientific and regulatory difficulties still exist, and the most disruptive applications for this technology will take time to mature.

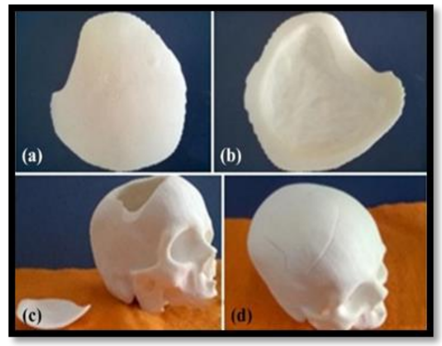


Fig. 7. 3D printed cranial and pelvic bone

B. Classification of Additive Manufacturing Process

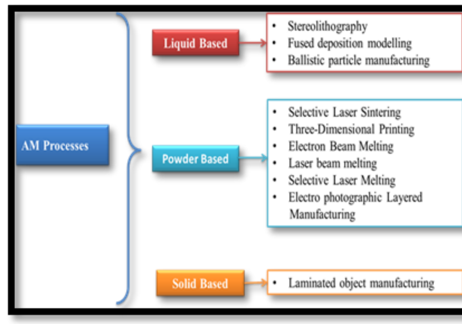


Fig. 8. Manufacturing process

1) Advantages of 3D printing

- Complexity is free
- Digital object storage
- Extreme light weight design
- No assembly required
- Reduce material wastage
- Tool less

2) Disadvantages of 3D printing

- Extensive knowledge in material design
- High production costs
- Limited component size
- Poor mechanical properties
- Slow build rates

4. Introduction of solid works

Solid Works is a computer-aided design (CAD) tool that allows you to model and draw any simple or complicated mechanical shape or assembly. The drawn project can then be fed into CNC laser cutters or used for additional simulation and analysis. On your project, you can run several sorts of simulations (thermal, flow, frequency, etc.) and utilize the data to improve your system. Solid works is primarily concerned with removing challenges in the fields of design and manufacturing by allowing for easy detection of stress deflection and other parameters during simulation without requiring actual production. That is, it relieves us of the burden of producing trash and less palatable products than we truly require. Solid labor, without a doubt, improves output in every way due to its significant contribution and numerous benefits. Simply put, the design you create in Solid Works will be directly created by a CNC machine that speaks the coded language.

1) Usage of solid works

From start to finish, SOLIDWORKS is used to build mechatronic systems. The software is initially used for project management, planning, visual ideation, modelling, feasibility evaluation, prototyping, and feasibility assessment. After that, the program is used to design and create mechanical, electrical, and software components. Finally, the program can be used to manage devices, analytics, data automation, and cloud services. Mechanical, electrical, and electronics professionals use the SOLIDWORKS software solutions to create an integrated design. The set of applications is designed to keep all engineers in the loop and able to respond quickly to design modifications or requests.

According to their website, SOLIDWORKS includes the following products:

- Circuit Works is an electronic CAD/ECAD translator that allows engineers to design precise 3D circuit board models.
- *CAM:* a SOLIDWORKS CAD add-on that allows you to prepare your designs for manufacturing earlier in the development cycle.
- *Electrical 3D:* allows you to add electrical components in a 3D model and use SOLIDWORKS routing technology to connect electrical design elements automatically. Any changes to 2D schematics and 3D models are automatically updated because they are synchronized bi-directionally in real time.
- *Simulation:* simulates CAD models to anticipate a product's real-world physical behavior using Finite Element Analysis (FEA).
- *Visualize*: Use your 3D CAD data to quickly and easily produce photo-quality content, ranging from photos to animations, interactive web content, and immersive Virtual Reality.

Based on user feedback, SOLIDWORKS continues to improve its solutions to accommodate new features. Improved performance, simpler workflows, and 3D Experience, a cloud-based platform are among the new features of SOLIDWORKS 2020. Programs like SOLIDWORKS are essential for anyone working in the field of Mechatronics. Mechatronics students at Capitol will pursue CAD, automated systems design, and mechatronic systems design classes.

2) Ambu bag or bag – valve – mask

As a result of the covid-19 epidemic, there are acute shortages of ventilators all across the world. For covid-19 patients with critical respiratory failure, a manual ventilator with BMV is employed in emergency situations. The Artificial Manual Breathing (AMBU) bag, as shown in fig, is used as a commercial device in emergency situations and as a part of the basic kit in hospitals.

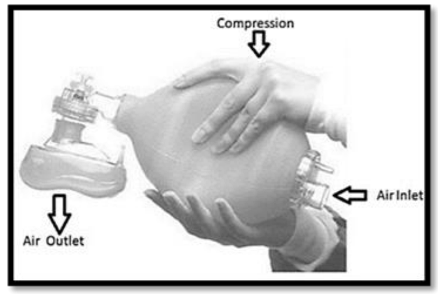


Fig. 9. AMBU bag

Manual ventilators are often used in hospitals to provide ventilation or to move patients inside and outside of the hospital. In the absence of endotracheal intubation, the BMV is an effective device for delivering ventilation. Even for skilled teams, however, this manual ventilation strategy is challenging to handle in emergency situations.

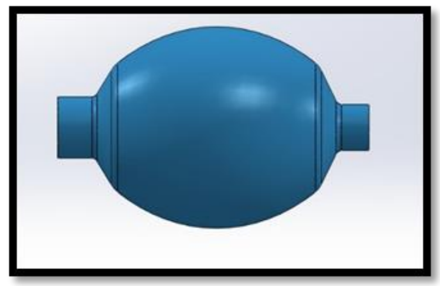


Fig. 10. AMBU Bag CAD design

5. Reciprocating Rack and Pinion Mechanism

The rack and pinion mechanism is the most extensively used mechanism in various industries, however it can only move back and forth. A new system for combining reciprocating and rotating motions, as well as vice versa, is disclosed. The goal of the research is to analyze the mechanism’s operation and look into its potential applications in various industries.

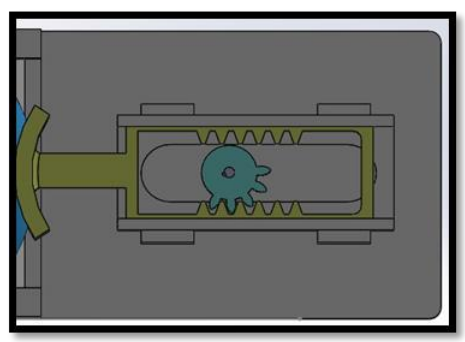


Fig. 11. Reciprocating rack and pinion

1) Rack

It is a type of gear rack which is used to convert rotating movements into linear motion. A gear rack has straight teeth cut into one surface of a square or round section of rod and operates with a pinion, which is small cylindrical gear meshing with the gear rack. Generally, gear rack and pinion are collectively called “RACK AND PINION”.

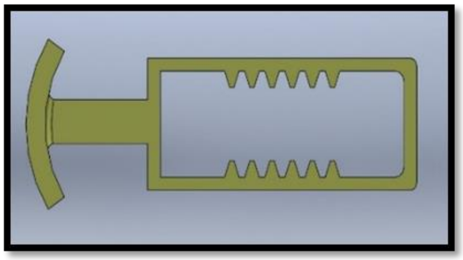


Fig. 12. Rack

2) Pinion

A pinion is a round gear that is usually the smaller of two meshing gears and is used in a variety of applications such as drive trains and rack and pinion systems. Also, it refers to the cylindrical gear that meshes with a rack in a rack and pinion mechanism which transforms rotational motion to linear motion.

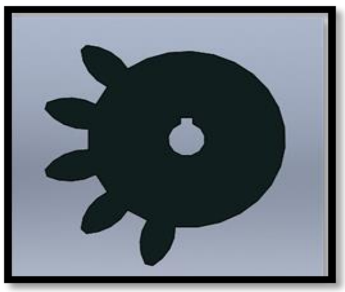


Fig. 13. Pinion

6. How Does A Reciprocating Rack and Pinion Works?

Its function is to convert rotational motion into reciprocating linear motion. It follows the same principle of traditional rack and pinion with the difference that the rack has been modified. For demonstration purposes, only the two main parts are shown gear and rack. The input angular speed on the axis of the gear has been set to four revolution per minute (4 rpm). One revolution takes seconds. The rack can move only in the frontal plane, from left to right and right to left & the gear can only rotate on its axis. A second example where the gear can both rotate and move simultaneously is shown at the end. The gear is missing some teeth where the gear moves but the rack doesn't move there is a loss of force transmission and it is called backlash.

Depending on the application of backlash might be desired or not low to none backlash allows a reciprocating motion with no stop at the ends. Some backlash allows periodization between motion and full stop. The gears angular velocity is equal to the motors angular velocity attached to the gear. The linear velocity of the gear pitch diameter and the rack pitch line are the same.

Linear velocity is equal to two times Pi times gear pitch radio divided by the time it taken to complete one revolution.

$VL = 2\pi r/t$

VL = Linear velocity t = time

π = Pi constant r = Gear pitch radio

The displacement of the rack is equal to as many steps as the teeth moves it.

$d = z/n$

d = displacement

z = number of pinion/gear teeth

n = number of rack teeth

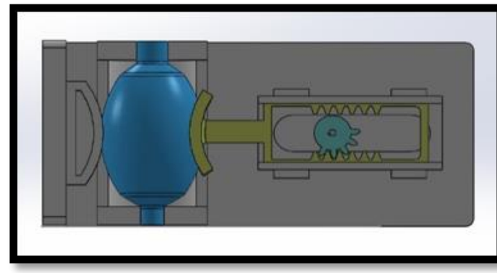


Fig. 14. Top View

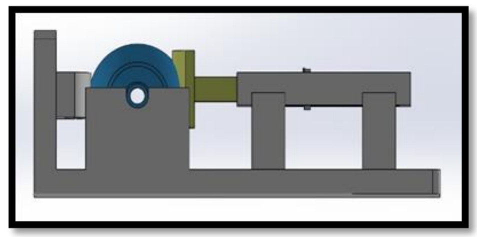


Fig. 15. Front View

1) Advantages of reciprocating rack and pinion

- Easiest way to convert rotation motion into linear motion
- It gives easier and more compact control over the equipment
- It is easy to operate with accuracy and easy to manufacture
- It improves motion control, simple and compact with small number of parts
- Cheap and lightweight and needs less steering effort
- Robust, Constant and varying steering ratio

2) Dis-advantages of reciprocating rack and pinion

- Only a certain amount of friction can be tolerated
- If the friction is too high, the mechanism will wear out faster than usual and will take more force to function
- Wear and backlash of rack and pinion may create problems in functioning
- Vibration and noise is larger

7. Brushless DC Motor (BLDC)

A motor converts electrical energy into mechanical energy when it is supplied. Different types of motors are commonly used. Brushless DC motors (BLDC) are a type of motor that has a high efficiency and outstanding controllability and is widely utilized in a variety of applications. In comparison to other motors, the BLDC motor saves energy.

Brushless DC Motors: What are they good for Brushless DC motors are typically 85-90 percent efficient, whereas brushed motors are typically 75-80 percent efficient. Brushes wear down over time, creating dangerous sparking and shortening the life of a brushed motor. Brushless DC motors are quitter, lighter, and have a substantially longer lifespan than traditional DC motors. Brushless DC motors are frequently employed in modern electronics when low noise and low heat are necessary, particularly in systems that run continuously, due to all these advantages.

Fig. 16. BLDC motor

1) Advantages of BLDC motor

- High efficiency
- Noiseless operation
- Higher speed ranges
- High dynamic response and low maintenance
- Long operating life due to a lack of electrical and friction losses

2) Dis-advantages of BLDC motor

- Higher cost
- Requires additional sensors
- Complex management system
- Wiring becomes complex
- Magnet demagnetization

3) Li – ion Rechargeable Battery

BLDC motors powered by Li – ion these are rechargeable batteries in which lithium ions travel from negative electrode to the positive electrode via an electrolyte during discharge and then back again during charging. The positive electrode of a lithium-ion battery is made of an intercalated lithium compound, while the negative electrode is usually made of graphite.

Fig. 17. Rechargeable battery

8. Problem Statement

The goal of this project is to provide practical answers to the need for portable ventilators that are economical, effective, and easy to use. Solving this challenge will reduce limits for people with lung diseases, such as acute respiratory failure, and help meet the demand for more ventilators caused by the present COVID-19 pandemic.

1) Motivation

Patients with breathing problems are frequently treated with Artificial Manual Breathing Unit (AMBU) bags. A medical expert squeezes the bag manually to deliver oxygen into the patient's lung. Typically AMBU bags are utilized at the site of an emergency or during the transport of a patient to a hospital. They are also utilized to move patient from one region to another while they are breathing. For breathing help, hospitalized patients are frequently placed on a respiratory or ventilator. As an alternative to mechanical ventilators, motorized AMBU bags are currently being developed and tested (BERGMAN, 2020).

2) Project objective

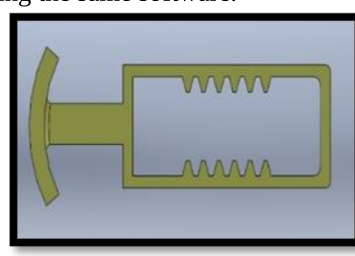
The goal of this study is to see if it is possible to construct a low-cost, portable motorized AMBU bag ventilator that is fully functional and effective. This is the first stage in developing Solutions to the need for portable ventilators that are economical, effective, and easy to use. Solving this challenge will reduce the limits for persons suffering from lung diseases such as acute respiratory failure, and will help meet the demand for additional ventilators.

A portable, motorized AMBU sack ventilator may likewise be utilized in innumerable different situations. For instance, this gadget might decreases the danger of overinflating the patient's lungs and permit the paramedic to take care of different wounds instead of pressing the AMBU bag. The gadget has potential to be autonomously worked via parental figures and advanced individuals with breathing handicaps outside of a clinical office.

9. Design Details of Rack and Pinion

1) Rack

The rack are the mechanical devices which converts the rotational motion into linear motion. They are mostly use in steering system of cars and many industries in which the machines need the linear horizontal or vertical motion. The designs are made use of SOLIDWORKS software and assembled using the same software.



Number of teeth = 6	Angle of teeth = 45 o
Length of rack = 295 mm	No of rack = 2
Width of rack = 80 mm	Thickness = 30 mm

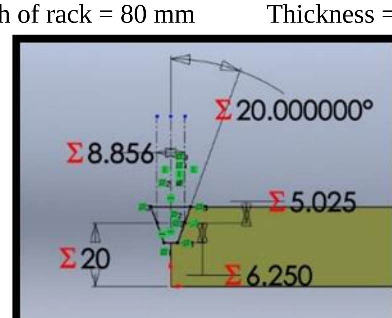
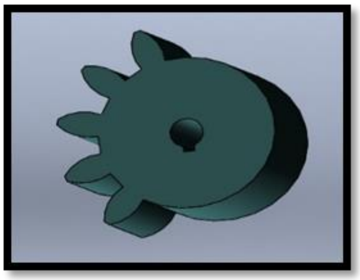


Fig. 18. Dimensions of the rack tooth

2) Pinion

A pinion is a round gear used in several applications usually the smaller gear in a gear drive train, although in the first commercially successful steam locomotive the pinion was rather large. In many cases, such as remote-controlled toys, the pinion is also the drive gear. The smaller gear that drives in a 90-degree angle towards a crown gear in a drive. The small front sprocket on a chain driven motorcycle.



Pinion diameter = 70 mm No of teeth = 5
Centre hole = 9 mm Thickness = 30 mm

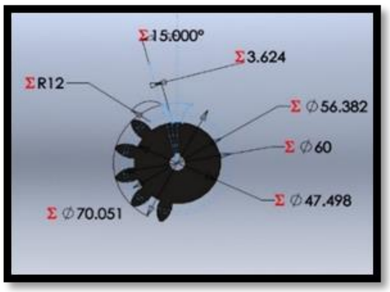


Fig. 19. Dimensions of the Pinion

3) Shaft

A mechanical shaft is a rotating part with a circular cross-section that transmits power and rotational motion. It can be solid or hollow. Gears, pulleys, flywheels, clutches, and sprockets are machine parts that are mounted on various types of shafts and used to convey power from the driving device, such as a motor or engine. As seen in picture, a vehicle crankshaft is an excellent example of a mechanical shaft.

Fig. 20. Shaft

4) Key

A key is a machine element used to link a spinning machine element to a shaft in mechanical engineering. The key allows torque transmission by preventing relative rotation between the two sections. A keyway and a key seat, which is a slot and pocket in which the key fits, must be present on the shaft and spinning machine element for the key to function. A keyed joint is the name given to the entire system. A keyed joint allows for relative axial movement between the components. Gears, pulleys, couplings, and washers are examples of keyed components.

Fig. 21. Key

5) Base Plate

The base plate is the part where the entire parts such as rack and pinion setup, ambu bag, battery, motor etc. were placed. The motor with pinion is placed on the base plate and these pinion starts rotating when power is supplied from the battery. When pinion starts rotating the rack which is meshed with the pinion tooth starts moving in a reciprocating motion. Due to this motion the bag gets compress and decompress and the breathing is supplied to the patient.

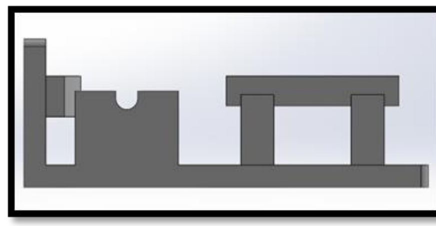
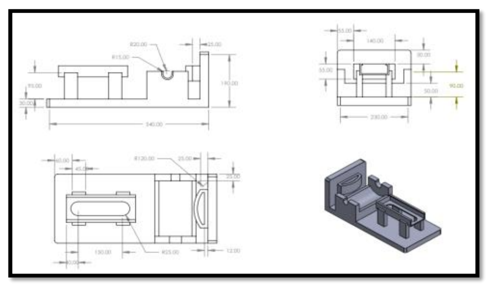
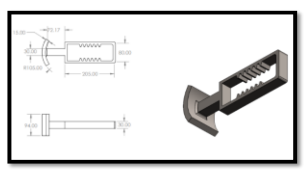


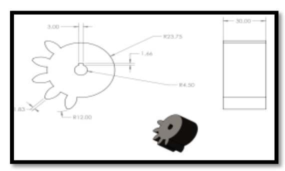
Fig. 22. Base plate

Dimensions of the all parts

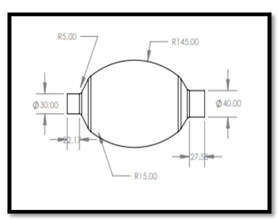


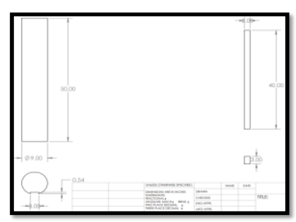
Base plate





Rack **Pinion**





Bag Valve Mask **Shaft and key**

Fig. 23. Dimensions of all parts

10. Conclusion

The paper presented an overview of Design of an Emergency

3d Printed Electro-Mechanical Ventilator with Bag -Valve – Mask (BVM).

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