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Electro-Pneumatic Based Ventilator for Covid19

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Abstract: ***Automation is the creation and application of technologies to produce and deliver goods and services with minimal human intervention. The implementation of automation technologies, techniques and processes improve the efficiency, reliability, and/or speed of many tasks that were previously performed by humans. Automation is being used in a number of areas such as manufacturing, transport, utilities, defines, facilities, operations and lately, information technology. Pneumatic systems form the most primitive and distinct class of control engineering. They are classified under the term 'Fluid Power Control', which describes any process or device that converts, transmits, distributes or controls power through the use of pressurized gas or liquid. When high-pressure liquids (like oil) are used to transmit power, the system is termed as hydraulics. In a pneumatic system the working fluid is a gas (mostly air) which is compressed above atmospheric pressure to impart pressure energy to the molecules. This stored pressure potential is converted to a suitable mechanical work in an appropriate controlled sequence using control valves and actuators. Pneumatic systems are well suited for the automation of a simple repetitive task. The working fluid is abundant in nature and hence the running and maintenance cost of these systems are exceptionally low. All fluids have the ability to translate and transfigure and hence pneumatic systems permit variety of power conversion with minimal mechanical hardware. Conversion of various combinations of motions like rotary-rotary, linear-rotary and linear-linear is possible. The simplicity in design, durability and compact size of pneumatic systems make them well suited for mobile applications. These features make them versatile and find universal applications including robotics, aerospace technology, production and assembly of automotive components (power steering, chassis and engine assembly), CNC machines, food products and packaging industry, medical and fabrication process of plastic products. Coronavirus pandemic has drastically shifted everyday lives already, with millions changing the way they work & socialize. COVID19 is fuelling the wave of Innovations in India. The Covid-19 pandemic has catalyzed the evolution of many technologies in India. Encumbered by an extended lockdown, people are seeking new solutions to routine tasks, be it food delivery, medical consultations, or education. Medical Workers are working continuously giving their major contribution. Presently, Medical Ventilators is an area where significant contribution is needed from engineering & technology. In this paper, we are going to explore the different types of Ventilators and understand their implementation & development. We will also understand the functionality, construction & working with design and development of fluid power control through pneumatic, electro pneumatic & mechatronics design.***
Keywords: Automation, Fluid Power, Pneumatic, Hydraulic, Ventilator, COVID19

I. INTRODUCTION

With the recent developments in technology, all processes are being automated. Apart from industrial automation, automation is prevalent in the domestic domain making homes more smart and secure. It has also helped reduce human effort enabling the control of devices/appliances with great ease while being energy efficient. Various home automation models have been implemented incorporating Android platforms, Global System for Mobile communications (GSM) modules, Wi-Fi- based systems, etc., into the fundamental microprocessor, sensor and actuator network. The wide application of microprocessors is not confined to domestic/home automation applications but can also be further extended into the industrial environment. In the industrial domain, a fundamental automation system model is a basic control system, which includes an input/sensor, a controller and an output/actuator. This model can help implement any industrial application with appropriate hardware and software selection. A repetitive sequential switching operation replicates a traditional production line. Sequential operations are widely used in industries for packaging, production and similar activities. A simple example of such an operation would be the production of a batch of screws in a factory. The sequence of the process flow for the mentioned activity would be cutting, heading, lathing, threading, heat treatment, electroplating, and packaging. This repetitive sequential nature of activities is widely observed in all industries and can be easily replicated on a small scale for small factories. Level determination and monitoring systems are used in wastewater treatment plants, oil and gas industries, chemical and food processing industries, medical industries etc., for several applications including liquid storage, monitoring and control.

These systems use sensors based on different working principles namely magnetic, ultrasonic, and Radiofrequency technology. The controllers used are mostly PLC‘s or conventional Proportional-Integral (PI)/Proportional-Integral-Derivative (PID) controllers, which communicate between the sensor and the output device (usually pump) to assist the inflow or outflow of fluid as required. Temperature control and monitoring systems find its application in a wide range of process control industries. The input is derived from contact temperature sensors like thermistors, thermocouples or resistance temperature detectors or non-contact sensors based on infrared or similar technologies. These devices provide there quired input to the system and trigger output as determined by the controller. Depending on the entire system either conventional controller like the PI/Decontrolled or an ON/OFF controller is used. The latter is used if the temperature isn‘t a very critical parameter in the system. As evident, industrial processes are mostly based on PLC, DCS or SCADA systems. These systems prove to be complex for small-scale industries and also expensive because of their high initial cost of setup. Expertise, thus, an Arduino helps reduce assembly, manufacturing and maintenance cost in such scenarios. With all these facts stated, an Arduino cannot completely replace the existing systems but can be a viable option for small-scale industries and initial start-up‘s as it helps rapidly prototype, code and interface different types of sensors, devices and modules and is also widely available. Microprocessors like the ATmega 328P (present on the Arduino), can make a number of logical control decisions by mere programming in C/C++ languages. Arduino UNO is compatible with a number of software‘s like Matrix Laboratory (MATLAB), Parallax Data Acquisition (PLX-DAQ) tool apart from its main software, which is the Arduino IDE. The applications of this board can be extended even further by using compatible shields and external modules like GSM, Bluetooth, etc. With its affordable price, it thus, becomes a feasible option for a wide range of applications like Access Control, Data Logging and Automation. Fluid power is a term describing hydraulics and pneumatics technologies. Both technologies use a fluid (liquid or gas) to transmit power from one location to another. With hydraulics, the fluid is a liquid (usually oil), whereas pneumatics uses a gas (usually compressed air). A fluid power system uses either liquid or gas to perform desired tasks. Operation of both the liquid systems (hydraulic systems) and the gas systems (pneumatic systems) is based on the same principles. For brevity, we will focus on hydraulic systems only. A fluid power system typically consists of a hydraulic pump, a line relief valve, a proportional direction control valve, and an actuator. Fluid power systems are widely used on aerospace, industrial, and mobile equipment because of their remarkable advantages over other control systems. The major advantages include high power-to- weight ratio, capability of being stalled, reversed, or operated intermittently, capability of fast response and acceleration, and reliable operation and long service life. Due to differing tasks and working environments, the characteristics of fluid power systems are different for industrial and mobile applications (Lameck, 1983). In industrial applications, low noise level is a major concern. Normally, a noise level below 70 dB is desirable and over 80 dB is excessive. Industrial systems commonly operate in the low (below 7 MPa or 1000 psi) to moderate (below 21 MPa or 3000 psi) pressure range. In mobile applications, the size is the premier concern. Therefore, mobile hydraulic systems commonly operate between 14 and 35 MPa (2000–5000 psi). Also, their allowable temperature operating range is usually higher than in industrial applications.

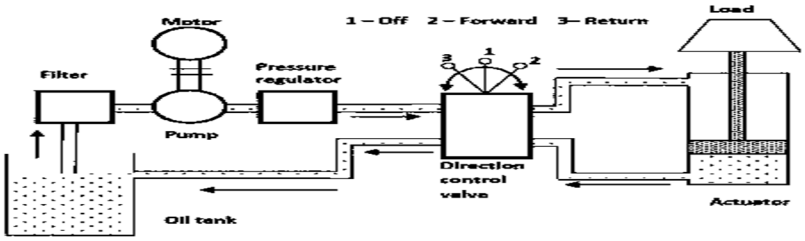

Figure 1.1. Schematic diagram of a fluid power system

II. PNEUMATIC IN AUTOMATION

Pneumatic systems are well suited for the automation of a simple repetitive task. The working fluid is abundant in nature and hence the running and maintenance cost of these systems are exceptionally low. All fluids have the ability to translate and transfigure and hence pneumatic systems permit variety of power conversion with minimal mechanical hardware. Conversion of various combinations of motions like rotary-rotary, linear-rotary and linear-linear is possible. The simplicity in design, durability and compact size of pneumatic systems make them well suited for mobile applications. These features make them versatile and find universal applications including robotics, aerospace technology, production and assembly of automotive components (power steering, chassis and engine assembly), CNC machines, food products and packaging industry, medical industry, bomb deployment units and fabrication process of plastic products.

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III. AUTOMATION IN MEDICAL INDUSTRY

Health care is predicted to have a 36% automation potential. This means more than a third of healthcare tasks—especially managerial, back-office functions—could be automated, allowing healthcare providers to offer more direct, value-based patient care at lower costs and increased efficiency. Automation in healthcare involves the use of different software that promotes efficiency in the provision of medical services. This technology employs modern techniques and tools for efficiency reasons. They help monitor safety, security, and Automatic control, which has been the foundation of automation, has been here for centuries. As far back as the 17th century, systems with automatic control devised for the regulation of steam engines, temperature control, and other applications. Automation has come a long way since then. Its application in the health care sector that has been especially noteworthy since it has made huge strides in saving costs, labour, and lives! This blog will have an in-depth into how automation is revolutionizing the health care sector. Before we get into the role automation has played in the healthcare sector, it makes sense to have an overview of how the Healthcare Industry has been doing. Innovation and R&D in the past few decades have contributed to more effective medicines, improved diagnostic aids, and technological solutions to non-invasive procedures. These are naming just a few of the accomplishments in the healthcare industry. Along with the accomplishments, there have been a few challenges as well. The availability of quality and affordable healthcare for its people is an important indicator of how well a nation fares on the Human Development Index (HDI). The problem is that even developed countries are struggling to meet this need effectively.

IV. VENTILATOR: NEED OF THE HOUR IN COVID19

In the face of the COVID-19 pandemic, in addition to lockdowns, curfews and economic upheaval, most planning centres and living rooms have been debating the shortage of ventilators and the need for critical care in the days to come. We have seen heart-breaking scenes from Italy, Iran and New York, where many lives have been lost, hospitals are full and ventilators are in short supply. It is important to delve on these issues and develop rational approaches and solutions, in the Indian context, to an impending surge of critically ill patients. The modern ventilator is an advanced medical device that performs the complex task of allowing a patient to survive respiratory illnesses in various settings. To ICU specialists, also known as intensivists, the ventilator is a powerful ally when managing patients who need critical care. When we breathe in, we create a negative pressure in our chest cavity using the muscles in our chest wall and the diaphragm to suck air into the lungs. This is known as negative pressure ventilation. A ventilator on the other hand pushes air into the lungs and creates a positive pressure ventilation (PPV) system. A patient on a ventilator typically has a plastic breathing tube inserted into their mouth or airway to allow this to happen, rendering it an invasive therapy. A COVID-19 related lung injury is typically classified as an acute respiratory distress syndrome (ARDS). The lung‘s lining that participates in gas exchange is adversely affected in this disease. Contrast this with, say, polio, where the lung is often essentially normal but the muscles that support breathing are weak. In muscular disorders, simple ventilators – even those not using supplemental oxygen – would suffice. But with ARDS, where the lung lining is damaged, a patient will need supplemental oxygen in addition to mechanical ventilation. Severely ill COVID-19 patients will need ventilators, and India will need to increase its ventilator capacity. Data from around the world suggests that a high percentage of these patients will unfortunately succumb to their illness. When mobilising resources such as equipment and personnel, the government would be prudent to consider easier strategies – ones that might allow doctors to save potentially hundreds of patients who don‘t meet the evidence-based threshold for ventilator use. One option is to produce high-flow devices in masse and ensure sufficient oxygen supply. Ventilators also need significant clinical effort by a nursing team to reduce the chances of causing harm. Ventilator-associated pneumonia (VAP) is a common complication that occurs in about 30% of mechanically ventilated patients. The incidence of VAP is reduced by high-quality nursing care and strict protocols.

V. VENTILATOR: CONCEPT, FUNCTIONING, WORKING

A ventilator is a machine that provides mechanical ventilation by moving breathable air into and out of the lungs, to deliver breaths to a patient who is physically unable to breathe, or breathing insufficiently. Ventilators are computerized microprocessor-controlled machines, but patients can also be ventilated with a simple, hand-operated bag valve mask. Ventilators are chiefly used in intensive-care medicine, home care, and emergency medicine (as standalone units) and in anaesthesiology Ventilators are sometimes called "respirators", a term commonly used for them in the 1950s However, contemporary hospital and medical terminology uses the word "respirator" to refer to a protective face- mask.

A. *Ventilator Function*

In its simplest form, a modern positive pressure ventilator consists of a compressible air reservoir or turbine, air and oxygen supplies, a set of valves and tubes, and a disposable or reusable "patient circuit". The air reservoir is pneumatically compressed several times a minute to deliver room-air, or in most cases, an air/oxygen mixture to the patient. If a turbine is used, the turbine pushes air through the ventilator, with a flow valve adjusting pressure to meet patient- specific parameters. When over pressure is released, the patient will exhale passively due to the lungs' elasticity, the exhaled air being released usually through a one-way valve within the patient circuit called the patient manifold. Ventilators may also be equipped with monitoring and alarm systems for patient-related parameters (e.g., pressure, volume, and flow) and ventilator function (e.g., air leakage, power failure, mechanical failure), backup batteries, oxygen tanks, and remote control. The pneumatic system is nowadays often replaced by a computer-controlled turbo pump. Modern ventilators are electronically controlled by a small embedded system to allow exact adaptation of pressure and flow characteristics to an individual patient's needs. Fine-tuned ventilator settings also serve to make ventilation more tolerable and comfortable for the patient. In Canada and the United States, respiratory therapists are responsible for tuning these settings, while biomedical technologists are responsible for the maintenance. In the United Kingdom and Europe the management of the patient's interaction with the ventilator is done by critical care nurses. The patient circuit usually consists of a set of three durable, yet lightweight plastic tubes, separated by function (e.g. inhaled air, patient pressure, exhaled air). Determined by the type of ventilation needed, the patient-end of the circuit may be either non-invasive or invasive. Non-invasive methods, such as continuous positive airway pressure (CPAP) and non-invasive ventilation, which are adequate for patients who require a ventilator only while sleeping and resting, mainly employ a nasal mask. Invasive methods require intubation, which for long-term ventilator dependence will normally be a tracheotomy cannula, as this is much more comfortable and practical for long-term care than is larynx or nasal intubation.

B. *Ventilator Working*

A ventilator uses pressure to blow air into the lungs. This pressure is known as positive pressure. A patient usually exhales the air on their own, but sometimes the ventilator does it for them too. The amount of oxygen the patient receives can be controlled through a monitor connected to the ventilator. If the patient‘s condition is particularly fragile, the monitor will be set up to send an alarm to the caregiver, indicating an increase in air pressure. The machine works by bringing oxygen to the lungs and taking carbon dioxide out of the lungs. This allows a patient who has trouble breathing to receive the proper amount of oxygen. It also helps the patient‘s body to heal, since it eliminates the extra energy of Laborde breathing. A ventilator blows air into the airway through a breathing tube. One end of the tube is inserted into patient‘s windpipe and the other end is attached to the ventilator. The breathing tube serves as an airway by letting air and oxygen from the ventilator flows into the lungs. Depending on the patient‘s medical condition, they may be able to use a respiratory mask instead of the breathing tubes.

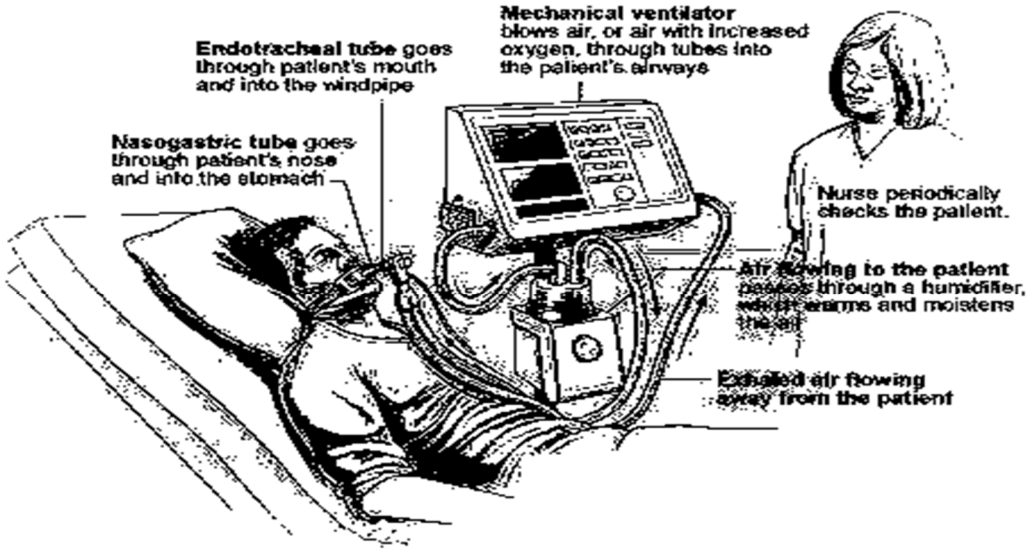

Figure 5.1. Schematic diagram of a fluid power system

VI. CHALLENGES IN VENTILATOR AVAILABILITY

A. *Ventilator and its Importance in COVID-19 Pandemic*

Ventilators are life saving machines required for severely ill COVID-19 patients. Two types of ventilation may be used in these patients: a) Invasive and b) Non-invasive ventilation. Invasive ventilation is superior.Ventilator is a medical equipment/machine which is employed to provide respiratory support to the patients whose lungs are significantly compromised due to infection (pneumonia) etc. leading to severe respiratory problems. The ventilator uses a positive pressure to supply oxygen into the lungs through the inner ways and fully regulate the breathing process of the patients. A humidifier is used in ventilator to add moisture and heat to the oxygen so as to match with the temperature of the body of the patient. The lungs of the patients who require mechanical ventilation due to COVID-19 are so much inflamed that the oxygen is unable to reach the alveoli when a patient breathes, and the mechanical ventilator acts to force the oxygen flow under pressure to these small air passages.

B. *Challenge of Shortage and the Cost of Ventilators*

There is an acute shortage of ventilators for COVID-19 patients. Their high cost and availability is a challenge. The present outbreak of COVID-19 pandemic has resulted in the dramatic increase in the number of patients who need respiratory care. Health care systems worldwide are facing the extreme shortfall of ventilators particularly mechanical ventilators and their components. The shortage of ventilators has already been experienced by most of the countries who are extremely hit by this pandemic . One of the main reasons for the shortage of ventilators is the issues related to their global supply chain. Due to the worldwide spread of infection, the exports of the medical equipment‘s including ventilators have come to a halt. The situation has been become so alarming that as many as fifty four countries have stopped exporting the goods related to medical field including ventilators . The production of medical machines such as ventilators demands more intensive capital and expertise.

C. *Effects of Shortages of Ventilators*

Severely sick people are getting affected from getting the optimal treatment. Innovative means of manufacturing and optimising their use is being tried out. Lot of efforts are urgently required to reduce and minimize the gap between the requirement and the supply of ventilators.

VII. AMBU BAG

Respiration is basic requisite for survival of living beings. Unfortunately, when this drive to breathe is dysregulated by a variety of health conditions, one‘s biological equilibrium transposes to the state of respiratory failure. In such conditions, mechanical or assisted ventilation is cornerstone of management and proves to tide over this crisis, presently, a large number of patients are being ventilated with the help of a mechanical device manually an artificial manual breathing unit (AMBU), which is a simple hand- held self- inflatable device that needs to be compressed manually by patients‘ attendant/caretaker on a regular basis to deliver air or oxygen to patients‘ lungs. Providing continuous manual ventilation has certain inherent drawbacks; the first and foremost is maintenance of required regular rate and volume of oxygen/air, and the same cannot be ensured. It is very labour intensive, tiring to operators and exposes attendants as well as hospital staff to infection risks. A bag valve mask (BVM), sometimes known by the proprietary name Ambu bag or generically as a manual resuscitator or "self-inflating bag", is a hand-held device commonly used to provide positive pressure ventilation to patients who are not breathing or not breathing adequately. The device is a required part of resuscitation kits for trained professionals in out-of-hospital settings (such as ambulance crews) and is also frequently used in hospitals as part of standard equipment found on a crash cart, in emergency rooms or other critical care settings. Underscoring the frequency and prominence of BVM use in the United States, the American Heart Association (AHA) Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiac Care recommend that "all healthcare providers should be familiar with the use of the bag-mask device. Manual resuscitators are also used within the hospital for temporary ventilation of patients dependent on mechanical ventilators when the mechanical ventilator needs to be examined for possible malfunction or when ventilator dependent patients are transported within the hospital. Two principal types of manual resuscitators exist; one version is self-filling with air, although additional oxygen (O2) can be added but is not necessary for the device to function. The other principal type of manual resuscitator (flow-inflation) is heavily used in non-emergency applications in the operating room to ventilate patients during anaesthesia induction and recovery. Use of manual resuscitators to ventilate a patient is frequently called "bagging" the patient and is regularly necessary in medical emergencies when the patient's breathing is insufficient (respiratory failure) or has ceased completely (respiratory arrest). Use of the manual resuscitator force-feeds air or oxygen into the lungs in order to inflate them under pressure, thus constituting a means to manually provide positive-pressure ventilation. It is used by professional rescuers in preference to mouth-to- mouth ventilation, either directly or through an adjunct Such as a pocket mask.

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Figure 7.1. AMBU Bag

VIII. OUR SOLUTION

Our solution is very simple, that is mechanical ventilator based on Electro Pneumatic Mechanism. It works with compressed air. We will be having regulated flow of compressed air as per the needed AMBU Bag Actuation. Timing & Speed of the system can be controlled using Flow Control Valve attached with the pneumatic cylinder.

Position of cylinder can be regulated suing Limit Switches. Tidal Volume can also be adjusted here.

A. Key Components

1) Compressed Air Source
2) Double Acting Cylinder
3) AMBU Bag
4) Direction Control Valve
5) Flow Control Valve
6) Limit Switches
7) Electrical Unit
8) Frame
9) Pressure Regulator

B. Methodology

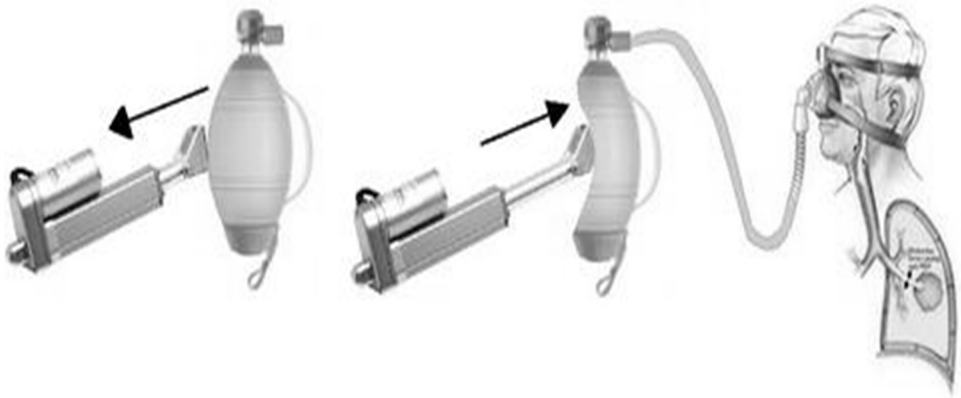

Figure 8.1. Methodology

C. Circuit Schematics

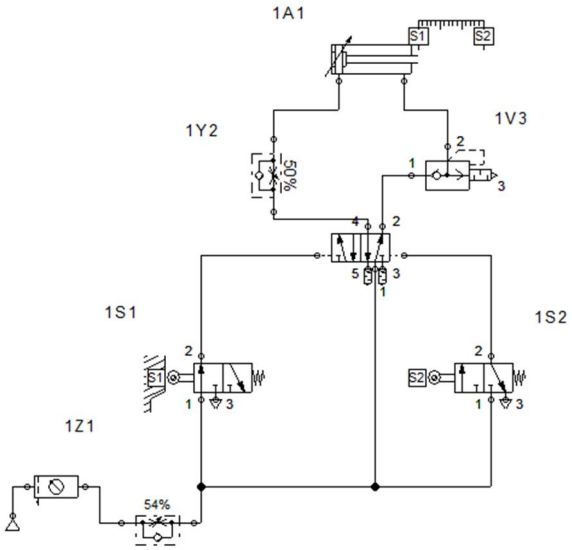

Figure 8.2. Circuit Schematics

D. Flow Chart

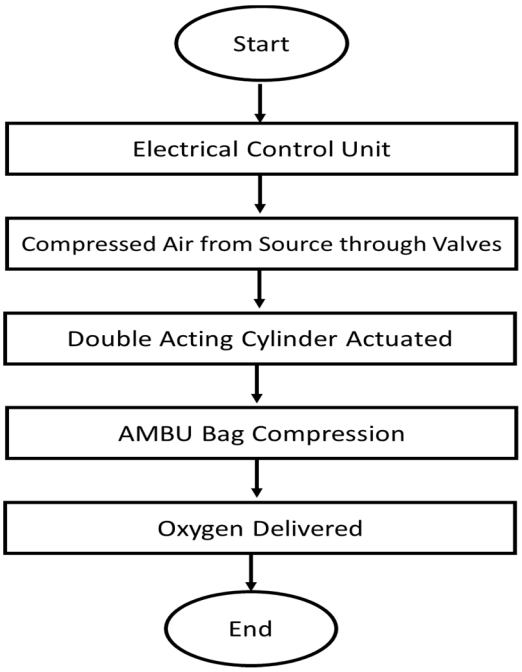

Figure 8.3. Flow Chart

IX. CONCLUSIONS

The automation market in India is estimated to be 1/10ththat of China. If India has to become one of the leading economies in the world, based on manufacturing, it will have to attain higher technological standards and higher level of automation in manufacturing. In the past 30 years, fluid power technology rose as an important industry. With increasing emphasis on automation, quality control, safety and more efficient and green energy systems, fluid power technology should continue to expand in India .Fluid power industry is gaining a lot of importance in Indian industry. According to a recent survey, it has shown a growth of 20% over the last 10 years and the size of market is estimated to be close to 5000 crores per annum. The growth rate of this industry in India is typically about twice the growth of economy. Automation & Mechatronics approach will be the game changer for Medical Industry. Ventilation Process can be effectively executed using Electro-Pneumatic based Mechanical Ventilator as low cost, portable and accessible solution amid this COVID19 Pandemic.

X. ACKNOWLEDGMENT

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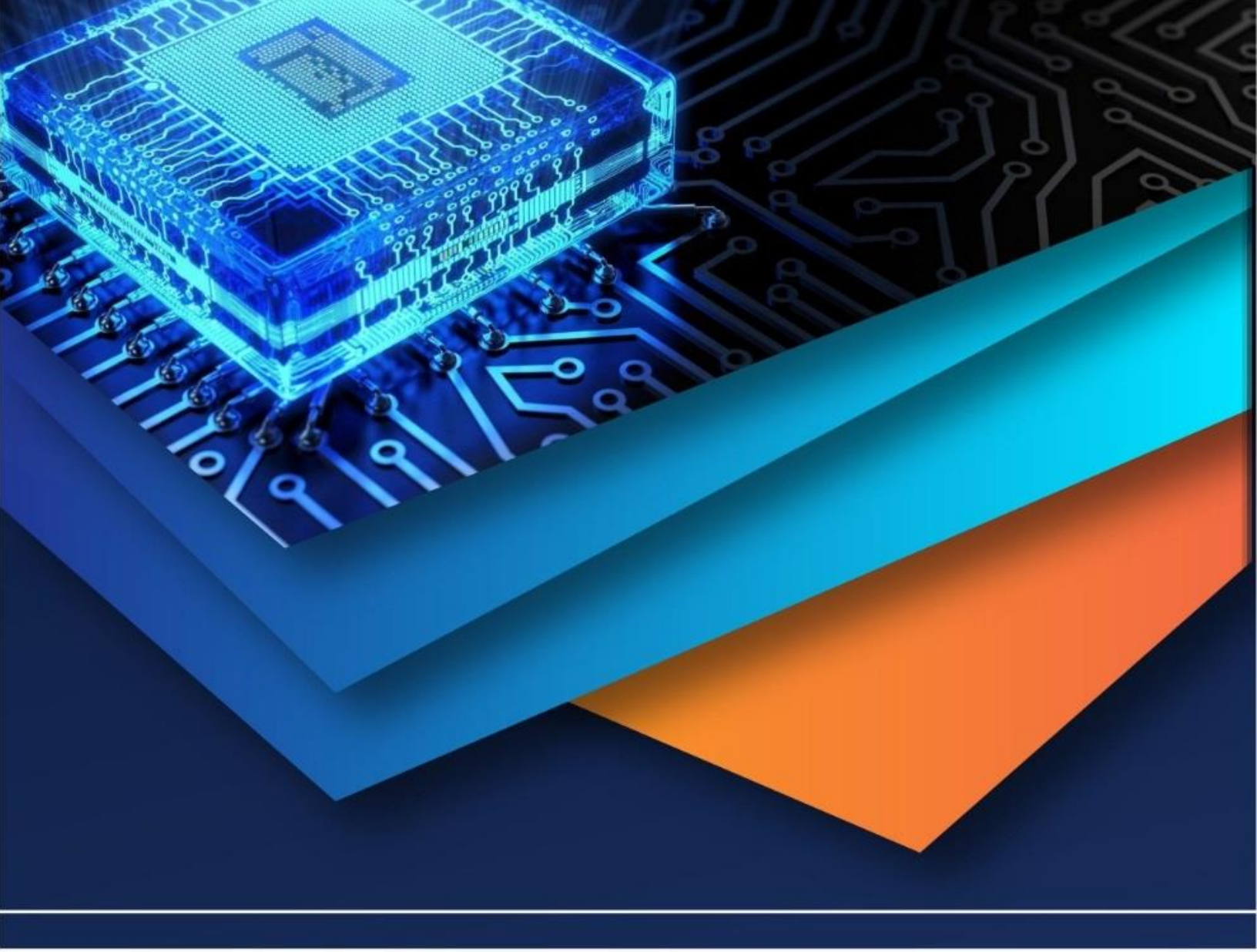

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