A LOW PRESSURE ALARM DEVICE FOR MEDICAL OXYGEN CYLINDERS: A DESCRIPTION OF A PROTOTYPE

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Abstract

This paper presents the design and evaluation of an oxygen low-pressure alarm for use in conjunction with medical oxygen cylinders. Patients, who are dependent on oxygen supply through portable, high pressure oxygen cylinders, rely on staff vigilance to ensure that the volume of oxygen in the cylinder does not drop below a critical level, thereby compromising their safety. To minimise such risks, a low cost, mechanically driven, easy to interface, low pressure alarm was developed to generate an audible warning intended to alert patients and their carers of depleting oxygen pressure levels. The device is designed to interface with portable medical oxygen cylinders and their pressure regulators. It implements a spring-loaded diaphragm mechanism, which opens a vent when the pressure level in the cylinder drops below a pre-set level of 15 bars (1.5 MPa). The gas then passes through a nozzle incorporating an orifice, thus generating an audible whistling sound. The proposed device is compact and cost effective in terms of manufacture and power consumption.

1 Introduction

Compressed oxygen cylinders are commonly used in hospitals, community-based care centres, and in patient’s homes for the provision of oxygen enriched air to patients in need. These are portable units containing pressurised oxygen gas typically stored at 137 bars (13.7 MPa) [1].

Users reliant on oxygen supply generally wear a nose/mouth mask, which interfaces between the oxygen cylinder and patient. Typically, medical oxygen cylinders are fitted with regulators, used to reduce the high pressure in the cylinder to suitable pressures for patients to breath. The pressure regulator has a flow meter to control the rate of oxygen delivered to the patient, which is typically in the range of 2 – 15 l/min. The use of such gas supply units requires monitoring of the tank gas pressure in order to determine the amount of useable gas supply left in the cylinder. The pressure in the cylinder is typically measured using a mechanical pressure gauge, which indicates indirectly the volume of compressed oxygen available for use.

Patients who require oxygen supply may suffer from illnesses due to pulmonary or cardiovascular conditions and hence are highly reliant on being provided with a reliable supply of oxygen [2]. It is of critical importance that users of these devices and their carers are aware of diminishing pressure levels, to ensure a constant supply of oxygen is maintained and that cylinders are replaced in due time.

Typical portable oxygen delivery systems implemented as described earlier rely on the constant vigilance of staff to monitor the pressure levels at regular intervals. The pressure gauge can be hard to read and interpret by non-technically oriented staff. In some situations the primary focus of staff may be on performing tasks to maintain the patient’s life and gas depletion may go unnoticed. Therefore, patients who rely on oxygen delivery through these cylinders are at risk of staff not noticing the depletion of oxygen levels in the cylinders which compromises their safety. Although the scale of this problem has not yet been officially quantified in clinical practice, healthcare workers in wards and care centres appreciate the frequency of such incidents.

In addition to the health care sector, the requirement for pressure monitoring and warning alarm systems for use in industrial sectors is well established. To this end, several devices have recently been demonstrated and patented [2-5].

One of the earlier pressure alarm devices was presented in 1985 by De Pasquale and co-workers, [3]. They developed a pressure indicator and alarm system to provide an audible and visual warning when the gas supply in a cylinder is exhausted and requires replacement. This was achieved by incorporating a pin through the lens of the pressure gauge, at a location corresponding to the gas pressure level below which the cylinder required replacement. As the pressure in the cylinder drops, the indicator arm on the gauge rotates counter clockwise and makes contact with the pin at the predetermined low pressure point. This completes an electric circuit, which activates an electrically powered alarm.

MacDermott (2000) presented a more advanced pressure monitor and alarm system for high pressure gas cylinders used in medical or industrial sectors [1]. The device was designed to allow removable mounting and integration between the pressure regulator and outlet tank of the cylinder. The device incorporates an electronic pressure switch to continuously monitor the pressure of the gas in the cylinder.
The device is configured to activate visual and auditory alarms (flashing lights and audible buzzer) when the gas remaining inside the cylinder drops below a predetermined level.

Harvie (2003) presented a monitoring, alarm and automatic adjustment system for oxygen and compressed air delivery cylinders [4]. The system is able to monitor and adjust the oxygen or compressed air flow rate to the user based on their requirements, which are estimated by measuring pulse and blood oxygen concentration levels. It calculates how much time the user has left with the cylinder and alerts the user of low or depleted pressure levels by providing tactile feedback. The system includes sensors (pressure, temperature and pulse oximetry) to measure the oxygen flow rate, an LCD display unit, a microprocessor for calculating the useable oxygen left and for generating the choice of visual, audio and electrically powered vibration alarms.

The devices described above meet the requirements for an oxygen cylinder pressure alarm. However, they are quite complex in their operation and also require external electrical power supply. In situations where production costs and power supply are major considerations, as in many developing countries, such devices may be too complex and expensive to implement. Additionally, there are fire and explosion hazards associated with electrical sparks in the presence of oxygen, which may add complexity to devices with electrical components, as adequate safety systems are required to prevent such disasters. Consequently there exists a need for a simple, easy to interpret system to detect the low oxygen pressure level and provides a warning to users and their carers of the impending depletion of oxygen supply. The focus of this work is to develop such a low-cost, portable alarm system that can be operated using simple mechanical principles and can be easily interfaced with standard medical oxygen cylinders and regulators. The aim is to develop a mechanical non-electric device, which provides an auditory alarm unit in order to draw attention to low levels of oxygen in medical oxygen cylinders while they are in use. Based on professional advice, a cylinder pressure of 15 bar was selected as the threshold level at which the device was required to provide the warning alarm. The other main requirements include low production cost, compact design, removable mounting and ease of installation and interfacing with medical cylinders.

2 Design and operating principle

The alarm system is designed to allow easy incorporation into medical oxygen cylinders. It consists of two main components:

1. An adapter unit with mechanical spring: The adapter unit has a standard female bull-nose socket for interfacing with a mechanical pressure gauge, and a male bull-nose connector for interfacing with the compressed oxygen cylinder. It has a radius of 19 mm and a length of 42 mm. A cylinder protruding from the adapter unit houses a mechanical spring-loaded diaphragm.

2. Whistling unit: A whistling component connects to the adapter through a screw fitting. It has a radius of 5.5 mm and a length of 24 mm. An orifice is incorporated in the casing of the nozzle.

The principles of operation of the device are illustrated in Figure 1. When the pressure of oxygen in the cylinder is greater than a threshold pressure, the spring is under compression due to the applied pressure on the diaphragm. Under such conditions, the diaphragm is pushed against the nozzle whose diameter is lower than that of the diaphragm, thereby preventing airflow from the cylinder through the nozzle. When the pressure in the cylinder drops below the threshold level, the spring and attached diaphragm relaxes and extends by a distance determined by the stiffness of the spring. The displacement of attached diaphragm away from the nozzle creates a passage for oxygen to flow into the whistling unit. As the gas flows into the whistling nozzle, it passes through the orifice emitting an audible whistling sound.

![Figure 1: Schematic illustrating the working principle of alarm](image)

The threshold pressure ($P_{th}$) at which the spring and diaphragm move and allow airflow (causing whistling), is determined by the stiffness of the spring and the area of the diaphragm.

The stiffness of the spring determines its restoring force ($F_i$) as described by Hooke’s law:

$$F_i = -kx$$  \hspace{1cm} (1)

Where $k$ is the spring constant/stiffness of the spring and $x$ is the distance by which the spring is compressed.

The force exerted on the diaphragm due to pressure from the oxygen cylinder ($F_p$) is given by the following equation:

$$F_p = P*A$$  \hspace{1cm} (2)

Where $P$ is the oxygen pressure and $A$ is the area of the diaphragm.
When the force applied on the diaphragm due to air pressure \( F_p \) is lower than the restoring force of the spring \( F_r \), the diaphragm moves away from the nozzle. Thus, for diaphragm movement to occur, the following conditions exist:

\[
F_p < F_r \quad (3)
\]

\[
P_{th}A < -kx \quad (4)
\]

Thus, the threshold pressure can be increased by increasing the stiffness of the spring or by decreasing the area of the diaphragm. In order to estimate the stiffness of the spring that is required to allow the diaphragm to move (causing the alarm to whistle) at the threshold pressure, Equation 4 can be rearranged as follows:

\[
k > -\frac{P_{th}A}{x} \quad (5)
\]

Assuming a spring deflection of 4 mm, a diaphragm radius of 3 mm and a threshold pressure of 15 bars (1500 kPa), a spring stiffness greater than 10.6 kPa is required. For the prototype alarm device, a spring having a stiffness of 13.6 kPa was employed.

![Figure 2: Mechanism of operation of spring loaded diaphragm.](image)

The device is manufactured from a brass rod substrate using standard lathe manufacturing techniques. Figure 3 shows the manufactured device along with a standard pressure gauge with which it interfaces.

### 3 Preliminary testing

Initial preliminary tests of the prototype device were conducted using a cylinder (with a 2 l volume capacity) containing oxygen at a pressure of 50 bars. The valve of the cylinder was opened to allow a flow rate of 4 l/min to allow the pressure in the cylinder to drop. The pressure at which the alarm sounded was found to be 15 bar ± (2 bar). A sound pressure level of 87 dB was recorded using a sound level meter. This is higher than that emitted by other medical alarms such as those for infusion pumps (73 – 78 dB) and cardiac monitors (72 – 77 dB) [6]. The whistling sound was emitted for a time period of approximately 7 minutes.

![Figure 3: Photograph of the alarm system consisting of the adapter-spring unit, the whistling unit and commonly implemented pressure gauge.](image)

### 4 Discussion and Conclusions

The design of a mechanical pressure monitoring alarm device used to indicate diminishing levels of oxygen in medical oxygen cylinders is presented. The device provides an audible feedback to alert patients and their carers/staff when the pressure in the cylinder drops below 15 bars. The device is configured such that it can be easily interfaced and used in conjunction with high-pressure portable medical cylinders and regulators. It is compact and adds an additional length of 42 mm to the overall cylinder unit. Unlike previously presented systems, which are electrically powered, the device operates based on simple mechanical principles thereby keeping the running costs to a minimum. The costs for producing such a device are also low due to the use of readily available materials and standard manufacturing techniques. These are important considerations in global healthcare settings where the burden of technology costs are high while patient safety is still paramount. Further work will explore adaptation of the whistling unit to emit sound levels as prescribed by the safety standards and regulations for acoustic sound levels in patient environments. Additional experimental testing of the device will also be carried out to establish performance reliability.

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