Design and Maintenance of Mechanical Ventilator

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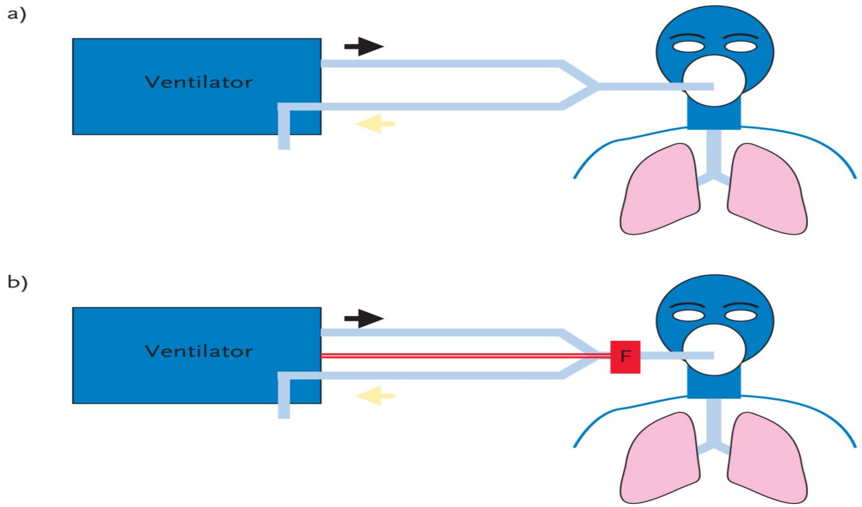
Mechanical ventilator

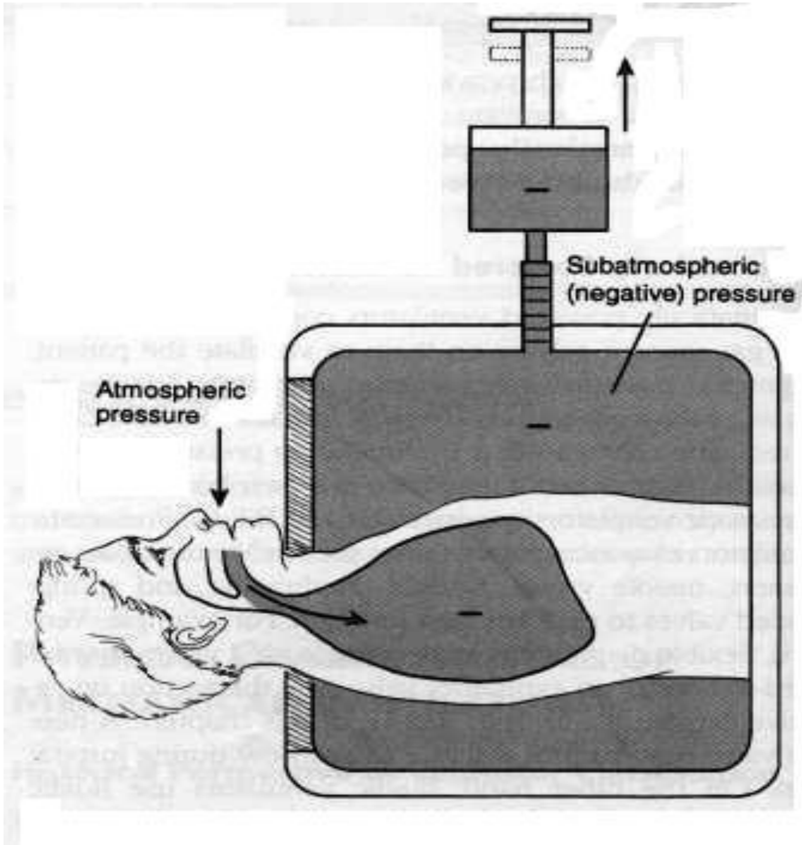
- Automatic machine
- Provide all or part of the work the body must produce to move gas into and out of the lungs.
- Breathing or ventilation.



Pressure Delivery

Negative-pressure ventilators

- Iron lung
- Chest cuirass



Negative-Pressure Ventilator

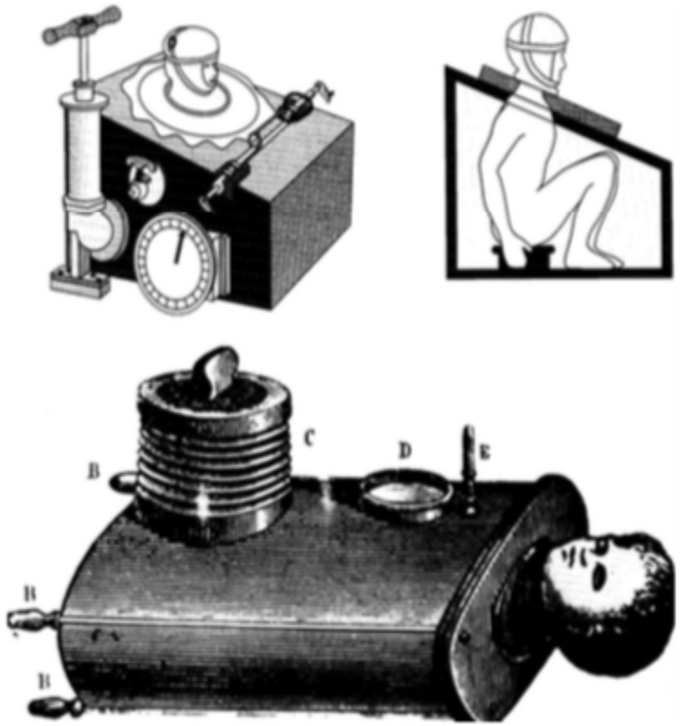


Fig. 1. 19th-century negative-pressure ventilators. (Top: from Reference 1, with permission. Bottom: from Reference 2, with permission.)

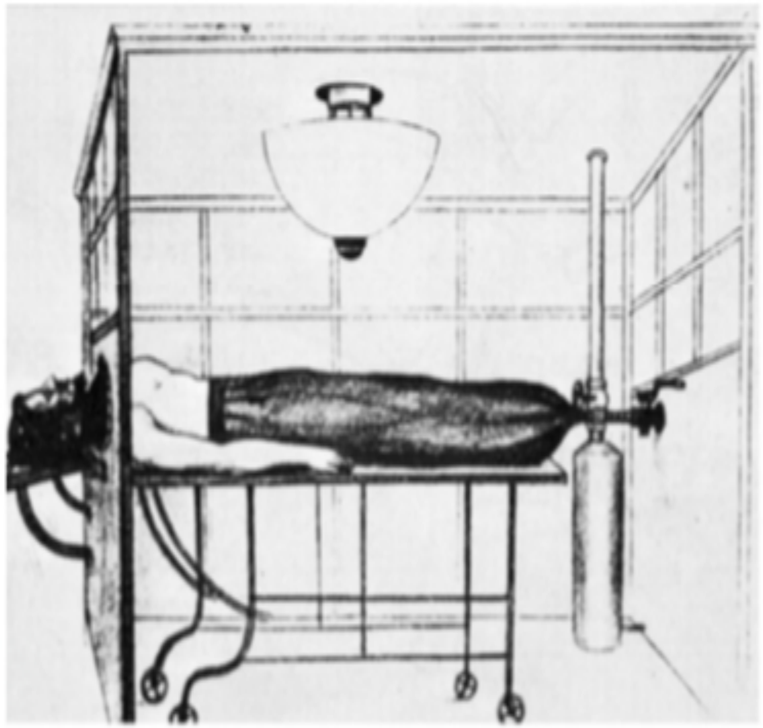


Fig. 2. Negative-pressure operating chamber. (From Reference 3, with permission.)

Fig. 3. Poliomyelitis epidemic patients at Ranchos Los Amigos Hospital, California, 1953. (From Reference 8.)

Negative-Pressure Ventilator

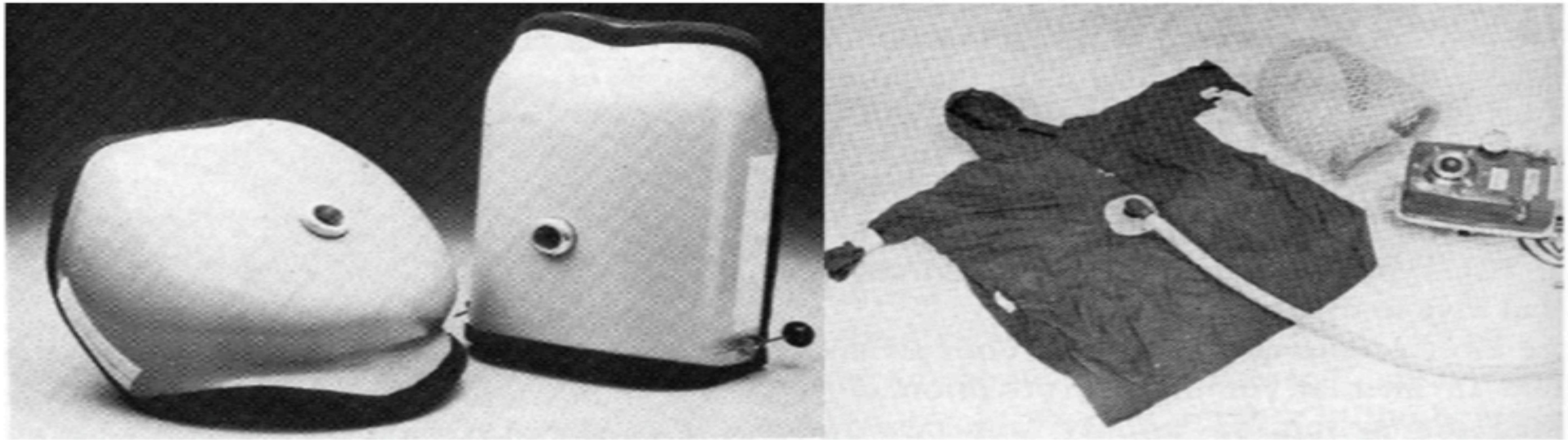


Fig. 5. Left: Chest cuirass ("turtle shell"), Right: "Raincoat" wrap with wire grid and Emerson 33-CRE negative-pressure ventilator. (From Reference 9.)

Pressure Delivery

Positive-pressure ventilators

- Most ventilators used today are positive-pressure ventilators
- Examples include: Puritan Bennett 840, Servoi, and Hamilton G-5

Combined Pressure Devices

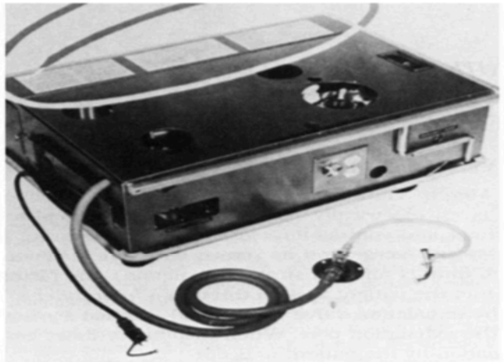
- High-frequency oscillators

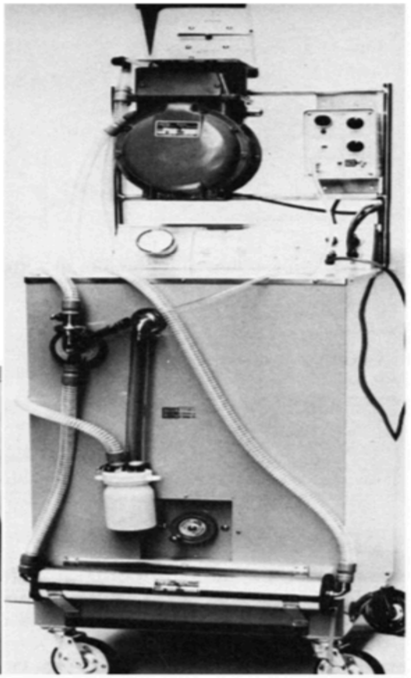
Positive-Pressure Invasive Ventilator

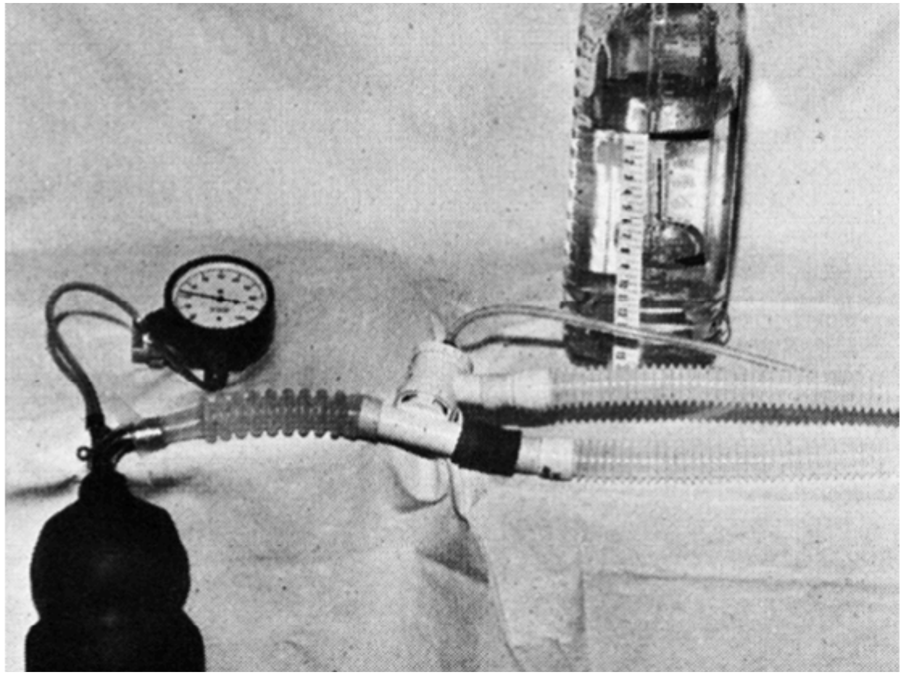
Table 1. Generations of Intensive Care Ventilators

Generation	Years	Distinguishing Features
First	Early 1900s to mid-1970s	Only volume-controlled ventilation

First-Generation





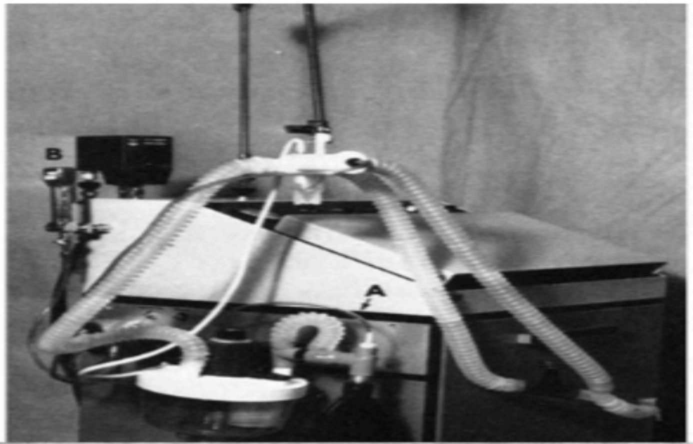


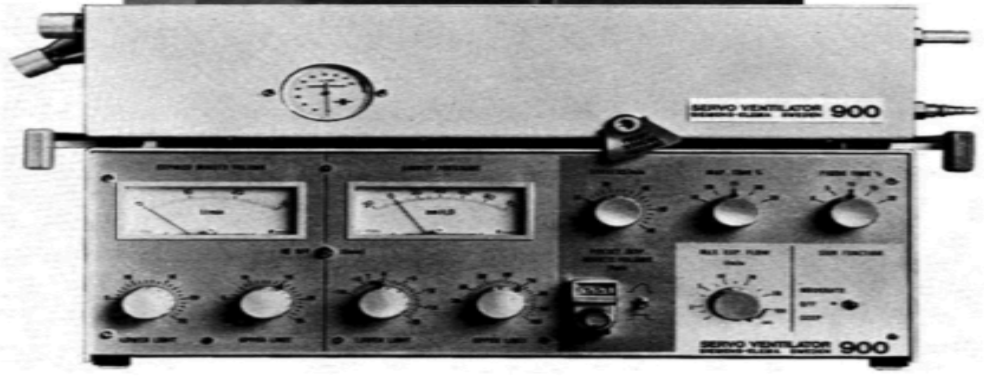
Positive-Pressure Invasive Ventilator

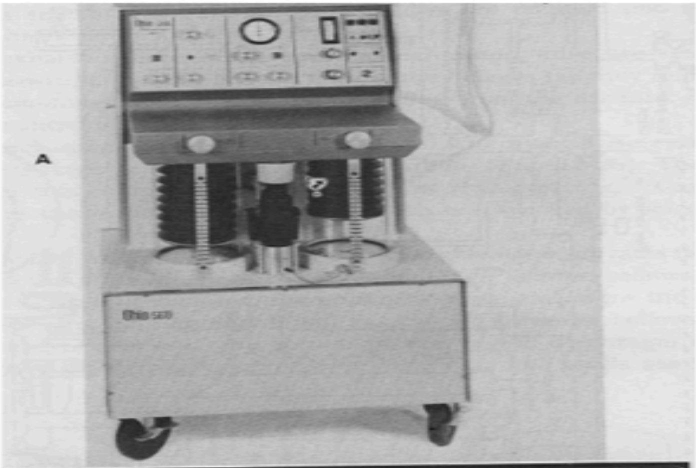
Table 1. Generations of Intensive Care Ventilators

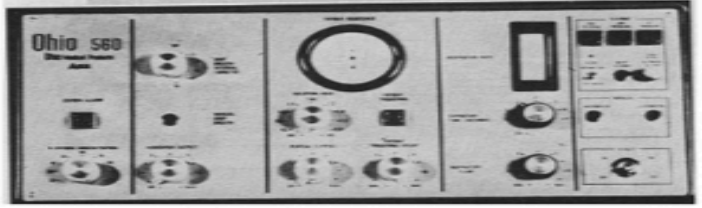
Generation	Years	Distinguishing Features
Second	Mid-1970s thru early 1980s	First appearance of patient-triggered inspiration

Second-Generation









Positive-Pressure Invasive Ventilator

Table 1. Generations of Intensive Care Ventilators

Generation	Years	Distinguishing Features
Third	Early 1980s through late 1990s	Microprocessor control

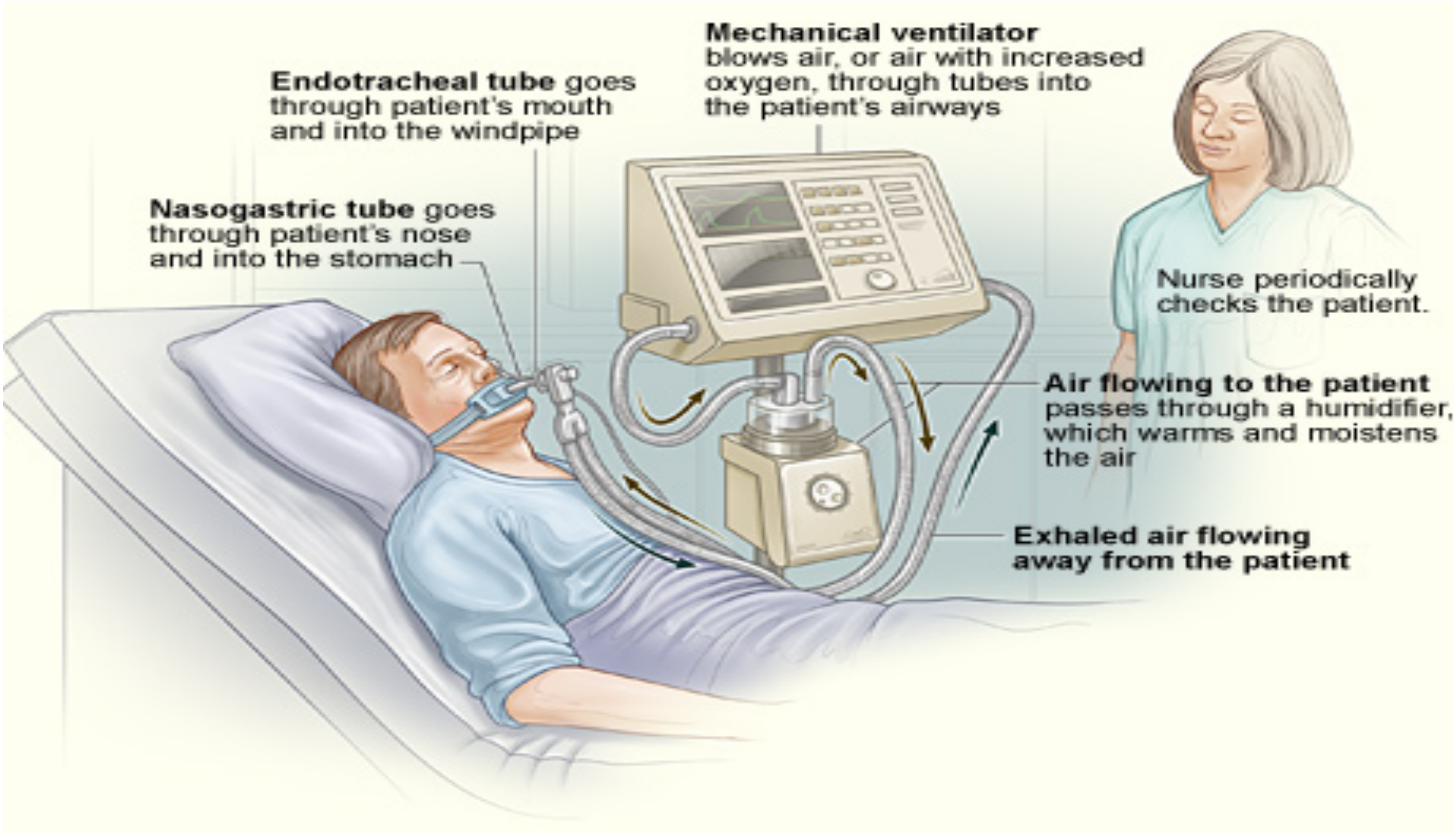
Third-Generation

Positive-Pressure Invasive Ventilator

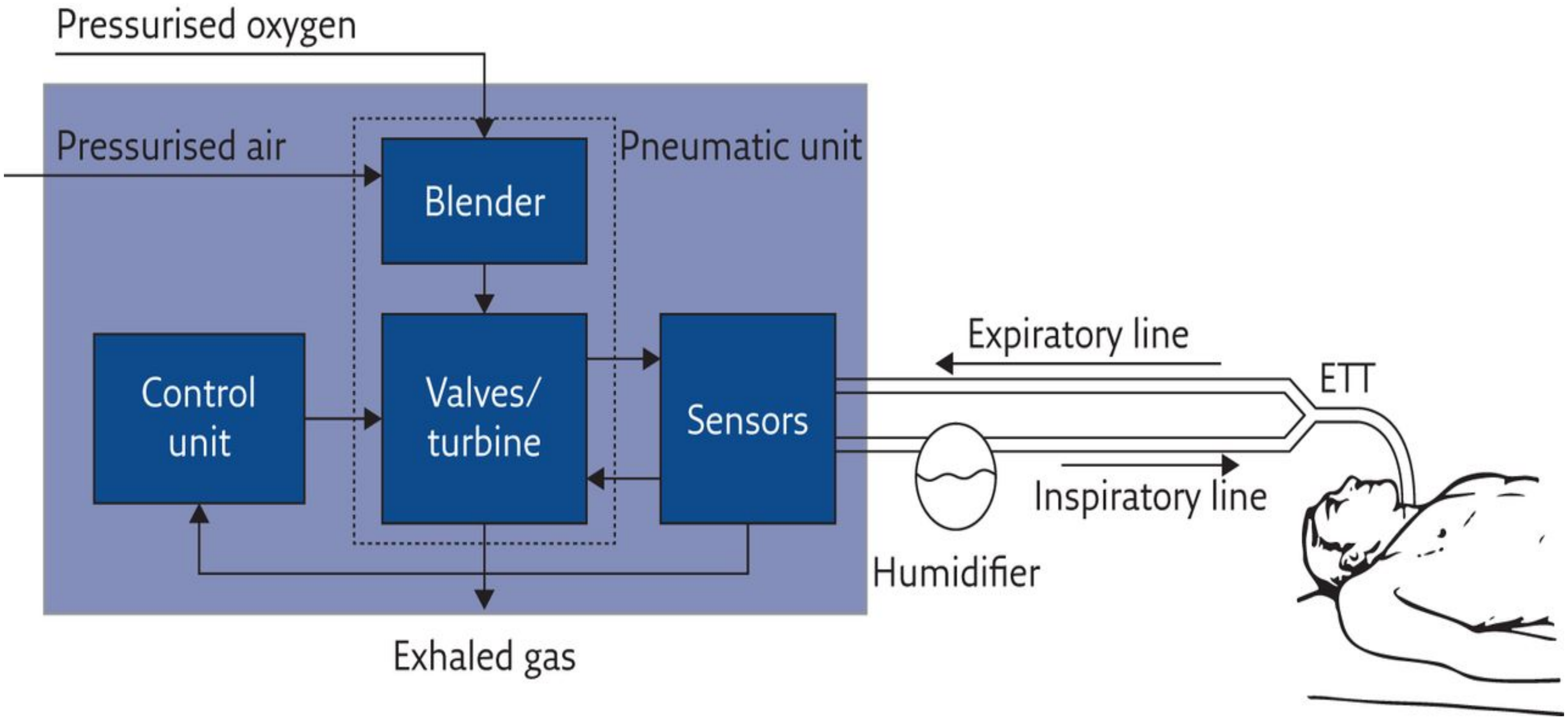
Table 1. Generations of Intensive Care Ventilators

Generation	Years	Distinguishing Features
Fourth	Late 1990s to present	Plethora of ventilation modes
Future	Only time will tell	Smart ventilation providing decision support

Fourth –Generation(current)


Mechanical ventilator blows air, or air with increased oxygen, through tubes into the patient's airways
Endotracheal tube goes through patient's mouth and into the windpipe
Nasogastric tube goes through patient's nose and into the stomach
Nurse periodically checks the patient.
Air flowing to the patient passes through a humidifier, which warms and moistens the air
Exhaled air flowing away from the patient

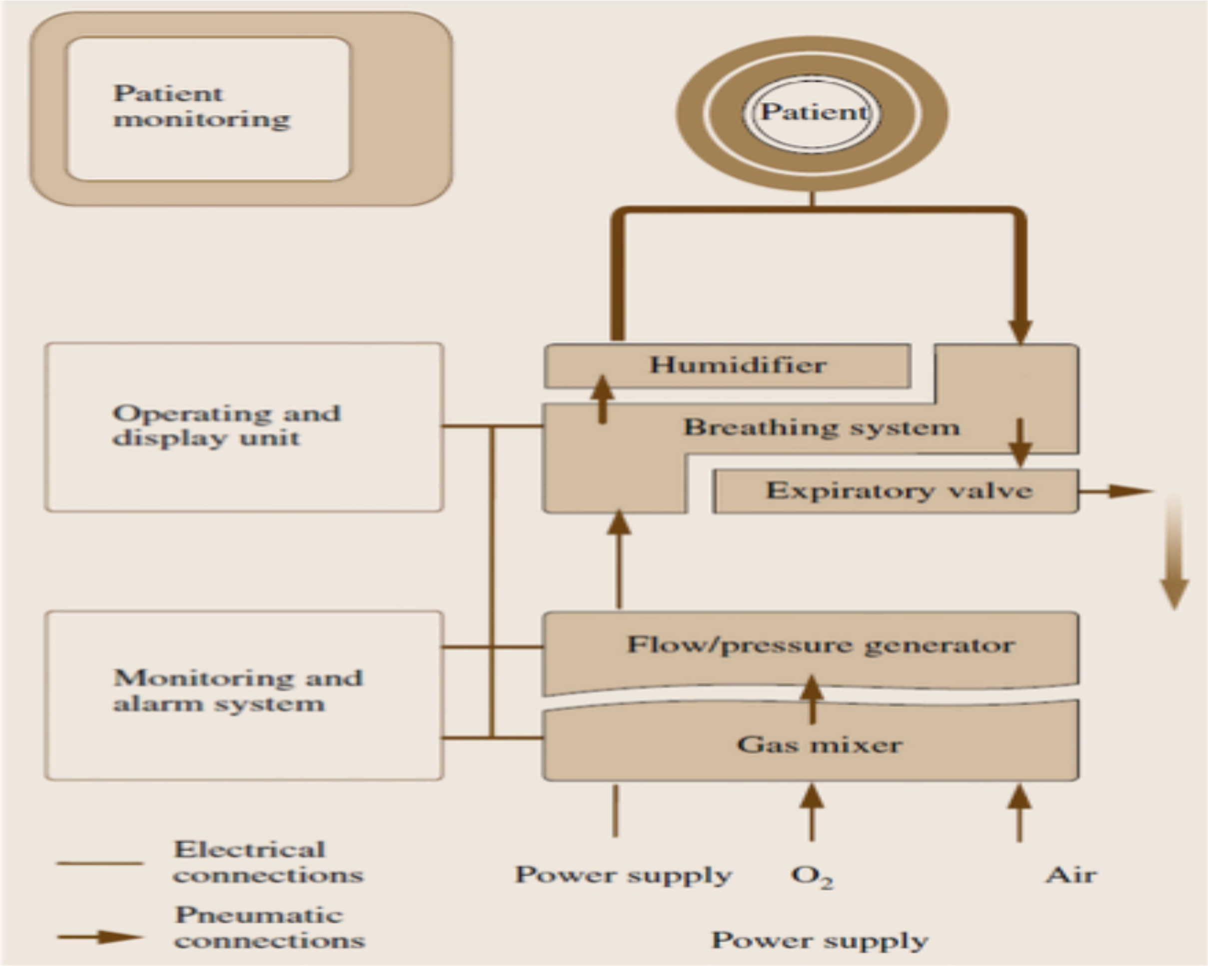
Basic structure and main functional components of a mechanical ventilator.



Desired operation requires:

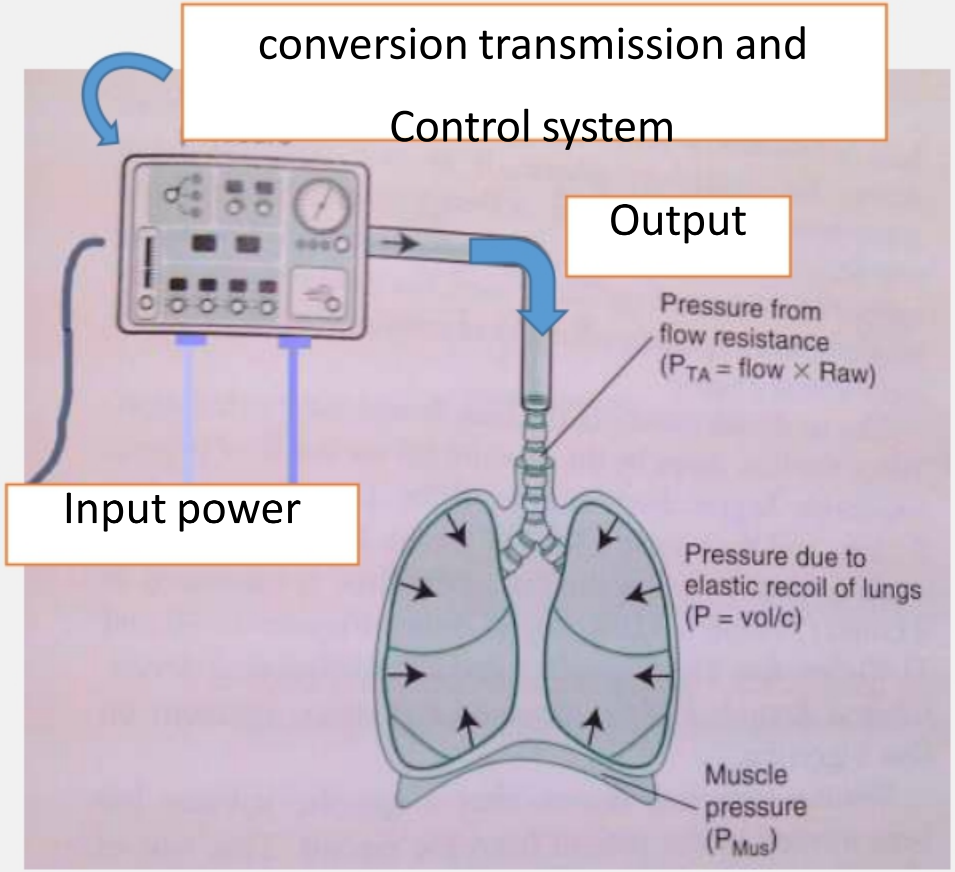
- A source of input energy to drive the device.
- Converting input energy into output energy in the form of pressure and flow to regulate the timing and size of breaths.
- Monitor the output performance of the device and the condition of the patient.

Functional Block Diagram



Ventilator characteristics

- Input power (Electrical, pneumatic)
- Power conversion and transmission
- Control system
- Output (flow: Pressure and volume)

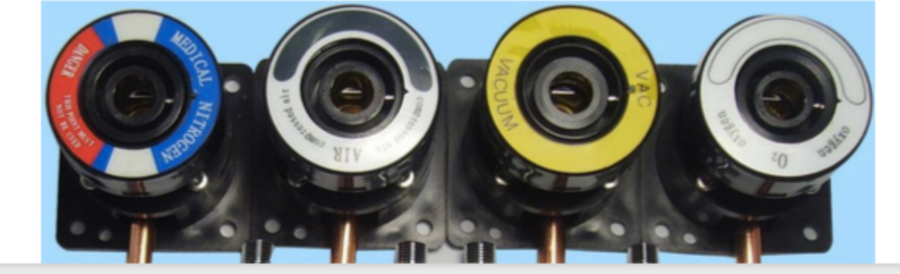


Input Power

- Pneumatic : compressed gas from wall outlets

  Usually supplied via external power source as well as via hospital's

  central gas supply (approximately 50 psi)



- Electric
  - AC(100~240 volts)
  - DC (battery)

Source of Gas Supply

- Air - Central compressed air, compressor, turbine flow generator,
- Oxygen – Central oxygen source, O2 concentrator, O2 cylinder
- Gas mixing unit – O2 blender

Input Power

Combined Power Ventilators

- Current ICU ventilators use microprocessor control and 50 psi sources of oxygen and air and are Combined Power Ventilators
- Current ICU ventilators are classified as Electrically Powered-Pneumatically Driven-Microprocessor Controlled Ventilators

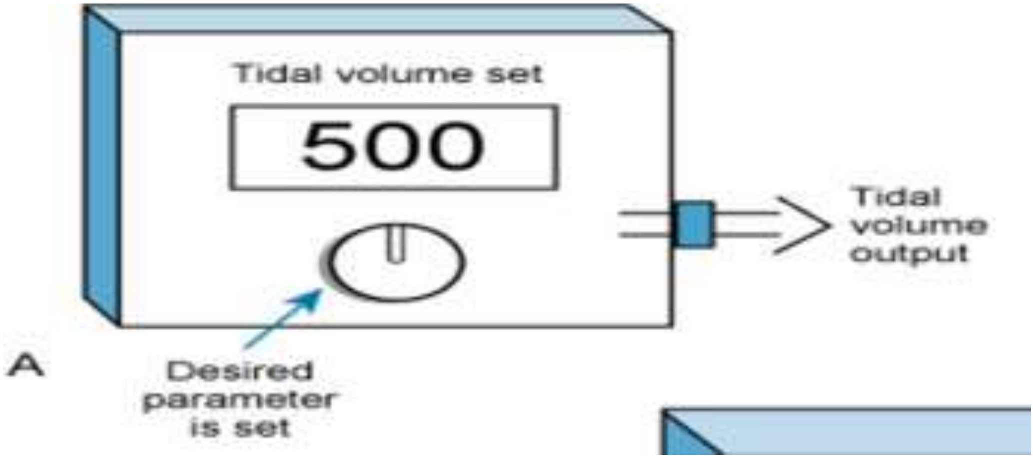
Control System & Circuit

- Control systems and circuits
  - Open- and closed-loop systems (Control level)
  - Control panel: user interface
  - Pneumatic circuit (internal and patient circuit)

Control Type (level of control)

Open loop control system

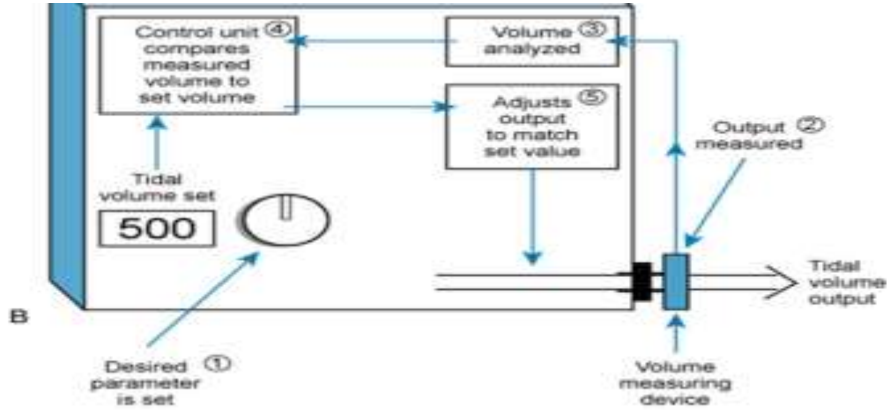
- An open-loop system cannot distinguish between the volume actually delivered and the set volume and respond to this difference.
- Operator sets parameter that is delivered by ventilator
- No assurance that volume or pressure is actually delivered to lungs



Control Type (level of control)

Closed loop control system

- Closed-Loop systems are an intelligent system
- Flow/volume or pressure are set & measured, with feedback to drive mechanism altering output to maintain desired (set) levels
- Microprocessor is used to control ventilation
- When specific tidal volume is set, ventilator adds to volume if there is leak in circuit
- Ventilator adjusts delivered volume or pressure to ensure that set parameter is delivered



Drive mechanism (Power Transmission System)

- Drive mechanism is part of the breath delivery unit.
- Responsible for breath delivery to the patient
- Develop and control pressure gradient between ventilator and patient
- It contains pneumatic and electronic modules that control the breath delivery to the patient
- Electrically powered ventilators use compressors, blowers, or other volume displacement devices
- Pneumatic systems use compressed gas from wall to deliver volume to lung

DRIVE MECHANISM

- Compressor: low flow -> container ->high level pressure (e.g.,20psi.),intensive care ventilator,
- Can be driven by pistons, rotating blades, moving diaphragms, or Bellows
- Most common type of compressor: rotary compressor
- Examples:
  - Viasys Avea
  - LTV ventilators

- **Piston mechanism**

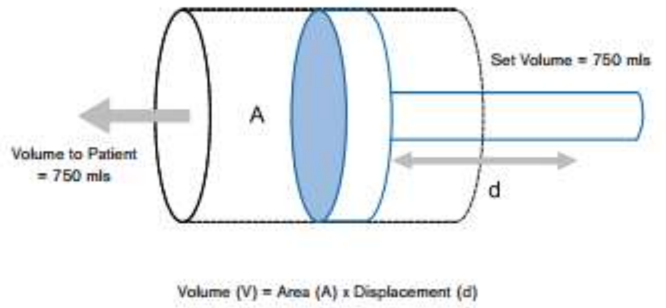


Fig. 1: The volume delivered by the piston is determined by the distance the piston moves. When a volume is set to be delivered (eg. 750 mls), the piston is moved the distance required to deliver the set volume to the patient.

DRIVE MECHANISM

- Blower : large flow -> moderate increase pressure(e.g.,2psi.),
- home-care and portable device

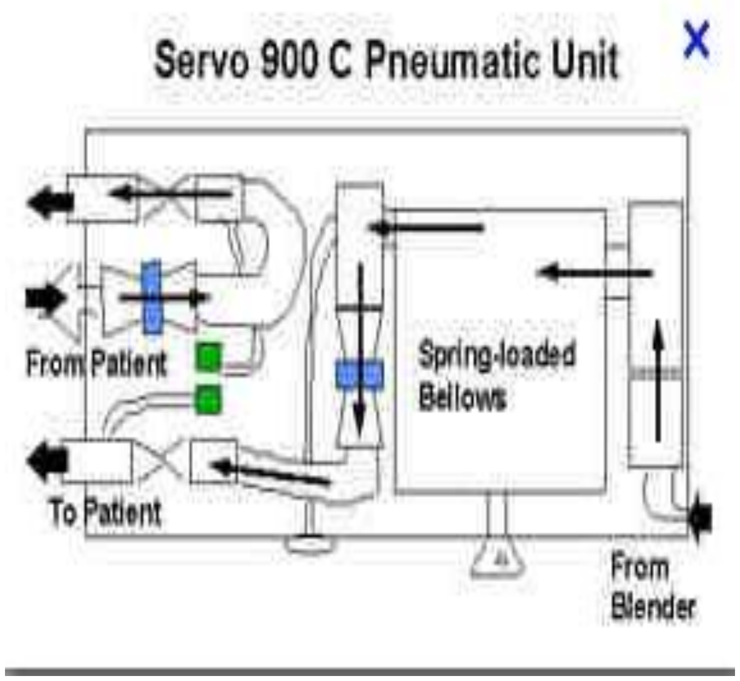
Bellows mechanism

DRIVE MECHANISM

Pneumatic circuits- uses pressurized gas as power source.

- microprocessor controlled with solenoid valves.
- use programmed algorithms in microprocessor to open and close solenoid valves to mimic any flow or pressure wave pattern.

Pneumatic mechanism

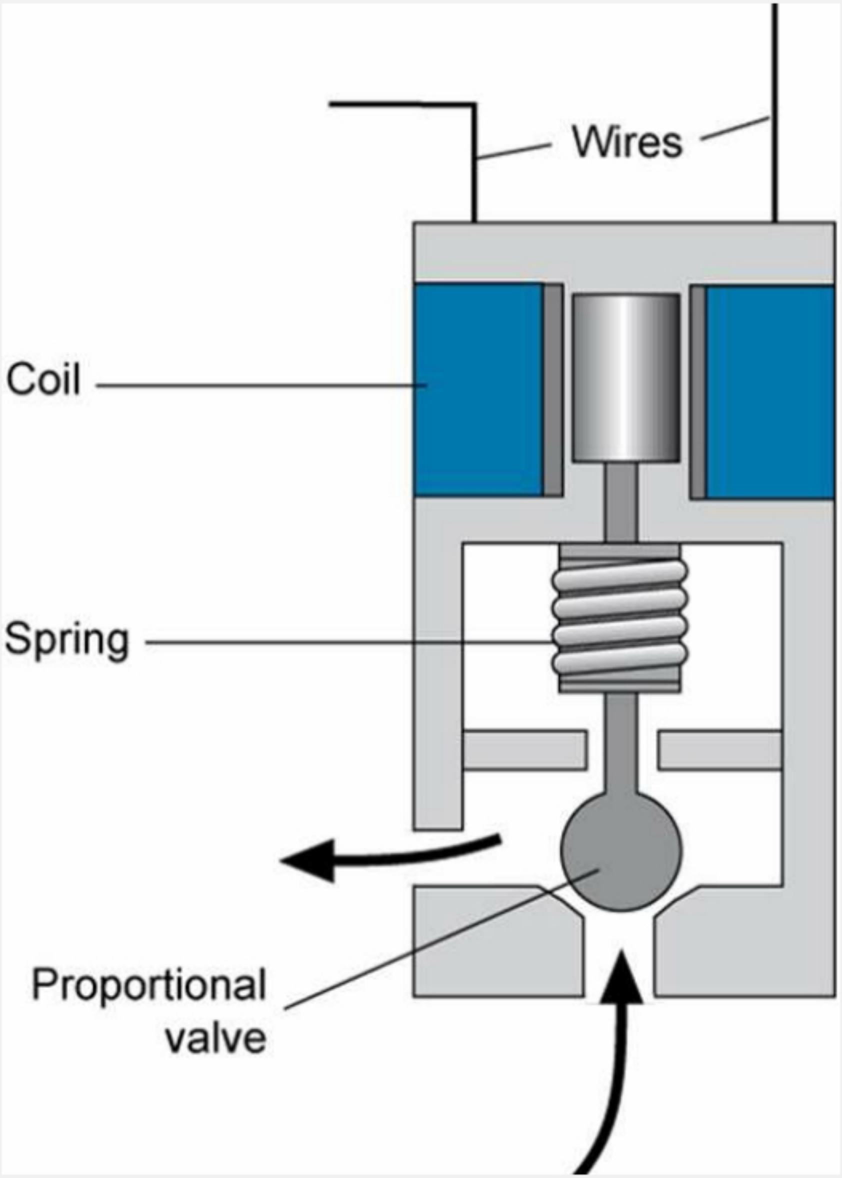


Flow-Control Valves

- Three types of flow controlling valves

1. Proportional solenoid valve
2. Stepper motors with valve
3. Digital valves with on/off configuration

- Current ICU ventilators use Proportional solenoid valve.



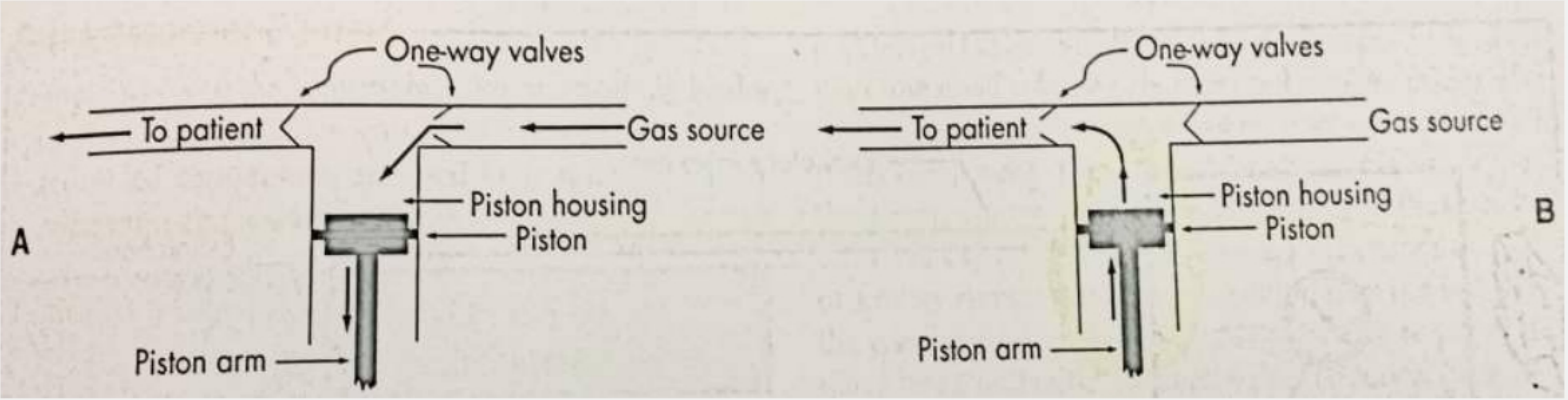
Pneumatic Circuit

- **Consists of two series of tubing:**

1. Internal Circuit: directs flow within the ventilator. It can be single or double circuit.
2. The External Circuit (Patient Circuit): directs the flow from the ventilator to the patient.

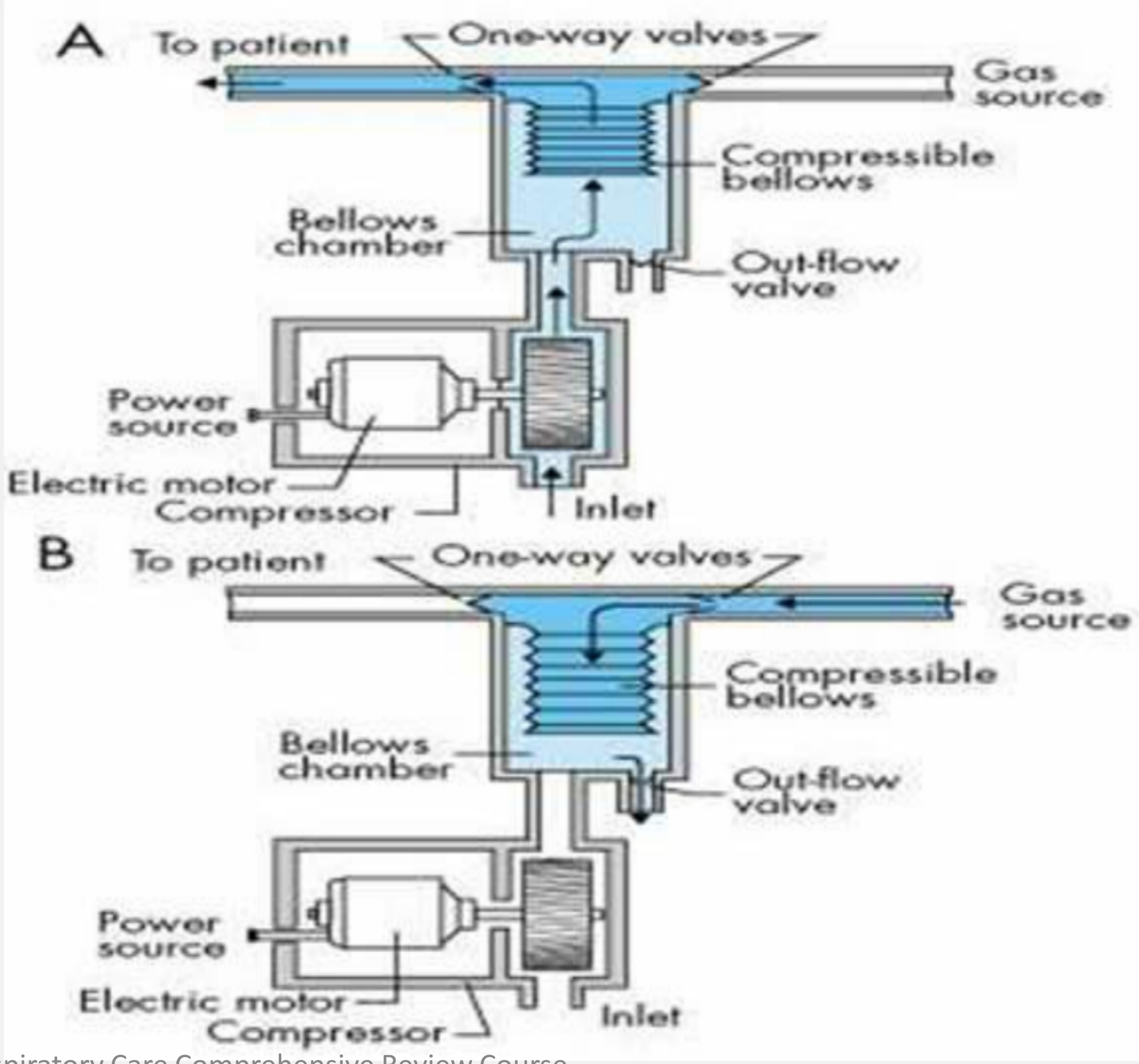
Internal Circuit (Single-circuit design)

- Single circuit: gas moves through ventilator and is delivered to patient circuit. Most commonly used

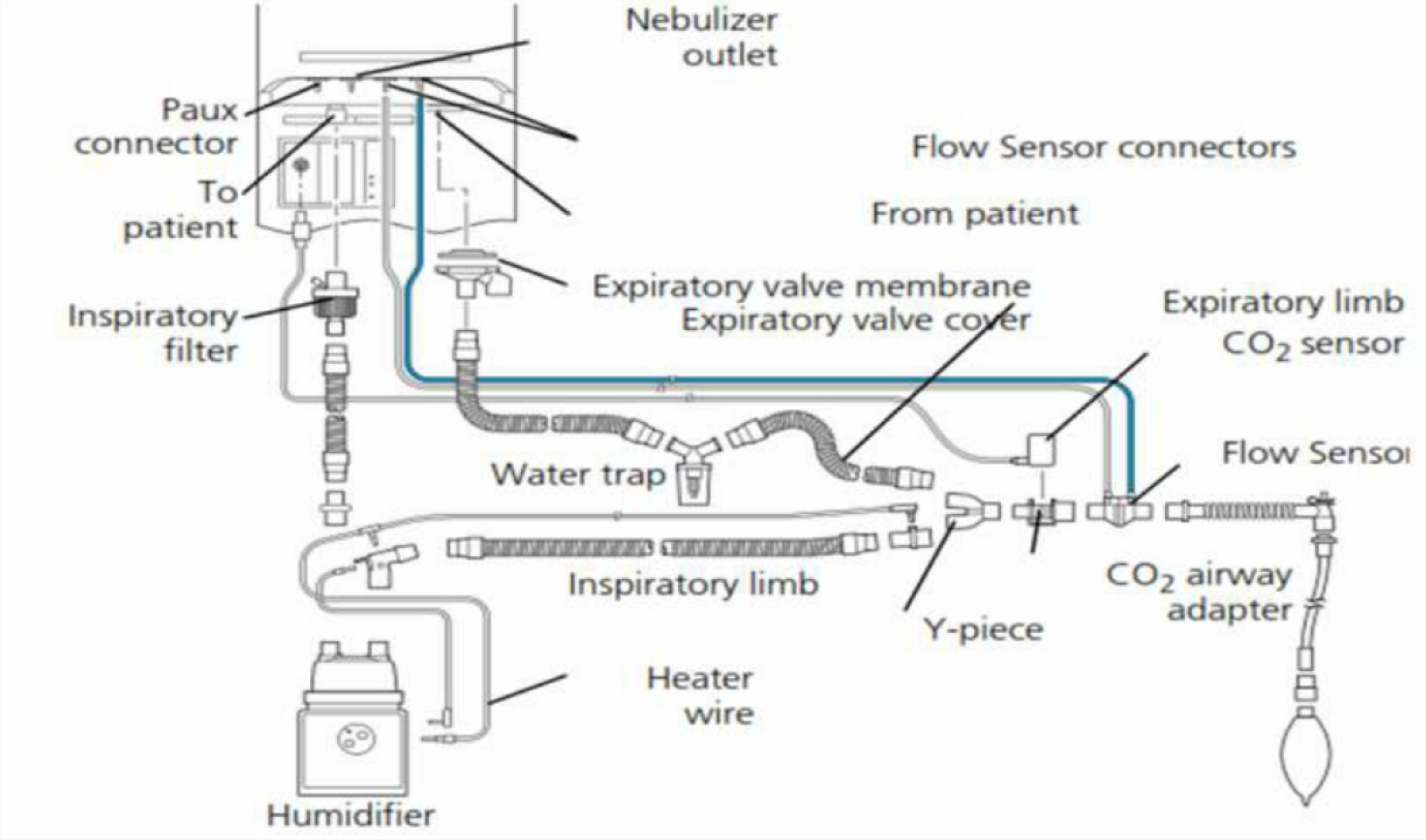


Internal Circuit (Double-circuit design)

- Double circuit includes bellows or a bag containing desired tidal volume
- Bag is compressed and desired tidal volume is delivered to lungs



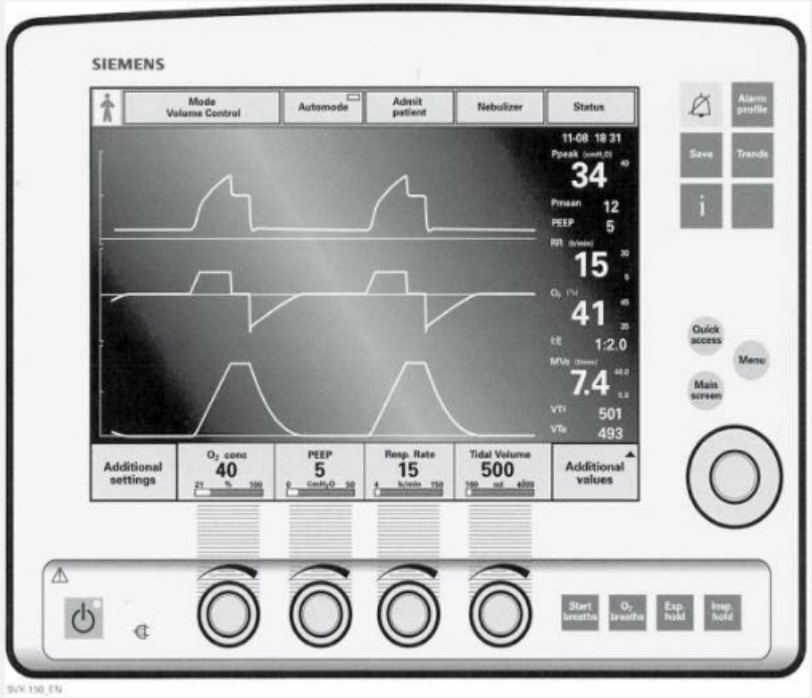
The External Circuit (Patient Circuit)



Control Panel

- Referred to as user interface
- It contains all controls used to set the ventilation and monitoring parameters
- As well as It displays other important parameters and graphics

Control Panel (Cont.)



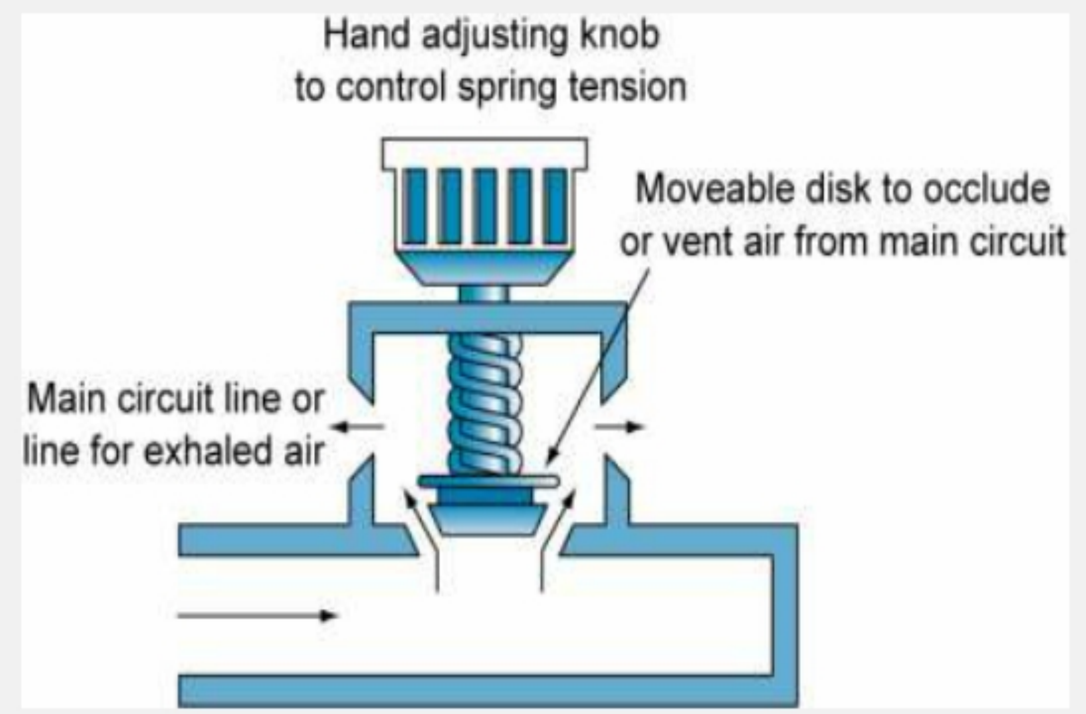
Expiratory Valves

Expiratory Valves

- Close during inspiration to direct gas flow to patient
- Open during exhalation allowing patient to exhale gas into atmosphere
- PEEP is used to improve oxygenation
- PEEP is provided by threshold resistor or flow resistance
- Both valves prevent complete exhalation of expired tidal volume

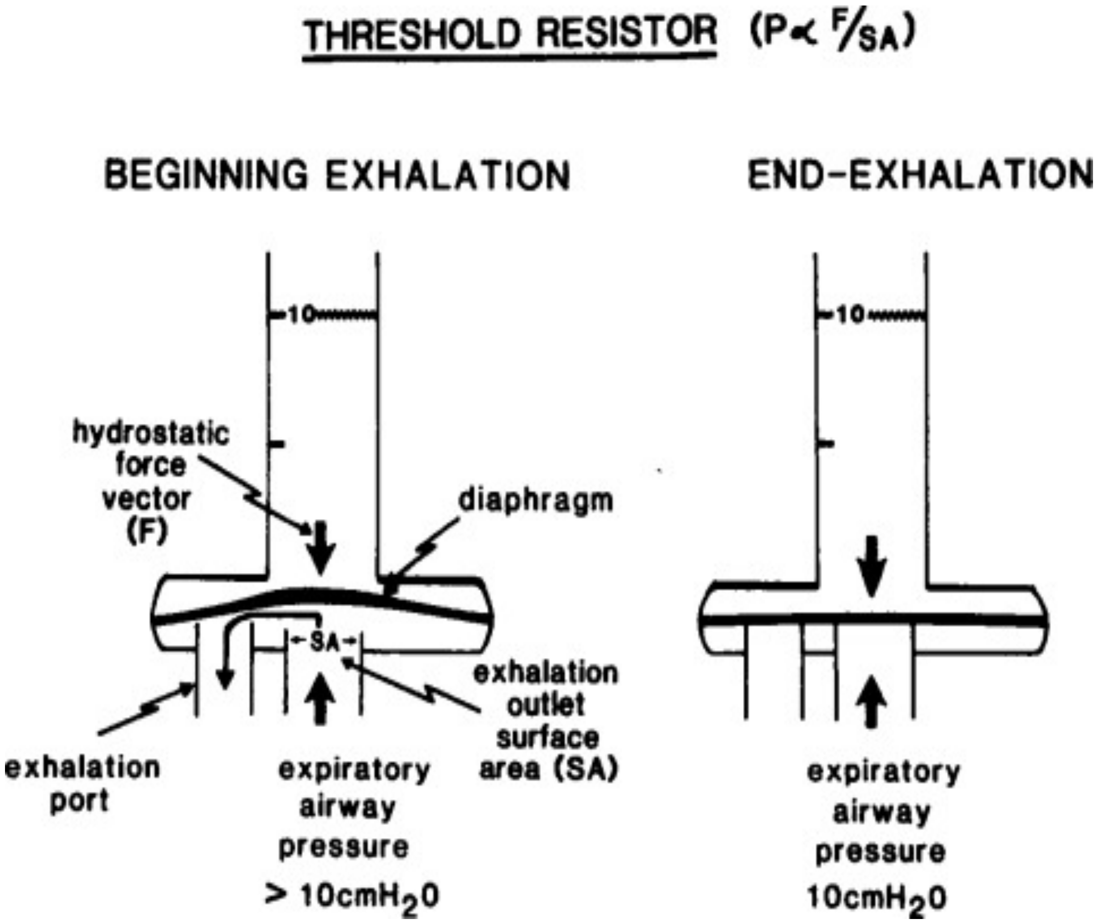
Spring-Loaded Valves

- Can be used to provide PEEP
- Spring is used to adjust amount of pressure applied against exhalation valve to prevent complete exhalation



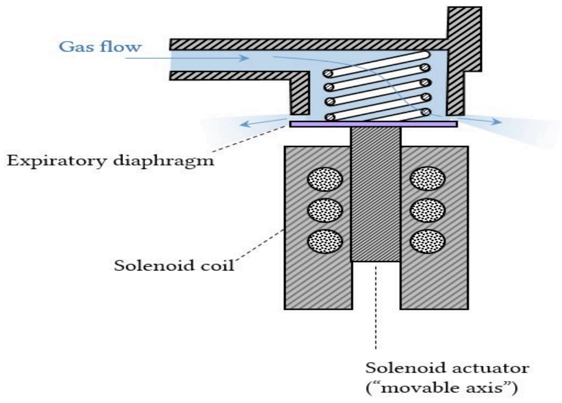
Diaphragm Expiratory Valve

- Diaphragm over exhalation valve closes during inspiration
- During exhalation, pressure on diaphragm is released
- When PEEP is used, pressure against diaphragm is maintained thus preventing complete exhalation



Electromagnetic Valves

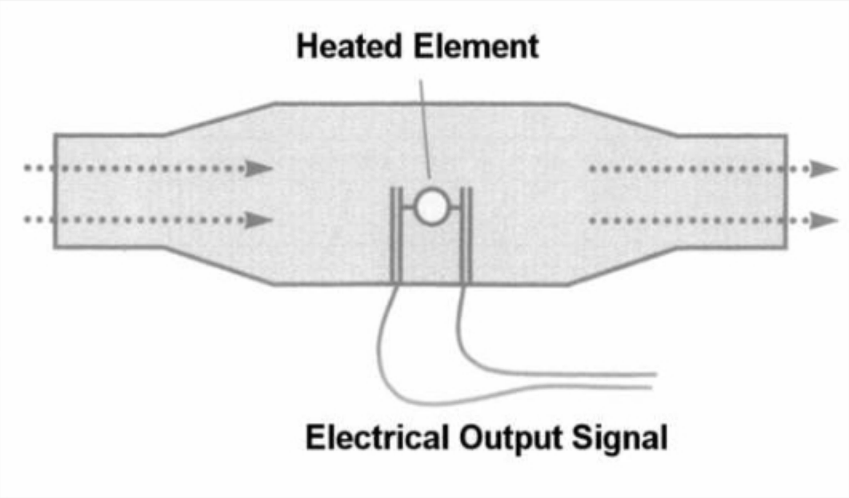
- Amount of electrical current is adjusted to regulate amount of force applied to expiratory flow
- The higher the level of current, the more force applied to exhaled gas
  Increases PEEP level
- microprocessor-controlled mechanical ventilator, the expiratory solenoid valve coordinates with the inspiratory proportioning valve and gas blender

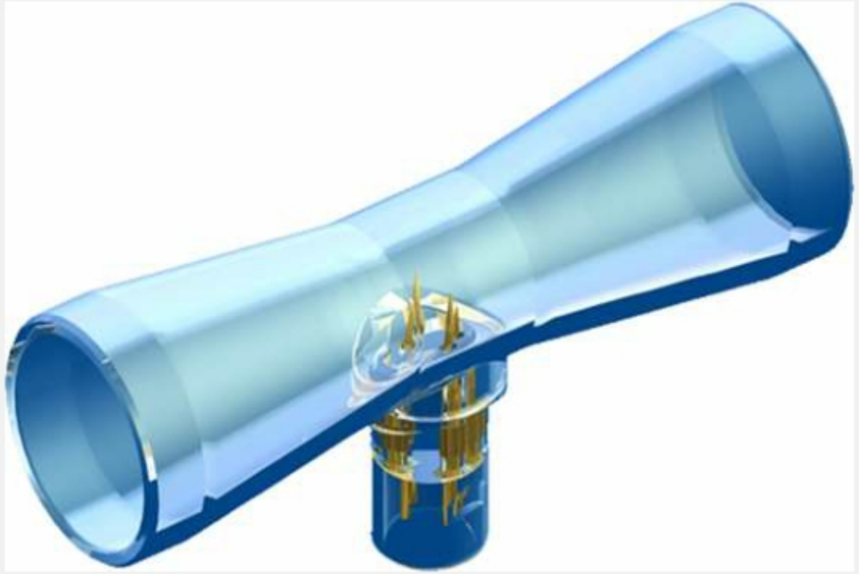


Flow sensor

Heated wire flow sensor

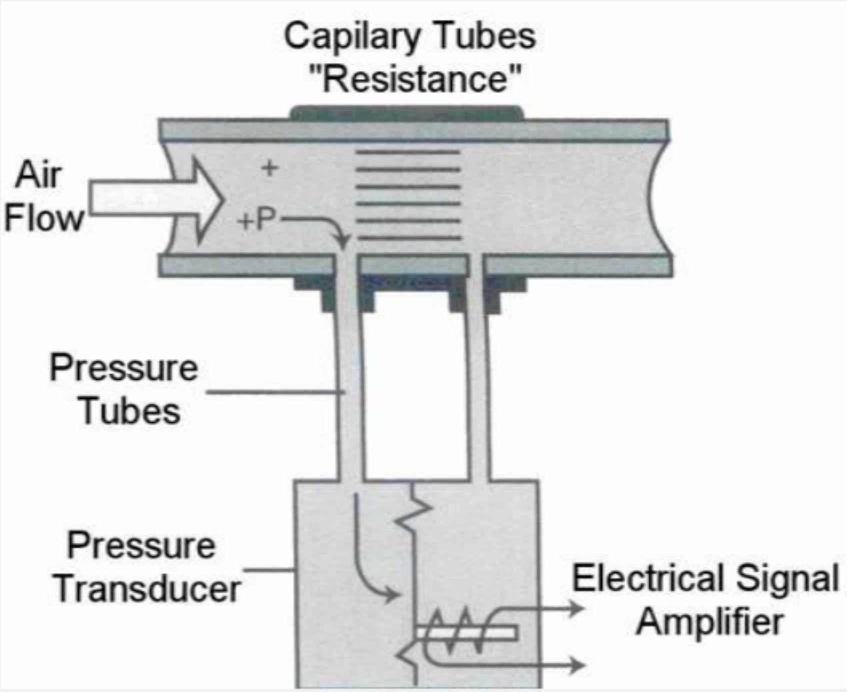
- As flow passes through the sensor, the ventilator tries to keep the wire temperature constant
- The electric currant consumed to keep this temperature is proportional to gas flow
- This type of sensors is affected by condensate, secretion and calcification.
- An example of a ventilator using this type of sensors is Dräger Evita XL™





Differential pressure flow sensor

- As flow passes through the sensor's resistive element a pressure deference develop
- Using Boyle's Law [P1V1 = P2V2] the gas flow can be calculated
- This type of sensors can be affected by condensate, secretion and calcification.
- An example of a ventilator using this type of sensors is Hamilton G5 & S1



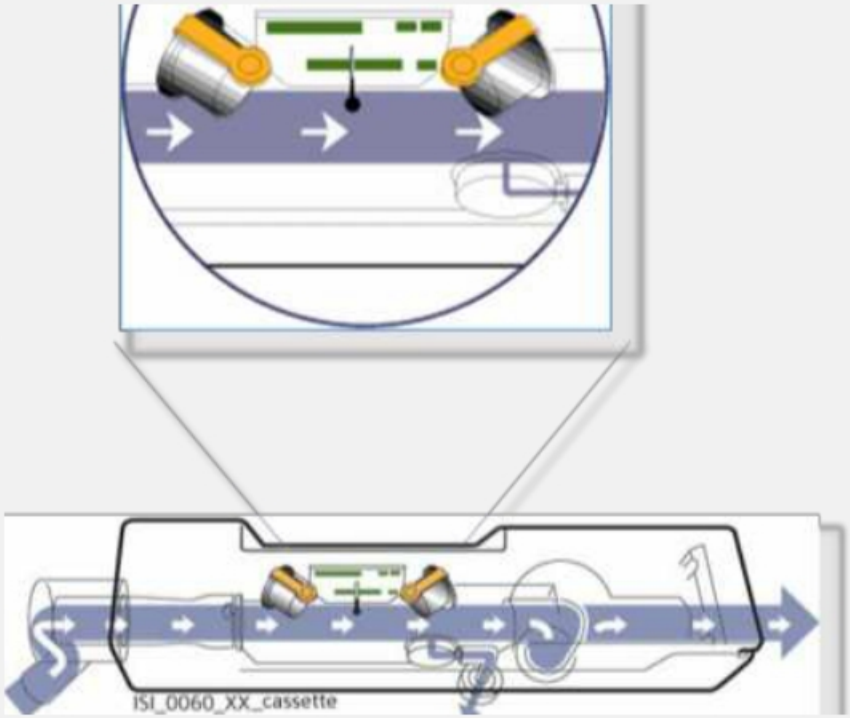
Ultrasonic Flow Sensor

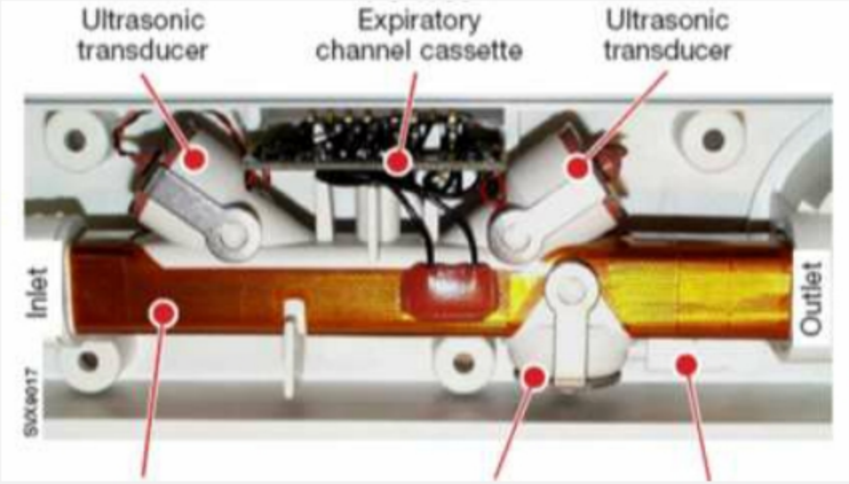
Ultrasonic transducer technology:

$$T_2 - T_1 = T_{diff}$$

T_{diff} is proportional to the gas flow

New measurement every 4 ms





Specifications for an alarm

(1) conditions that trigger the alarm,

(2) the alarm response in the form of audible and/or visual messages,

(3) any associated ventilator response such as termination of inspiration or failure to operate, and

(4) whether the alarm must be manually reset or resets itself when the alarm condition is rectified.

	Event Priority			
	Level 1 Critical malfunction	Level 2 Non-critical malfunction	Level 3 Pt. status change	Level 4 Operator alert
Alarm Characteristics				
Mandatory	yes	yes	no	yes
Redundant	yes	no	no	no
Noncancelling	yes	no	no	yes
Audible	yes	yes	yes	no
Visual	yes	yes	yes	yes
Automatic backup	yes	no	no	no
Automatic Reset				
Audible	yes	yes	yes	yes
Visual	no	yes	yes	yes
Alarm Events				
Input				
Electrical power	yes	n/a	n/a	n/a
Pneumatic power	yes	n/a	n/a	n/a
Control Circuit				
Inverse I:E ratio	no	yes	no	yes
Incompatible settings	no	no	no	yes
Mech./elect. fault	yes	no	no	no
Output				
Pressure	yes	yes	yes	yes
Volume	yes	yes	yes	yes
Flow	yes	yes	yes	yes
Minute ventilation	yes	yes	yes	yes
Time	yes	yes	yes	yes
Insp. gas (FiO_2/temp.)	yes	yes	no	yes

Maintenance of Mechanical ventilator

一級保養

日期						1	2	3	4	5	6	7	8	9	10	11	12	13	14
項目/星期		一	二	三	四	五	六	日	一	二	三	四	五	六	日	一	二	三	四
每日	1.清潔機體版面																		
	2.警告燈號及設定值																		
	3.更換或添加蒸餾水																		
	4.檢查潮濕器功能																		
	5.排除管路之積水																		
	6.檢查吐氣 flow sensor 有無藥物結晶(ex:T-Bird,VELA,VIP BIRD...)																		
每週	1.更換呼吸管路及加水系統,並檢查有無漏水,漏氣																		
	2.更換或消毒 flow Sensor 及瓣膜(ex:T-Bird,VELA,VIP BIRD...)																		
	3.清潔過濾網																		
	4.檢查管路脫落警報																		
	5.確認機體 Air& O2 inlet 無積水																		
每月	1.測量溫度																		
	2.氧氣濃度校正（當時或三段式）																		
每季	1.更換白色吐氣過濾器																		
待機空機	1.拆髒管路																		
	2.完成終期消毒																		
	3.裝置新管路及標示管路有效期限																		
	4.Pre-setting																		
	5.檢查電源脫落警報																		
	6.註明：空機『 ○』，待機『★』，使用『✪』，故障『？』																		
備註	1.機器自我檢測/時數/執行者																		

一級保養

每日

1.清潔機體版面

2.警告燈號及設定值

3.更換或添加蒸餾水

4.檢查潮濕器功能

5.排除管路之積水

6.檢查吐氣flow sensor有無藥物結 晶(ex:T-Bird,VELA,VIP BIRD…)

一級保養

每週

1.更換呼吸管路及加水系統,並檢查有無漏水,漏氣

2.更換或消毒flow Sensor及瓣膜(ex:T-Bird,VELA,VIP BIRD…)

3.清潔過濾網

4.檢查管路脫落警報

5.確認機體Air& O2 inlet無積水

一級保養

每月

1.測量溫度

2.氧氣濃度校正（當時或三段式）

3.機體自我測試（SST/EST/UVT）

每季

1.更換白色吐氣過濾器

二級保養

Table 7-4: Service preventive maintenance procedures and intervals

Frequency	Part	Maintenance
Every 6 months	Entire ventilator	Run Extended Self Test (EST).
Every year	Atmospheric pressure transducer, expiratory valve, flow sensors, and vent inop test	Perform calibration/test.
	Entire ventilator	Run performance verification. This includes running an electrical safety test and inspecting ventilator for mechanical damage and for label illegibility.
When ventilator location changes by 1000 feet of altitude	Atmospheric pressure transducer	Perform atmospheric pressure transducer calibration.
Every 2 years or as necessary	BPS internal battery pack	Replace BPS internal battery pack. Actual BPS life depends on the history of use and ambient conditions.
Every 10,000 hours	Various parts	Install appropriate preventive maintenance kits.

Ventilator of the future

Table 2. Features of the Ventilator of the Future

Integration with other bedside technology
Ability to effectively ventilate all patients in all settings, invasively or noninvasively
Ventilator management protocols incorporated in the basic operation of the ventilator
Tidal volume displayed in mL/kg predicted body weight
Smart alarm systems
Display of information instead of unrelated data
Decision support
Closed-loop control of most aspects of ventilator support

Thank You For Your Attention !
Have a Nice Day!