A New Approach in the Regulation of the Partial Pressure in Cardiotomy Suction During Open Heart Surgery

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Abstract

During open heart surgery, the drainage of cardiotomy is sometimes interrupted by occlusion of the suction tip or vent against cardiac or thoracic tissue, causing a rise in partial vacuum in the suction system, which may lead to increased hemolysis.[1-3] Mechanical safety valves can be used to avoid this. However the use of such valves is limited for negative pressure regulation on fixed levels. In order to be able to control the existing or created pressure, we developed an electronic system capable of monitoring and adjusting the pressures to a selected level. When this level is reached, and electromagnetic valve is opened, titrating air into the system until the partial pressure has dropped to 80% of the preselected value. This electronic approach also offers the possibility to make use of the signal as a feedback to control the vacuum, by controlling the rotations of the roller pump. Furthermore, the signal can be used for trend registration or application in hemodynamic calculations. This vacuum regulation system enables the perfusionist to minimize possible destruction of blood elements in the cardiotomy suction system and to devote his attention to the physiological state of the patient rather than to the equipment.

Introduction

During extra-corporeal circulation valves can be applied to prevent patient exposure to pressures which might be harmful to the blood and/or cardiac tissues during suction of blood.

Mechanical valves are presently commercially available for this purpose. Most of these valves, however, have a fixed opening pressure which cannot be changed by the perfusionist in relation to the patient's needs.

This has led to the development of an electronic vacuum regulation system that controls the opening and closing of an electromagnetic valve by an in-line pressure measurement. There are two basic ways these valves could be applied in the prevention of high partial vacuum in suction systems:

a) By allowing air to flow into the suction system and
b) By controlling the pump velocity in relation to the partial pressure measured.

An important third application of this system is the control and optimization of flow in a closed-loop system as used for instance in ECMO.

The System

In the partial vacuum regulation system the vacuum is measured continuously using an electronic pressure transducer (Honeywell Micro Switch PK8771 1) Figure 1. The voltage originating from this transducer, representing the partial pressure, is compared to a voltage determining the maximum vacuum, selected by the user. If the measured (negative) pressure exceeds the selected maximum value, an electromagnetic valve is opened and air is allowed in, resulting in a decrease in partial pressure. The continuously measured pressure is compared to a second set pressure level, equal to N percent of the selected maximum value. This represents the lower limit of the control range. If, by introducing air, this value is reached, the valve is closed again.

The transducer voltage, representing the vacuum measured, is available for registration and/or control of other parts of the suction system.

The Setup

The partial vacuum in a suction system can be controlled by two methods.

In the first mode (Figure 2) the vacuum is continuously monitored; and if the preselected partial pres-

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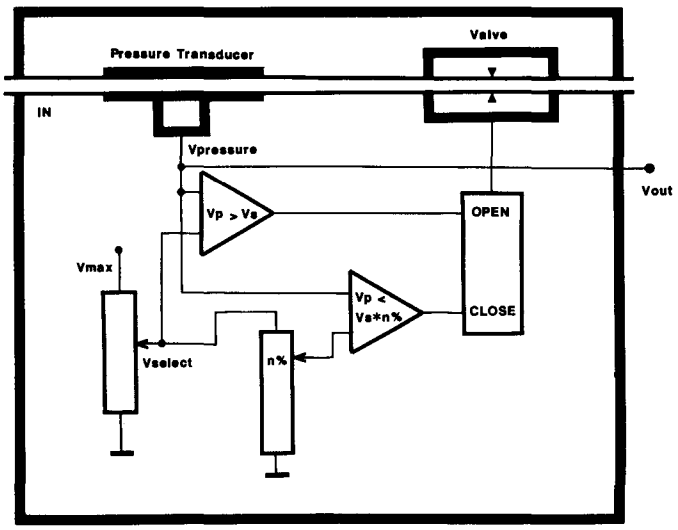

Figure 1. The basic parts of the pressure regulating system. The partial vacuum is measured continuously and compared to two values. The first value represents the maximum partial pressure in the system without opening of the electromagnetic valve. The second (lower) value should be reached before the valve can be closed again.

sure is exceeded, air is introduced into the suction system through a bacterial filter. If the suction line remains occluded, the measured partial pressure will oscillate between the upper and lower limit until flow is restored and the vacuum decreases.

In the second method the air inlet is occluded. The measured partial vacuum is used as a negative feedback signal to the roller pump that has created this vacuum. (Figure 3).

The voltage representing the measured partial vacuum is subtracted from the voltage selected to control the speed of the roller pump. If after an occlusion the partial vacuum in the suction system increases, the pump will slow down automatically. If the occlusion remains present, the pump will finally come to a complete standstill until the occlusion is removed.

ECMO

Using these two set-ups to control the partial vacuum, it was realized that this device could also be used to control the blood flow in a closed system as, for instance, during ECMO. In this procedure blood, coming from the patient is buffered in a small bladder and from there it is pumped to an oxygenator and finally returned to the patient (Figure 4).

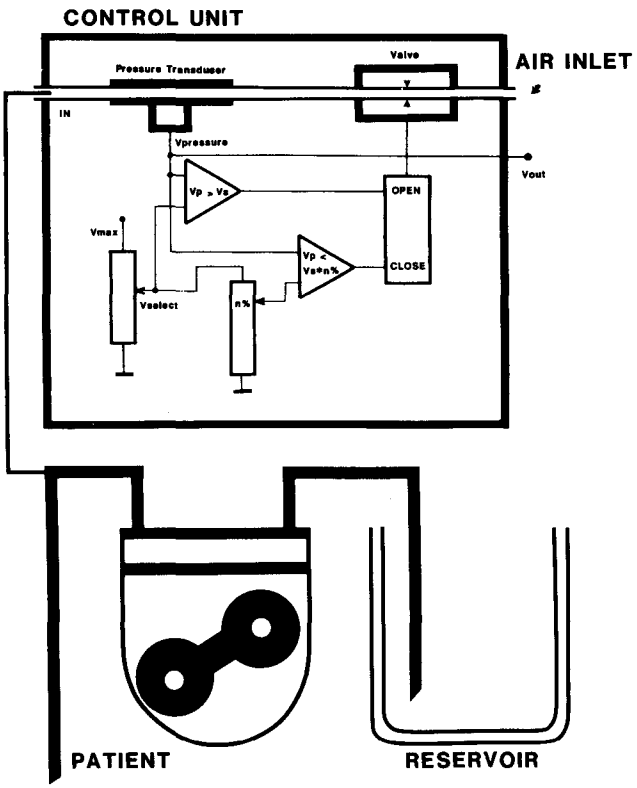

Figure 2. In this set-up the partial pressure is limited by admitting air into the downstream line when the suction intensity is too high.

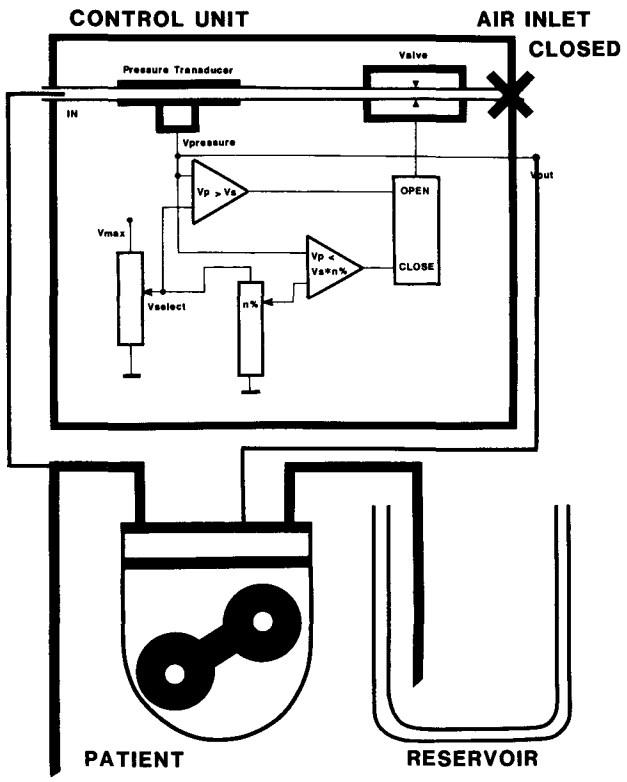

Figure 3. In this application the partial vacuum is controlled by using the electronic signal as a feedback for the roller pump. In this mode no air will enter the suction system.

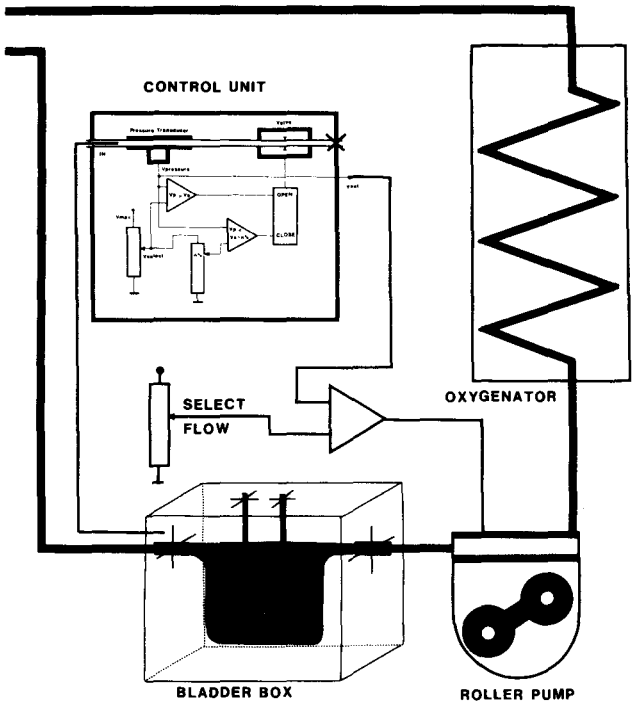

Figure 4. The system applied in a closed loop circulation. The alterations in blood flow cause changes in filling of the bladder, mounted in an airtight box. These volume changes will induce pressure changes in the box which can be measured by the pressure transducer. This signal is used to adjust the roller pump velocity to the new situation.

One of the major problems in such a set-up is the irregular bloodflow from the patient to the bladder in the system. The bladder can compensate for this partially, but if the bladder is empty the partial vacuum at the suction side will increase rapidly, with all the potential disadvantages mentioned before. In most centers this situation is avoided by adding a mechanical contact which switches off the pump as soon as the bladder is almost empty. This has the major disadvantage that the blood flow is started and stopped abruptly. Furthermore, the system cannot be moved without the risk of false alarms.

In the ECMO set-up used in our animal lab the bloodflow was controlled using the vacuum regulation system described previously. The bladder is mounted in an airtight box of which one side can be opened rapidly. During calibration the inside of the bladder box is exposed through a stopcock to atmospheric pressure. If the flow has reached a steady state value, the stopcock is closed. The pressure transducer is connected to the inside of the bladder box, and the air inlet is closed and inactivated. If the volume of blood pumped by the roller pump from the bladder box to the oxygenator is not compensated by the blood flow from the patient to the bladder box, the volume of the bladder will decrease. In the airtight box this will cause a decrease in pressure, and an increase in the transducer voltage. This voltage is subtracted from the voltage regulating the flow through the roller pump and will slow the roller pump down. The system has been calibrated so if the bladder contains 40% of its maximum volume, the feedback voltage and the regulation voltage are equal and the roller pump will come to a complete standstill. In this way the blood flow does not fluctuate abruptly but is adjusted to the actual supply of blood from the patient.

Conclusions

Mechanical safety valves can be replaced by an electronic vacuum regulation system. The separation of the site where the pressure is measured and the actual valve makes additional applications like ECMO possible.

References

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Questions from the Audience

Matt Tyndal, Denver, CO: Question: I wonder if with the pressure limits or the regulator could actually eliminate the bladder box from your CPB circuit—there would be a way to develop a system that had a limit of the negative pressure to slow down the speed of the pump—therefore eliminate the bladder box entirely?

Answer: Yes, that would be possible, then you have to connect your transfuser to the line and now completely separate from the system and you don't have to enter the blood line.