New Anesthetic Mechanical Lung Ventilation Apparatuses and Design of Gas Flow Commutators

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Anesthesia in surgery is often accompanied by relaxation of the respiratory muscles, thereby requiring mechanical lung ventilation (MLV) of the patient. Ventilation support during inhalation anesthesia (IA) is implemented in MLV apparatuses. The use of MLV apparatuses imposes limitation on the range of possible ventilation modes. However, in recent years there is a trend toward an increase in this range.

The requirements for MLV apparatuses used in anesthesia include:
- supply of gas mixtures (air, oxygen, nitrous oxide, vapors of anesthetics, etc.) to the patient through reversible and non-reversible respiratory circuit;
- conservation of respiratory mixture in the anesthetic unit up to the moment of its supply to patient’s lungs;
- safety measures in case of inflammable respiratory mixtures;
- compatibility with collection systems for exhaled gas;
- effect of respiratory mixture on pneumatic elements of the respiratory circuit.

New anesthetic devices and apparatuses for mechanical lung ventilation with electronic control available from VNIIMP-VITA, Ltd. meet these requirements. These devices are available with different drives:
- Diana1 and Diana-D with pneumatic drive;
- Elan-NR and Elan-R with electric drive.

The pneumatic system of the devices is based on rubber bellows. This provides ventilation and supply of gas mixtures to the patient’s lungs through reversible or non-reversible respiratory circuit. Schematic diagrams of the Diana and Diana-D apparatuses are shown in Fig. 1.

Bellows 5 is placed in a transparent housing. The bellows is compressed with gas (oxygen or air) supplied from injector 3 to the space between the housing and outer surface of the bellows. Compressed air is supplied to injector 3 from pressure regulator 1 and distributor 2. Regulator 1 maintains the input gas pressure of the injector at a constant level.

Parameters of injector 3 provide maximum productivity and stable operation at counterpressure 20-30 cm H₂O.

During inhalation, the respiratory gas mixture from bellows 5 through back valve 6 is supplied to the patient’s lungs. Throttle 4 regulates the cross-section of the injector 3 and gas flow rate. Safety valve 16 imposes limitation on the maximum gas pressure in the bellows.

The bellows 5 platform determines the volume of inhalation. The rotary disk with cord 11 is used to set required inhalation volume. Disk 11 is attached to the axis of a potentiometer that forms the electric signal proportional to the inhalation volume.

Control unit 15 and optical pair 12 is used to detect the moment of complete compression of the bellows. This moment coincides with the initial moment of the next respiratory cycle. In addition to regulation of distributor 2, control unit 15 sets off alarm signals. During exhalation the bellows 5 are expanded and through valve 6 is filled with respiratory mixture from the anesthetic apparatus. The inhalation and exhalation valves commutate gas flows in the respiratory circuit. The valves should be independent and controlled in spontaneous respiration and MLV modes, respectively.

In the Diana apparatus [3] trigger 10 combines functions of exhalation valve and distributor in the bellows. During exhalation, in the intermembrane cavity regulator 1 triggers gas flows in exhalation and gas discharge lines of bellows 5. However, high pressure (~0.2 MPa) in injector 3 increases gas expenditure and decreases membrane service life.

In the Diana-D apparatus (Fig. 1) these disadvantages are avoided by commutation [4] of gas supplied from injector 3. This function is implemented in membrane valve 13 and low-pressure trigger 14 in the line of

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1 Manufactured in collaboration with Electromedoborudovanie, Ltd. (St. Petersburg).
the gas supply to bellows 5. During inhalation, the line of exhalation is stopped with valve 13 driven by gas pressure from injector 3. The spring-loaded membrane of the valve regulates the exhalation resistance to provide positive exhalation end pressure (PEEP).

Membrane trigger 14 is in the space between the bell and bellows 5. This trigger connects the space with the line of injector 3 or with atmosphere during exhalation or inhalation, respectively. The construction of the low-pressure membrane trigger is shown in Fig. 2.

Flat 0.5-mm-thick elastic membrane is installed between nozzles a and b at its axis. The diameter of the nozzles a and b meets the condition of minimal resistance to gas flow [1, 2]. These devices are driven by compressed gas. Compressed oxygen and air are rather expensive, whereas autonomous air compressors used in domestic clinics are very noisy. These factors impose limits on the use of pneumatic MLV systems in medical practice.

The schematic diagrams of new apparatuses with electric drive are shown in Fig. 3. These devices are driven electrically rather than pneumatically. Electric motor 1 and screw gear 2 are used to drive bellows 3.

The position of bellows 3 and ventilation mode are determined by program unit 14, which controls the rotor of electric motor 1. The program also controls commutation of gas flows in the respiratory circuit of the apparatus.

Apparatus Elan-NR and Elan-R are used for anesthesia and intensive therapy. Membrane valve 8 in the inhalation line increases the capacity of the Elan-R apparatus, because it switches off bellows 3 during inhalation, thereby reducing the patient’s efforts for inflation.

The algorithm of the Elan-R apparatus implies switching off the inhalation line with controlled valve 8 during expansion of the bellows. This increases the accuracy of sensor 15 within the exhaled gas volume range 30-1500 ml and decreases the effect of extensibility of the respiratory circuit. The accuracy improvement is particularly important in children, because extensibility of their lungs is comparable with extensibility of the respiratory circuit.

The reliability of controlled valves is determined by stability of control signal. Generator of pneumatic pulses