Dräger Cato Operating Manual

I) Anesthetic Workstation Cato:

It is a universally applicable anesthetic workstation for:

- Inhalation anesthetic in semi-closed systems
- Inhalation anesthetic in virtually closed systems with “low flow” and “minimal flow” techniques for minimum gas and anesthetic consumption with:

    1. Automatic ventilation (IPPV)
    2. Synchronized intermittent mandatory ventilation (SIMV)
    3. Manual ventilation (MAN)
    4. Spontaneous breathing (SPONT)

II) Measurement and Monitoring Functions:

The available functions are:

- Measurement of ventilation parameters (pressure, flow, O_2 concentration inspiratory and expiratory).
- Continuous measurement of CO_2 concentration and N_2O/anesthetic concentration (halothane, enflurane, isoflurane, sevoflurane, desflurane). The flow rate for sampling the measuring gas can be varied and is returned to the circulation.
- Automatic adjustment of the alarm limits for automatic ventilation (IPPV).
- Anesthetic vaporizer with automatic vapor recognition.
- Optional:
    - Continuous non-invasive measurement of functional O_2 saturation.
    - Measurement of inspiratory breathing gas temperature.

III) Indicated Values:

The indicated values are:

- Continuous curve for airway pressure, peak and plateau pressure, mean pressure and PEEP[1].
- Patient compliance.
- Expiratory minute volume, tidal volume and respiration rate.
- Expiratory flow curve.
- Inspiratory and expiratory O_2 concentration.
- Inspiratory and expiratory concentration of N_2O and anesthetic halothane, enflurane, isoflurane, sevoflurane, and desflurane.
- Inspiratory and end-expiratory CO_2 concentration.
- Continuous CO_2 curve.
- List entries and trend displays.

[1] PEEP: Positive End-Expiratory Pressure

- Optional:

  - Functional O_2 saturation, pulse rate, and plethysmogram.
  - Inspiratory breathing gas temperature.

IV) Monitored Parameters:

The monitored parameters include:

- Airway pressure.
- Expiratory minute volume.
- Inspiratory O_2 concentration.
- Inspiratory and expiratory CO_2 concentration.
- Inspiratory anesthetic concentration.
- Optional:

  - Functional O_2 saturation and pulse.
  - Inspiratory breathing gas temperature with invariable upper alarm limit.

V) Keys:

A) Setting operating modes:

Left-hand side:

MAN SPONT	Key for manual ventilation or spontaneous breathing
IPPV	Key for IPPV mode

Right-hand side:

Test	Key for leakage test and compliance measurment
SIMV	Key for SIMV mode
⏻	Standby Key

B) Setting ventilation parameters:

Located below the display window:

P_{max}	Key for setting maximum pressure for IPPV and SIMV ventilation (in mbar)
V_t	Key for setting tidal volume (in mL or L)
f_{IPPV}	Key for setting ventilation frequency in IPPV mode (in breaths/min)
$T_I : T_E$	Key for setting time ratio between inspiration and expiration
$T_{IP} : T_I$	Key for setting realtive inspiratory pause
PEEP	Key for setting PEEP pressure for IPPV mode
f_{IMV}	Key for setting ventilation frequency in SIMV mode

VI) Structure of Display Screen:

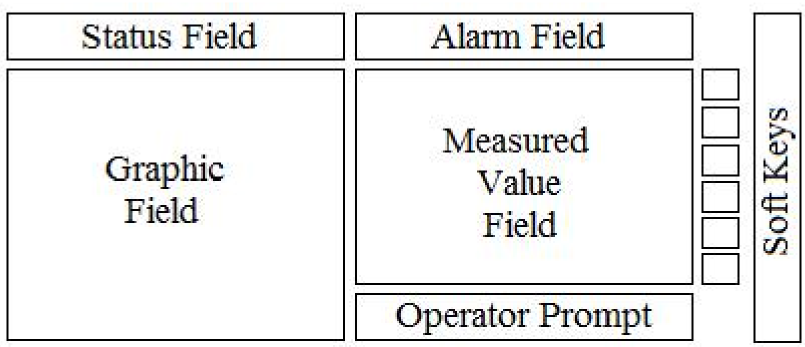

Figure 1 - *Structure of Dräger Cato Display Screen*

Figure 8 illustrates the diagram of the display screen structure on a Dräger Cato ventilation machine. The description of each section is given as follows:

- Status field: contains information on current alarm mode of monitor.
- Alarm field: indicates alarms and their priority.
- Graphic field: curves and bar graphs.
- Measured value field: for most important numerical values.
- Operator prompts: prompts to guide the operator.
- Soft keys: for rapid selection of functions displayed on screen.

VII) Screens:

The available screens are:

a. Standard screen: with CO_2 curve and another selectable curve (most important measured values are indicated to the right).
b. Data screen: contains all measured values with their units of measurement; simplifies completion of anesthesia record.
c. Trend screen: for displaying the changes in the measured values since the measurement started (current measured values are shown on the right).

VIII) O_2 Flush Capability:

The O_2 flush capabilities are possible with O_2^+ button.

IX) Oxygen Ratio Control (ORC):

ORC regulates the delivery of O_2, N_2O, and air where N_2O flow decreases below 0.8 L/min proportionally with O_2 flow for ORC low-flow, and N_2O flow decreases to "0" proportionally with O_2 flow for SORC. When the mode is switched to "air", the N_2O decreases to "0".

X) Automatic Calibration of O_2/Flow Sensors:

The side-stream calibration of O_2 measurement (O_2 sampling) and flow measurement are performed during the first breaths after starting ventilation. There's therefore no cause for panic if measured values for minute ventilation still appear in grey immediately after self-test. CO_2 measurement must function correctly before automatic flow calibration can be performed, otherwise the flow sensor must be calibrated manually.

XI) Manual Calibration of O_2 Sensor:

This manual calibration is only performed when the O_2 measurement has been set in inspiratory line.

Calibrating the O_2 sensor with 21% O_2 by volume – air:

The O_2 sensor can be calibrated while the flow calibration is being conducted:

1. Remove the sensor from inspiratory valve and expose it to ambient air.
2. Place it on table and wait for at least 2 minutes.
3. Use rotary control to select "Calibrating" in "Standby/configuration" menu and press to confirm.
4. Move the cursor frame to "O_2 Sensor 21 Vol %" by means of a rotary control and press it to confirm starting the calibration.

5. Plug the O_2 sensor onto the inspiratory valve again.

XII) Manual Calibration of Flow Sensor:

A) Without Removal: On anesthetic unit:

1. Set the AIR/N_2O selector to “AIR”.
2. Close the delivery valves for O_2 and N_2O, open the delivery valve for air and thoroughly flush the breathing system with air.
3. Close the delivery valve for air.
4. Press the rotary control on the monitor to start the calibration (timer icon appears and then tick appears when calibration has been completed correctly).
5. Tick off in the checklist, then the cursor frame automatically jumps to the “Ventilator Start-up Test”.

B) With Removal:

1. Set the AIR/N_2O selector to “AIR”.
2. Close the delivery valves for O_2 and N_2O, open the delivery valve for air and thoroughly flush the breathing system with air.
3. Close the delivery valve for air.
4. Press the rotary control on the monitor to start the calibration (timer icon appears and then tick appears when calibration has been completed correctly).
5. Remove the flow sensor as follows:

   - Unscrew the expiration nozzle.
   - Remove the flow sensor.
   - Briefly swing it to flush with ambient air.
   - Hold it horizontally with the cable connection pointing toward downwards (calibration in installation position improves the measuring accuracy).
   - Seal off one or both sides as shown on right preferably with thumb or palm.
   - Press the rotary control on the monitor to start the calibration.

6. Replace the flow sensor.

XIII) Ventilation Modes:

A) Manual Ventilation:

1. Deliver fresh gas.
2. Switch the pressure limiting valve APL to “MAN”; turn the lever to set the pressure limitation on the scale.
   On ventilator:
3. Press “MAN/SPONT” for at least 1 second.
4. Ventilate the patient with a breathing bag.

B) Mechanical Ventilation in IPPV Mode:

1. Deliver fresh gas.
   On ventilator:
2. "IPPV Mode?" message appears.
3. Press the rotary control to confirm.
4. Activate the ventilation parameters by pressing the corresponding keys.
5. Select and confirm with the rotary control.

C) Mechanical Ventilation in SIMV Mode:

1. Deliver fresh gas.
   On ventilator:
2. "SIMV Mode?" message appears.
3. Press the rotary control to confirm.
4. Activate the ventilation parameters by pressing the corresponding keys.
5. Select and confirm with the rotary control.

XIV) Parameters in Standby:

The parameters in standby are:

- SpO_2 measurement (on/off).
- Side-stream measurement O_2 (on/off).
- Sample rate: 60 or 200 mL/min.
- CO_2 units: mmHg, kPa, or % by volume.

XV) Calibration Options:

The calibration options include:

- Calibrate the O_2 sensor with 21 vol. % O_2.
- Calibrate the flow sensor.
- Perform the ventilation start up test.
- More:
  - O_2 sensor calibration with 100% O_2 by volume.
  - Linearity check of O_2 sensor.
  - Calibration of CO_2 sensor.

XVI) Curve Selection:

The curve selection is only possible in the standard screen. A second curve for bottom half of the screen can be selected from the menu presented to complement the CO_2 concentration curve which is always displayed. The following can be selected:

- PAW: Airway pressure
- Flow: Expiratory flow
- Volumeter: Display showing minute ventilation plus PAW and V_T as bar graph.
- Pleth.: Plethysmogram (optional)
- O_2: Oxygen concentration of breathing bag (optional)

XVII) Simplified Pneumatic Schematic:

Figure 9 illustrates the simplified pneumatic schematic of the Dräger Cato ventilation machine. It shows the valves and subsystems.

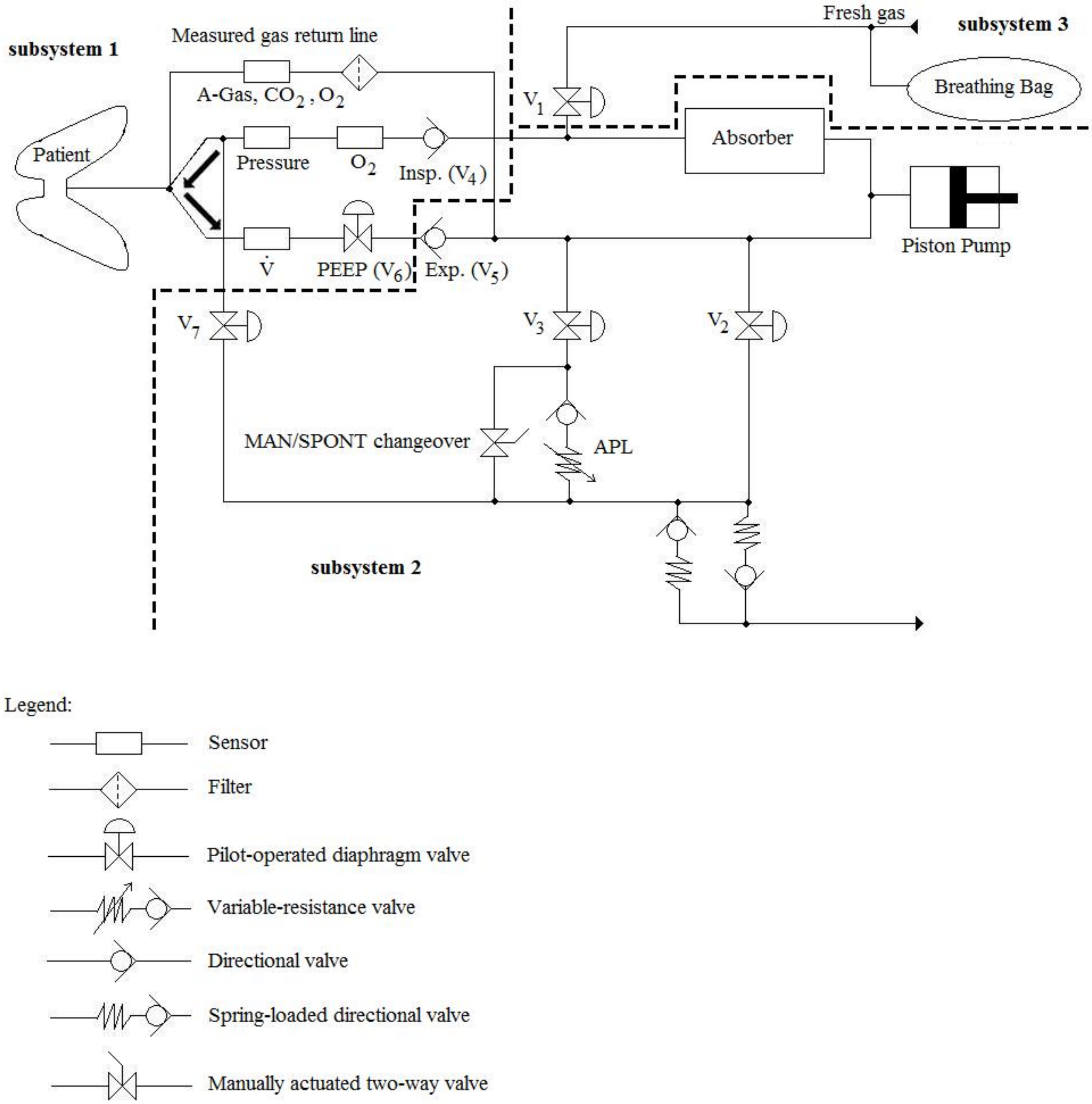

Figure 2 - *Simplified Pneumatic Diagram of Dräger Cato Ventilation System*

XVIII) Care Schematic:

Figure 10 shows the care schematic of the Dräger Cato ventilator.

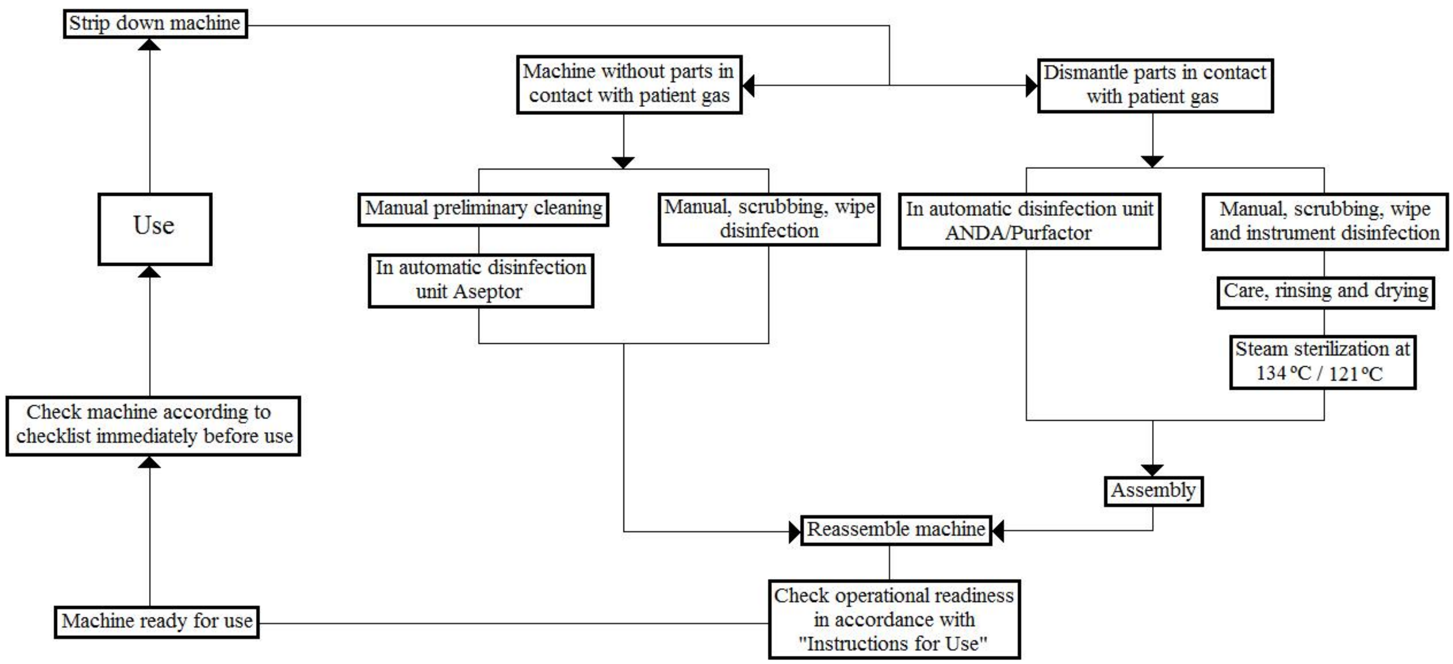

Figure 3 - *Care Schematic of Dräger Cato Ventilation System*

XIX) Choice of SpO_2 Sensor:

The choice of SpO_2 sensor (Nellcor) is based on the following criteria:

- Patient's weight
- Mobility of patient
- Possible application site
- Perfusion of patient
- Period of use (short or long term monitoring)

XX) Checking Operational Readiness:

The operational readiness of the machine must be restored and checked whenever it has been cleaned, disinfected, sterilized, repaired or serviced. Supplementary equipment must be checked in accordance with the respective "Instructions for Use". Note the applicable time limits for filters, maintenance and calibration, e.g. in conjunction with the equipment for measuring blood pressure or body temperature.

Checking the operational readiness includes the check based on the checklist, the self-test and the following:

- O_2 Shortage Signal:

    1. Open O_2 delivery valve.
    2. Interrupt O_2 supply.
    3. O_2 shortage signal must be given after approximately 3 seconds: continuous tone for at least 7 seconds.

- Supply of Anesthetic Agent:

    1. Check filling level.
    2. Replenish anesthetic agent if necessary – as specified in separate "Instructions for Use" of anesthetic vaporizers. If the last inspection took place more than 6 months previously.
    3. Check vapor.
    4. Lock hand-wheel in zero position.

- Temperature Measurement (Optional):

    1. Remove the temperature sensor from the Y-piece and place in water bath (21º → 49º C).
    2. Compare the measured value on the screen with that of the second thermometer with known accuracy.

- SpO_2 Measurement (Optional):

    1. Apply Dura-sensor DS 100A to own finger.
    2. Indication must be plausible.

- Power Failure Alarm:

    1. Interrupt power supply, e.g. disconnect plug from the socket.
    2. Switch on machine – press power switch, turn to I. Power failure alarm is given. Continuous tone – volume must remain constant for 30 seconds. If not, reconnect to mains and leave machine on for 24 hours so that the battery can recharge. Repeat test.
    3. Switch off machine, press power switch again and turn to "0". Alarm goes out.
    4. Reconnect to power supply.

- Self-test:

  The self-test must be completed successfully in order to establish readiness for operation. Supplementary equipment must not be switched on until after self-test. Start self-test: Switch on machine by pressing the power switch then conduct ventilator start-up test.

- Calibrate Flow Sensor:

  Check the manual calibration of the flow sensor.

- Calibrate Inspiratory O_2 Sensor with 100% O_2:

  This is necessary if the side-stream O_2 measurement is not used.

  1. Remove O_2 sensor and place test adapter 6801349 on sensor.
  2. Allow an O_2 flow of approximately 1 L/min to flow over the O_2 sensor for approximately 2 minutes.
  3. Select “More” with rotary control.
  4. Select “O_2 Sensor 100 Vol. %” with rotary control.
  5. Display: When the O_2 sensor has been flushed with O_2 for approximately 2 minutes:

     a) Press rotary control to confirm.
     b) Calibration is started and continuous automatically.
     c) Calibration is then complete when “✓” tick shows instead of the clock item.
  6. Replace the O_2 sensor in its mounts.

- Calibrate O_2 Sensor for Side-stream:

  It is necessary for monthly linearity check. Prepare substitute sampling line:

  1. Cut sampling hose through the middle.
  2. Unscrew the original sampling hose from water trap and screw on slit sampling hose.

  On Cato:

  1. Disconnect fresh gas hose from breathing system.
  2. Set an O_2 flow of 1 L/min O_2 at O_2 flow tube and slide sampling hose into fresh gas hose.
  3. Use rotary control to select “Calibrating” and then “More”.
  4. Select “O_2 Sensor 100 Vol. %” with rotary control.
  5. Display.
  6. Allow O_2 to flow for approximately 2 minutes.

7. Press the rotary control to confirm; calibration is then started and continues automatically. The clock icon "🕘" is then replaced by a tick "✓" icon.
8. Screw the original sampling hose back onto the water trap.
9. Plug the fresh gas hose back into the breathing system.

- Check Linearity:

  The linearity must be checked every month.

  1. Calibrate the O_2 measurement used (inspiratory or side-stream) with 100% O_2.
  2. Expose inspiratory O_2 sensor to ambient air for approximately 2 minutes (inspiratory).
     OR
     Unscrew sampling hose from water trap and allow it to take in the air for approximately 2 minutes (side-stream).
  3. Display on screen should show 18 – 24 vol. % O_2. If the value displayed is outside 18 – 24 vol. % O_2, then the sensor capsule is faulty.
  4. Put the inspiratory O_2 sensor back and calibrate (inspiratory).
     OR
     Put the O_2 sensor for side-stream O_2 measurement back and calibrate (side-stream).
  5. Put the O_2 sensor back.
  6. Screw the sampling hose back onto the water tap.

- Manual Ventilation Function:

  This function can be selected when the machine is in "Manual/Spontaneous" mode.

  1. Press "MAN/SPONT".
  2. Pressure the limiting valve (APL). Set to "MAN".
  3. Connect lung simulator, and exercise thorax or breathing bag to the Y-piece.
  4. Set the fresh gas flow.
  5. Set maximum ventilation pressure between 5 and 70 mbar on APL valve. Turn the valve head for this purpose.
  6. Compress the breathing bag.
  7. Compare the pressure indication on the monitor with setting on the pressure limiting valve. If excess pressure has to be relieved quickly, then press vertically down on the lever of the pressure limiting valve.

- Automatic Ventilation Function:

    1. Connect the lung simulator, and exercise thorax or breathing bag to the Y-piece.
    2. Set fresh gas.
    3. Press "IPPV".
    4. Press rotary control.
    5. Piston movement is indicated on bar graph. The machine starts with ventilation parameters set upon delivery.
    6. Lung simulator inflates regularly.
    7. Pressure profile is displayed on the monitor.
    8. Volume measurement yields plausible values.

- Machine and machine parts must be cleaned and disinfected before starting any maintenance work and before returning to the manufacturer for repair.
- Replace cooling air filter for monitor.
- Replace water separator.

XXI) Operating Elements and Displays on Ventilator:

Figure 11 illustrates the operating elements and displays on the Dräger Cato ventilator.

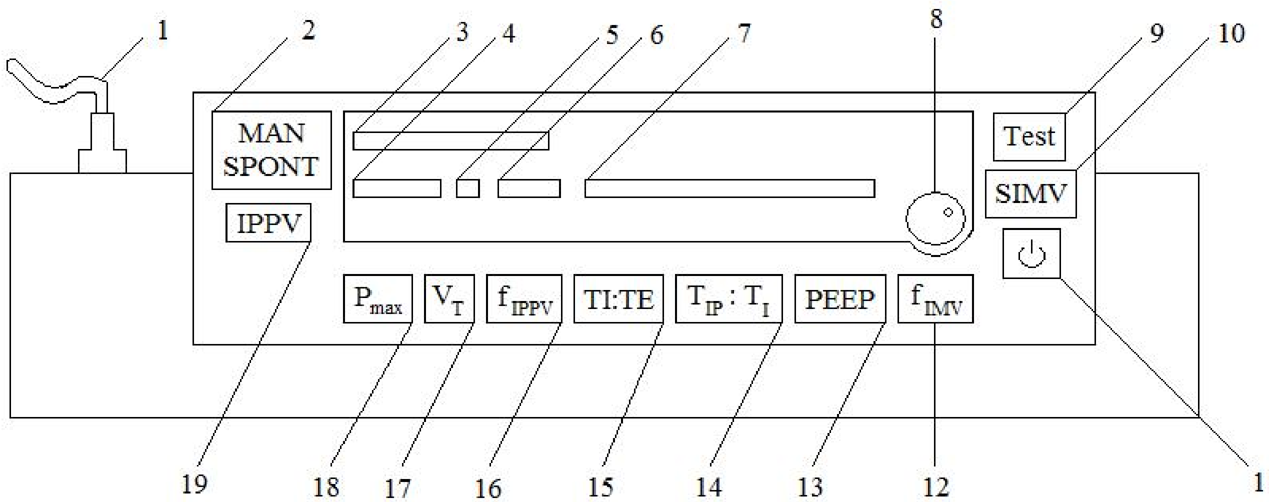

Figure 4 - *<u>Operating Elements and Displays on Dräger Cato Ventilator</u>*

1. Pressure limiting valve (APL) with "Manual/Spontaneous" change over
2. MAN/SPONT key for manual ventilation / spontaneous breathing
3. Bar graph of relative piston movement [%]
4. Indication of set maximum pressure (P_{max})
5. Indication of set tidal volume (V_T)
6. Indication of ventilation frequency (f_{IPPV})

7. Window for interactive settings and selection
8. Rotary control for settings and selection (confirmation)
9. Key for leakage test and compliance measurement
10. Key for mechanically-aided spontaneous breathing (SIMV)
11. Key for invoking "Standby" mode
12. Key for automatic ventilation (IPPV)
13. Key for setting maximum pressure (P_{max})
14. Key for setting tidal volume (V_T)
15. Key for setting ventilation frequency (f_{IPPV})
16. Key for setting ratio of inspiration time to expiration time ($T_I:T_E$)
17. Key for setting ratio of inspiration pause time to inspiration time ($T_{IP}:T_I$)
18. Key for setting positive end-expiratory pressure (PEEP). Only possible with IPPV.
19. Key for setting frequency for mechanically-aided spontaneous breathing (f_{IMV})

XXII) Descriptions:

A) Ventilation with Automatic Adjustment of Breathing to Match Fresh Gas Flow (review schematic diagram given in section XVII):

Most of the breathing systems used for anesthesia today are based on the re-breathing principle. Part of the expired gas is redelivered to the patient after absorbing CO_2 and enriching with anesthetic gases and anesthetic agent. The excess anesthetic is scavenged; the amount of scavenged anesthetic gas essentially depends on the set fresh gas flow. The administration of anesthetic gas with reduced fresh gas flow (low flow technique) yields a number of major advantages: lower consumption of anesthetic gases and agents, more effective humidification and heating of the inspiratory gas, lower environmental burden and good manual ventilation properties. The design of the breathing system is an aspect of essential importance for low flow anesthesia. The high degree of fresh gas utilization is a major prerequisite. Systems suitable for low flow techniques should be designed so that it is impossible, firstly, for too much expiration gas to disappear in the anesthetic scavenging line without building up a constant pressure and, secondly, for fresh gas to escape without first having been administered to the patient. In closed anesthetic systems, anesthetic gas cannot escape from the breathing system and no more fresh gas is delivered than is actually required by the patient. However, closed systems must also meet additional requirements: the breathing system must be absolutely tight and must feature additional monitoring and control elements. The breathing system implemented in the Cato automatically matches its degree of openness to the fresh gas flow. During inspiration, breathing gas streams from the piston pump to the patient. Valve V2 of the excess gas outlet and the fresh gas shut-off valve V1 are closed. Expiration is initiated when the fresh gas shut-off valve V1 is opened. Expired gas from the patient's lungs streams into the breathing bag which serves as a reservoir and also into the retracting piston pump. The excess gas outlet valve V2 is closed. Unlike the case with conventional semi-closed breathing system, the valve opening time for discharging excess gas is controlled as required. The system remains open longer for anesthesia with high fresh gas flow. If the fresh gas flow is inadequate in closed anesthesia systems, the pressure measuring function will detect that the patient's expiratory pressure has dropped below approximately -3 mbar. This shortage of fresh gas is signaled by the Cato and the piston pump stops in order to avoid a negative pressure in the patient.

B) Automatic Leakage Test IPPV:

This leakage test identifies any leaks of relevance for automatic ventilation in subsystems 1 and 2 of the Cato ventilation system. It also encompasses the breathing hoses up to the Y-piece, as well as the measured gas sampling and return lines if installed. The overall system compliance is determined at the same time. The IPPV leakage test and the leakage test started in "Standby" mode are carried out by building up a constant pressure of 30 mbar. The piston movement necessary to compensate the gas escaping through the leaks is measured, calculated and indicated as a volume per unit time. The effective leakage over the complete ventilation cycle is lower than the value indicated, since the effective mean pressure P_{mean} in IPPV ventilation mode is considerably lower than the test pressure. The relationship depends on the rate of the pressure increase, the plateau time and the ratio T_I:T_E. The effective leakage value varies with the value measured in the leakage test as P_{mean}:P_{test}. The effective leakage is defined as:

$$\text{Effective Leakage} = \text{Test Leakage} \times P_{mean}/P_{test}$$

C) Automatic MAN Leakage Test:

This leakage test is also part of the self-test and locates any leaks of relevance for normal ventilation in subsystem 3 (review Figure 9). The breathing bag, fresh gas hose, vapor and internal connections up to the bank of measuring tubes are tested for leaks. The test is normally carried out at a pressure of 30 mbar. If the leakage value remains below 300 mL/min, this is not indicated and the self-test continues. This subsystem contributes only marginally to the overall leakage, since the mean pressure is normally below 5 mbar.

D) Automatic Compliance Test:

The stroke volume applied by a ventilator not only ventilates the patient's lungs, but also the hose system connecting the patient to the ventilator. This means that only part of the stroke volume is effectively used to ventilate the lungs, the rest remaining in the compressible hose volume. This compressible volume must be known for ventilation to be effective ($P = V_T/C$). The compliance of the breathing system (breathing gas block, soda lime container, hoses, etc…) is determined during the leakage test and saved by the Cato system. This calculated compliance value is used to calculate the volume stored in the breathing system and hoses for each ventilation pressure. In order to correct it, the Cato starts with the set tidal volume and reaches the correct volume after 3 – 6 breaths. The corrected volume is constantly verified automatically. The measured value must be limited to plausible ranges for safety reasons. The limit is set at 3.9 mL/mbar when using adult hoses (V_T > 200 mL) and at 0.8 mL/mbar when using infant hoses (V_T < 200 mL). The maximum length of the breathing hoses should therefore not be exceeded.

E) Fresh Gas Flow:

- The patient's uptake of gas depends on the anesthesia and primarily comprises the consumption of O2 and N_2O. The consumption of O_2 can be calculated approximately using Brody's equation:

  BW = Body Weight in kg
  O_2 flow = 10 x $BW^{0.75}$ in mL/min

  This corresponds to an O_2 uptake of roughly 3.5 mL/min per kg body weight. Higher O_2 consumption results in lower inspiratory O_2 concentration due to re-breathing when low fresh gas flow is set.
- The uptake of N_2O varies with time and can be approximated by following the rule of thumb: $1/\sqrt{t}$ (approximately steady-state value N_2O per kg body weight: 1.5 mL/min)
- The leakage from ventilation system depends on airway pressure (mean value) and can be determined with the aid of automatic leakage test.
- The measuring gas sampled to measure the CO_2, N_2O, and anesthetic agent can be set on the system monitor (60 or 200 mL/min).
- The gas is returned to the breathing circulation via the measured gas return line.

F) Relationship Between Fresh Gas Flow and Gas Concentration in the Breathing System:

The inspiratory concentration differs from the set fresh gas concentration due to re-breathing and the O_2, N_2O, and anesthetic agent uptake by the patient. The lower the fresh gas, the larger the concentration gradient between the fresh gas, inspiratory, and expiratory gas concentration becomes. Since the concentration of the fresh gas flow in this flow range bears a little resemblance to the concentration at the patient, it is important to measure the anesthetic agent concentration as close to the inspiration tube as possible in this mode. The measuring system is integrated into the system monitor.

G) Relationship Between Fresh Gas Flow and Time Constants in the Breathing System:

The response time following a change of concentration of O_2, N_2O or anesthetic agent in the fresh gas depends on the set fresh gas flow. The inspiratory concentration in the breathing system corresponds more and more accurately with the fresh gas concentration as the fresh gas flow increases. At a low fresh gas flow, a change of concentration takes effect in the breathing system very slowly. This process can be speeded up by increasing the fresh gas flow abruptly.

The rule of thumb for estimating the system response overtime:

$$T = VC / \dot{V}FG$$

where T: time constant of system (min)

VC: system volume (L): i.e. breathing system ventilation hoses, residual volume of lungs

$\dot{V}$FG: fresh gas flow (L/min)

H) O_2 Measurement:

Measuring Principle of Galvanic Cell:

The O_2 sensor is based on the principle of galvanic cell. The oxygen molecules from the gas mixture to be measured diffuse through a plastic membrane into the electromechanical cell and are reduced on precious metal electrodes. Figure 12 illustrates a diagram of the galvanic cell construction.

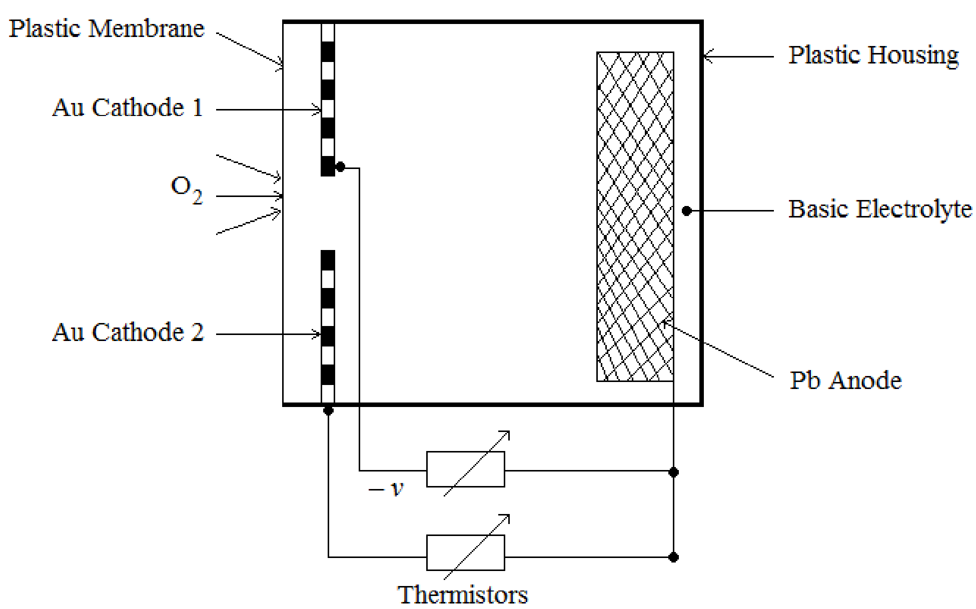

Figure 5 - *Galvanic Cell Module of O_2 Sensor in Dräger Cato Ventilator*

A base electrode is oxidized at the same time. It is depleted by the oxidation process and essentially determines the service life of the sensor. The current flowing through the cell is proportional to the partial oxygen pressure in the gas mixture to be measured. At constant pressure and constant temperature of the gas mixture to be measured, then measured value is directly proportional to the partial oxygen pressure.

I) Flow Measurement:

- Measurement Principle and Signal Processing:

  The sensor is based on the principle of a constant – temperature hot-wire aerometer. The breathing gas flows round a very thin, electrically heated platinum wire in a measuring tube. The wire is heated to a constant temperature of 180º C which is controlled by a control circuit. Heat is dissipated when gas flows past this wire. The larger the volume of gas flowing per unit time, the more heat will be dissipated. The heating current required to maintain a constant wire temperature is taken as an indicator for the gas stream.

- Gas Type Compensation:

  The effect of the various types of gas contained in the breathing gas is compensated by a second heated platinum wire. The heat dissipated by the second wire in the stationary gas column in the measuring tube is determined during a period in which there is no gas flow (i.e. during inspiration when the sensor is positioned on the expiration side). The gas compensation is determined on the basis of the specifically different thermal conductivity of the types of gases present in the breathing gas. Linearization is performed with the aid of internal calibration tables for the gas mixtures O_2/N_2O, air and 100% O_2.

J) Measurement of CO_2 and Anesthetic Agent:

- Measuring Principle:

  CO_2 and anesthetic agent absorb infrared light. A pump contains a small amount of breathing gas through a measuring cuvette irradiated with infrared light. Different filters make it possible to select a frequency band in which one of the gases to be identified is absorbed. All the gases can be measured quasi continuously by changing filters rapidly. The absorption reflects the gas concentration in the cuvette. The gas concentrations in the breathing gas can be calculated by simultaneously measuring the temperature and absolute temperature in the cuvette.

- Cross-sensitivity of the Anesthetic Gas Measurement:

  The measurement of the anesthetic agent can be falsified by vapors of organic substances (such as those contained in cleaning agents or disinfectants) in the air round about, the sampling hose or the T-piece. Elevated values for anesthetic agent will be displayed, particularly when using halothane, if the patient's breathing air contains alcohol. Mixtures of different anesthetic vapors may considerably impair the accuracy with which the concentration is measured.

K) SpO_2 Measurement:

Measuring Principle:

The light absorption properties of oxygenated arterial blood (oxyhemoglobin HbO_2) differ from those of unsaturated venous blood (reduced hemoglobin Hb). O_2 saturation is a logarithmic function of the irradiated light intensity (Lambert-Beer's law).

The effect of such dysheomoglobins as carbon monoxide hemoglobin HbCO and methemoglobin MetHb is normally negligible. The sensor comprises from two LEDs which alternately emit infrared and red light at typical wavelengths of 920 nm and 660 nm respectively. The radiation intensity is measured by a photodetector opposite the diodes. The sensor is positioned on a limb in which the arterial blood vessels can be irradiated, such as a finger, toe or nose (see Figure 13 for further illustration).

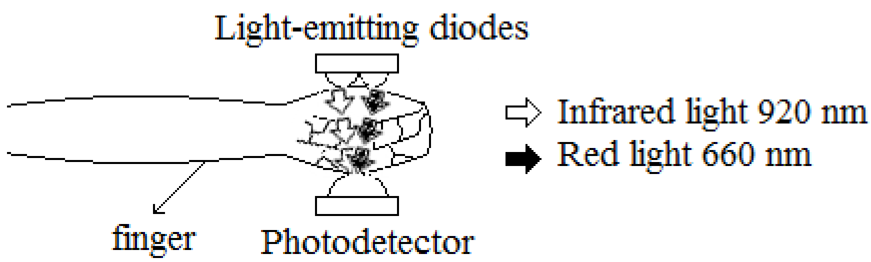

Figure 6 - *Diagram of Operation for SpO_2 Sensor*

These two wavelengths – 920 and 660 nm – are used because meaningful absorption values are still obtained for oxygenated and reduced blood, even in the presence of slight perfusion, and because they differ significantly. The light alternately emitted by the diodes is completely absorbed by the pulsating arterial blood, skin, finger, nails, muscular tissue, bones and venous blood. Except for the pulsating arterial blood, the amount of light absorbed by the other components remains constant as regards the quantity and optical density over a defined unit of time. The arterial blood pulsating with every beat of the heart, however, produces a change of volume synchronous with the pulse in the irradiated tissue. In other words, absorption of the irradiated light also changes in time with the pulse. Figure 14 shows a graphic scheme of how the absorption levels differ for different body part with time.

$$SpO_2 = K \times \frac{\frac{AC660nm}{DC660nm}}{\frac{AC940nm}{DC940nm}}$$

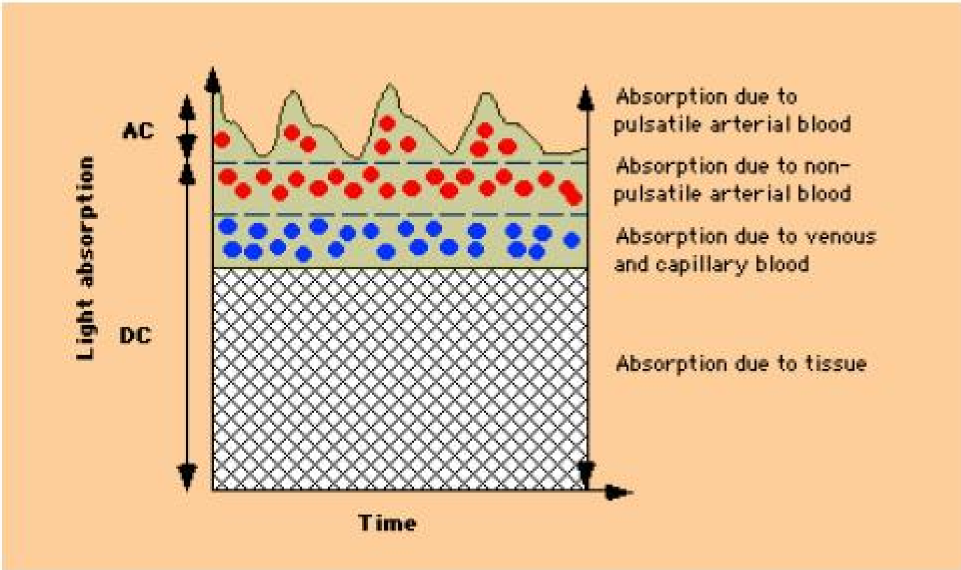

Figure 7 - *Absorption Levels of Light for Various Body Parts during the Pulsed Oxidation Sessions*

The light absorbed when there is no pulsating blood (during the diastole) is determined first. This yields the amount of light absorbed by tissue and non-pulsating blood. The absorption value does not normally change during the pulse part and provides a reference value for the pulsating part of absorption. Following the next beat of the heart, the absorption of light is measured again when the pulsating blood enters the tissue. The absorption of light changes for both wavelengths due to the pulsating arterial blood. At 660 nm, the absorption and corresponding pulse amplitude decrease with increasing the O_2 saturation, but rise at 920 nm. Since the absorption coefficients of HbO_2 and Hb are known for both wavelengths, the system can calculate how much of these two hemoglobin levels are present. The quotient obtained by dividing the oxygenated hemoglobin (HbO_2) by the reduced and oxygenated hemoglobin (Hb + HbO_2) is known as the functional saturation:

$$\% \ SpO_2 \ (func) = 100 \ x \ HbO_2/(HbO_2 + Hb)$$

and refers to the hemoglobin capable of transporting oxygen. Dyshemoglobins, $HbCO_2$ and MetHb are normally negligible, but may affect the accuracy of the measurement.

L) Temperature Measurement:

Measuring Principle:

The measurement principle is based on temperature – dependent change in the resistance of an NTC[2] thermistor with linearization circuit.

M) Pressure Measurement:

- Pressure Measurement:

  The pressure measurement is dependent on the piezoresistive change of resistance in a membrane.

- Determination of PEEP and Plateau Circuit:

  PEEP is the airway pressure at the end of expiration. The plateau pressure is the airway pressure measured 16 ms before expiration begins.

N) Definitions for "Low Flow" and "Minimal Flow" Anesthesia:

Low flow anesthesia is performed with a fresh gas flow considerably below the minute ventilation. When starting such low fresh gas volumes, the anesthetic gases must be returned to the patient via a semi-closed or closed re-breathing system. The re-breathing volume increases when the fresh gas flow is reduced and the excess gas volume decreases correspondingly. Although the fresh gas flow can be infinitely reduced to the gas volume taken up by the patient at a given moment of anesthesia in a completely hermetic system, a distinction is nevertheless made between the following methods:

The fresh gas flow is reduced to 1 L/min for low gas flow anesthesia and to 0.5 L/min for minimal flow anesthesia. In case of non-quantitative anesthesia in a closed system, the gas delivery settings are corrected frequently to adjust the fresh gas volume in line with the volume of gas taken up by the patient so that the internal pressure and charge of the breathing system do not decrease and the ventilation pattern remains unchanged. In case of quantitative anesthesia in a closed system, the composition of the fresh gas corresponds exactly to the volumes of oxygen, nitrous oxide and inhalation anesthetic taken up by the patient at a given moment in anesthetic gas also remains constant, in addition to the gas charge in the system and the ventilation pattern.

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[2] NTC: Negative Temperature Coefficient

O) Synchronous Intermittent Mandatory Ventilation or SIMV:

The mixture of mechanical ventilation and spontaneous breathing is known as synchronous intermittent mandatory ventilation (SIMV). In SIMV mode, the patient can breathe spontaneously at specified regular intervals. Between these intervals, mandatory (i.e. automatically delivered) ventilation strokes ensure a minimum degree of ventilation. The mandatory ventilation strokes are the same as those for IPPV ventilation. They are defined by the parameters V_T, IPPV frequency *f*IPPV, T_I:T_E and T_{IP}. Figure 15 shows a graph of the airway pressure over time.

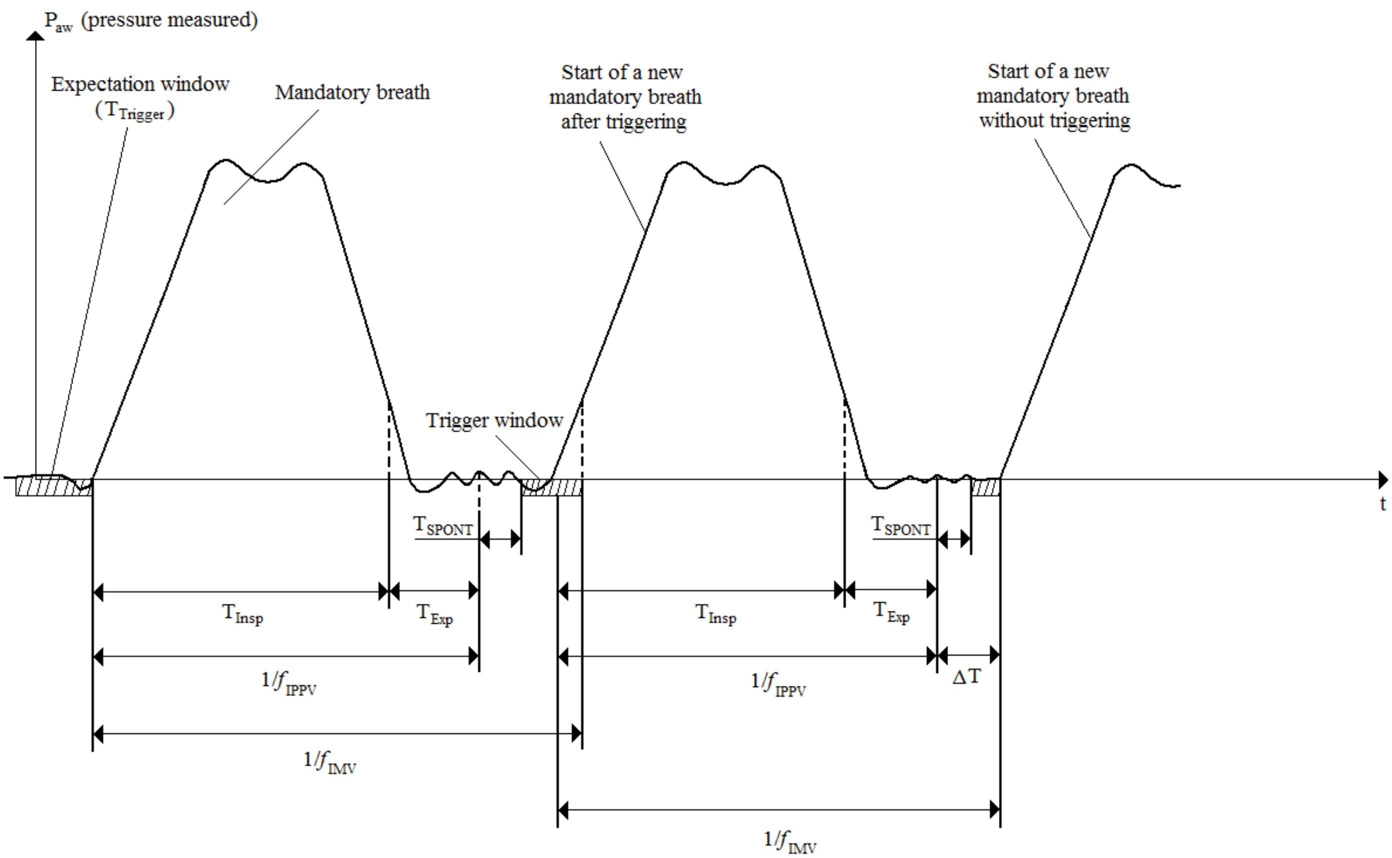

Figure 8 - *Graph of Airway Pressure Over Time for Dräger Cato Ventilator*

Each mandatory breath is followed by a pause in which the patient can breathe spontaneously. In order to prevent the next mandatory breath being applied during the expiratory phase of spontaneous breathing, a trigger function ensures that the mandatory ventilation stroke is synchronized with the inspiratory spontaneous breathing phase during an expectation period. The time between the end of each mandatory ventilation stroke and the beginning of the next is subdivided into a spontaneous breathing time T_{SPONT} and a trigger time $T_{Trigger}$.

During the trigger time, the system checks whether the airway pressure drops at least 1 mbar below the pressure measured at the end of the expiration phase. The mandatorily applied minute volume may increase if an automatic ventilation stroke is applied at the beginning of each trigger period. The duration of a mandatory stroke plus the spontaneous breathing time is calculated as follows:

$$1/f_{IPPV} + T_{SPONT}$$

This corresponds to a frequency of approximately 6 per minute and the applied minute volume increases to 6 per minute * V_T.

P) ORC Low Flow (with N_2O Bypass):

The delivery of N_2O is controlled as a function of the O_2 flow on a count of the reciprocal relationship between N_2O and O_2 flow, thus ensuring that the minimum O_2 fresh gas concentration cannot drop below 25% by volume. ORC is not effective at an O_2 flow of less than 0.5 L/min. A separate N_2O delivery can be used for low flow applications at such a low O_2 flow. ORC low flow can be bypassed to permit operation in the low flow range. When ORC low flow blocks the flow of N_2O at an O_2 flow of less than 0.5 L/min, between 0.5 and 0.8 L/min still flow through the bypass to the measuring tube and can be delivered there. This means that the O_2/N_2O fresh gas delivery must be individually adjusted by hand in the low flow range. The proportional action control of the ORC low flow becomes effective when the O_2 flow increases above 0.5 L/min. The O_2 and N_2O flow may have to be adjusted several times on account of pressure fluctuations. Regardless of whether or not ORC low flow is effective, care must be always taken to ensure that sufficient O_2 is delivered when the delivery fresh gas is in the low flow range. If the O_2 supply pressure, for instance, drops below 3 bar unnoticed, the O_2 flow can be reduced to such an extent that the O_2 concentration of the fresh gas declines to less than 21% by volume. This is particularly possible if a low O_2 flow – less than 0.5 L/min – was set. The O_2 shortage is signaled until the pressure drops to between 2 and 1.8 bar. ORC low flow cannot detect O_2 as a type of gas and does not offer any protection if gases have inadvertently been confused. For both these reasons, therefore: ensure that the O_2 concentration is always monitored.

Q) Oxygen Ratio Control S-ORC:

Figure 16 illustrates the diagram of a sensitive oxygen ratio control subsystem.

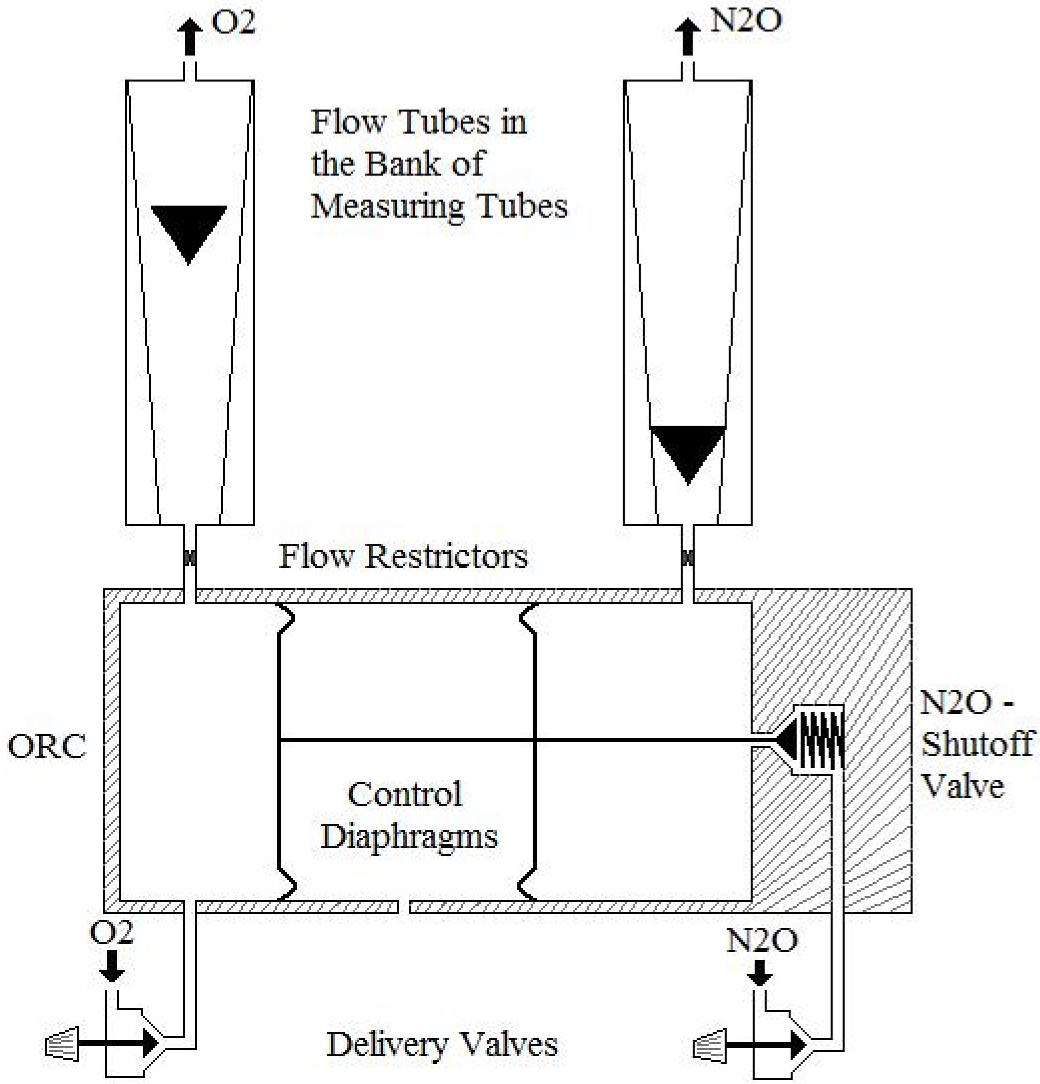

Figure 9 - *Sensitive Oxygen Ratio Control (S-ORC) Subsystem on Dräger Cato*

Cato is equipped with a sensitive oxygen ratio control (S-ORC) function in order to prevent the concentration of O_2 in fresh gas dropping too low when the O_2 supply is inadvertently deactivated or defective or if the O_2 flow has been set too low. The O_2 and N_2O flows which are set on the delivery valves build up control pressures for the control diaphragms of the S-ORC in 2 flow restrictors. The N_2O flow is controlled by the pressure ratio on the control diaphragms: the N_2O flow is limited when O_2 flow is set. N_2O is disabled when the O_2 flow drops below approximately 200 mL/min; it is slowly re-enabled as the value rises. The proportion of N_2O contained in the fresh gas can be set when the O_2 flow reaches approximately 300 mL/min again, the S-ORC ensuring that the O_2 concentration does not fall below 21% by volume. Since the O_2 and N_2O flow set on the flow tubes is limited by the S-ORC (but at least 9 L/min for each type of gas), the minimum O_2 concentration increases above approximately 3 L/min until both delivery valves are completely open and the mixing ratio of O_2:N_2O is approximately 50:50. The principle is illustrated in the diagram of Figure 16. The curve is displayed towards lower O_2 concentrations when anesthetic vapors (e.g. up to 18% by volume in the case of desflurane) are administered. O_2 concentration must be monitored via the airway monitor since the S-ORC is not specifically for monitoring O_2 and does not offer any protection if gases are inadvertently confused.

R) Abbreviations:

APL: Adjustable Pressure Limitation

ET CO_2: End-expiratory CO_2 Concentration

IPPV: Intermittent Positive Pressure Ventilation: Automatic Ventilation Mode

P_{aw}: Airway Pressure

$\dot{V}$: Inspiratory and expiratory flow

$\dot{V}_E$: Minute Ventilation

$\dot{V}_{FG}$: Fresh gas flow

V_T: Tidal or Stroke Volume