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DESIGN AND IMPLEMENTATION OF AN OXYGEN CONCENTRATOR WITH GPRS-BASED FAULT TRANSFER SYSTEM

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Long-term oxygen therapy (LTOT) is one of the several methods increasing the duration of survival in chronic obstructive pulmonary disease (COPD), with the oxygen concentrators being the most appropriate and economical choice for this treatment. Studies so far conducted show that a significant amount of oxygen concentrators in Turkey are used wrongly by patients, technical services are inadequate, no periodical maintenance is being done for devices requiring regular maintenance and control, and some devices do not yield the expected oxygen purity in long-term use. These problems in the oxygen concentrators are the most important factors causing delays in the treatment process because the patients are unable to receive oxygen at sufficient purity levels during the scheduled period. Therefore, it has become a necessity that oxygen concentrators are rearranged as devices fulfilling medical requirements and minimizing patient/device-based problems in parallel with the developments in the field of medical electronics. In this study, a low-cost oxygen concentrator with a GPRS-based fault transfer system is designed for patients receiving LTOT and the practical application of this device is realized on a prototype. The most important feature of the designed oxygen concentrator is the ability to detect the fault cases occurred in itself, and then to send them to the related technical service and hospital authority through the GPRS-based fault transfer system without reliance on the patient's statement. This ensures the prevention of delays during the treatment period caused by the functional problems of the device.

Keywords: Oxygen concentrator; microcontroller-based system design; GPRS-based fault transfer system; chronic obstructive pulmonary disease; long-term oxygen therapy.

1. Introduction

In recent years, the life quality of the patients with chronic obstructive pulmonary disease (COPD) has not only improved their health expenses but also seriously decreased due to the widespread use of long-term oxygen therapy (LTOT) and the developments in the monitoring opportunities of treatment.[1] When it is considered that the costs of a pulmonary blood gas measurement is equivalent to the costs of 2-day oxygen therapy and hospital stay expense is equivalent to the costs of 1-month oxygen therapy, the use of LTOT in the treatment of this disease can be clearly seen to be fairly economic.[2] A few studies published on LTOT have proven to be unique treatment method which extends the survival and improves the life quality due to the fact that it minimizes the decreases in the respiration functions during the treatment of the patients with COPDs.[3–6] A research carried out on the 8487 patients in Denmark[7] shows that the average life expectancy of a patient who receives the LTOT for about 15–24 h/day increased from 1.07 to 1.40 years.

In the literature, oxygen concentrators are reported to be the most suitable and economic choice for LTOT.[1,8] Today, although the utilization rate of oxygen concentrators used in LTOT is 90% in France and 80% in America,[8,9] this treatment first launched in Turkey in 1986.[10] The study made by Kurtar *et al.*[6] showed that the rate of the problems in LTOT was 39%. These problems was identified respectively as the device fault, device maintenance, device expenses and no periodical maintenance, low oxygen purity, power cuts, power consumption and insufficient training given to the patient. Whereas the malfunction rate of all devices was 45%, the yearly maintenance rate of these devices was found to be 16%. Technical service necessity is inevitable for the periodic maintenance of oxygen concentrators. The oxygen purity and oxygen flow velocity should be checked ideally once in a month. In a similar study, Turker *et al.*[2] observed that almost all of those devices were wrongly used by the patients, technical services were insufficient, the yearly maintenance rate of these devices was highly low, and no regular maintenance was fulfilled on a certain number of patient devices. In addition, the study showed that the hypoxemia in the patients could not be adequately improved by some oxygen concentrator because they were not supply oxygen at the expected purity level during long-term use. All of the results indicate the fact that a significant part of the problems results from the structural deficiencies of oxygen concentrators and non-periodic device maintenance done by firm.

The recent developments on wireless communication technology have made a major contribution to biomedical field as well as other fields. Thanks to the use of this technology to monitor both patient and device parameters during the treatment process, it has become possible to develop low-cost and portable health monitoring systems.[11] Nowadays, several wireless medical monitoring systems such as electrocardiograms (EKG),[12–14] pulseoximeters,[15,16] and sphygmomanometers[17,18] are being commercially sold. Most of the devices perform a communication on the standards of a Bluetooth, wireless medical telemetry service or IEEE 802.11.[19] In the literature, many studies such as Real-time ECG telemonitoring system design with mobile phone platform,[20] a multimedia telemonitoring network for health care,[21] Wireless (GPRS-based) mobile real-time patient monitoring,[22] a wireless PDA-based physiological monitoring system for patient transport,[23] and wireless stand-alone portable patient monitoring and logging system[24] was made to monitor data for medical purposes.

The most frequently encountered faults in oxygen concentrators — namely, high temperature, low pressure, high pressure and low-purity oxygen, may be sent to the technical service or device monitoring center using the wireless communication technology when faults occurred. Adding such a hardware performing this function to the oxygen concentrator not only will provide the maintenance and repairment of the device in a short time but also will prevent the delay in the treatment process arising from aforementioned problems. In this study, a low-cost oxygen concentrator with a GPRS-based fault transfer system which sends the faults encountered in the device to the related technical service and hospital authority are designed and implemented. This paper is organized as follow. A complete description of the proposed system is explained in Sec. 2. Section 3 presents the design procedure which contains the proposed oxygen concentrator; control circuit and GPRS based fault transfer system. The experimental results are given in Sec. 4. The obtained results are discussed in Sec. 5.

2. Description of the Proposed System

The proposed oxygen concentrator is a portable system that produces oxygen at a purity of 95–90.7% for a flow velocity of 1–4 L/min and sends the high pressure, low pressure, insufficient oxygen purity and high temperature faults occurring in the system to the related technical service and hospital authority by using a GPRS-based fault transfer system. The block diagram of the proposed system is shown in Fig. 1. Operation of the system can be explained in two operating mode. The first mode represents the operating case when no fault is encountered in the system. In this mode, the system provides oxygen at sufficient purity and flow velocity to the patient by controlling the pressure of product tank via the controller. The second mode is active when a fault occurs in the system. In this mode, the fault occurring in the system is detected, and then sent to the GPRS-based fault transfer system through the controller I/O port. The GPRS-based fault transfer system transmits the faults over the packet-switched radio service to the technical service and hospital authority

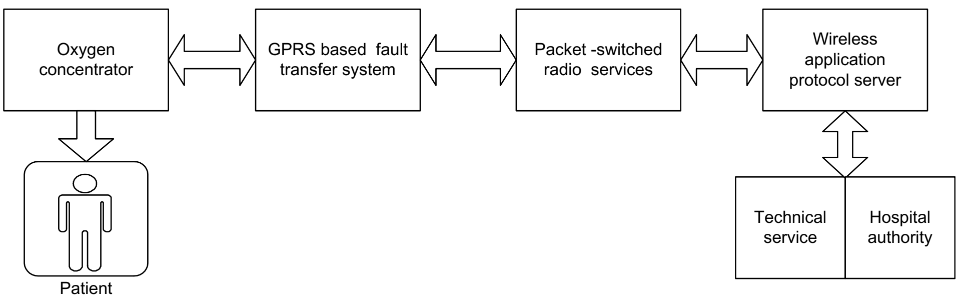

Fig. 1. Block diagram of the oxygen concentrator with GPRS-based fault transfer system.

via a wireless application protocol server, and then the oxygen given to a patient is stopped by sending a warning signal to the patient.

That GPRS technology integrated to the oxygen concentrators will minimize the delays originating from the patient and device during the treatment of the COPDs. In the current situation in Turkey, both the patient's data sent to the doctor and the hardware problems of the device sent to the technical service are depending on the patient's statement. The information relying on the patient's statement could be incorrect, which may result in some deviations in the doctor's evaluation of the treatment given. On the other hand, it may be a delay in solving hardware problems because of the fact that the device repair relies on the patient's awareness of the fault case and bringing the device to technical service. In this study, the GPRS technology is only used to send the fault cases to the related technical service staff and the hospital authority because a low-cost microprocessor is used to decrease the cost of the device.

3. Design of the Proposed System

The proposed system consists of an oxygen concentrator containing several equipments to obtain the required oxygen, the controller unit providing the control of whole system, the sensor circuits used to sense the pressure in the product tank, purity of oxygen given to the patient, and internal ambient temperature, and the GPRS-based fault transfer system used to send the system faults to the related technical service and hospital authority.

3.1. *Oxygen concentrator*

Oxygen concentrators are devices increasing oxygen in the air to a purity rate of 90% to 97%. The air which we breathe consists of approximately 78% nitrogen, 21% oxygen and 1% other gases. The easiest way to separate the oxygen from the air mixture is to use the pressure swing absorption technology developed by NASA. The process of obtaining oxygen using the pressure swing absorption technology is based on the air being filtered through the aluminosilicate minerals which are known as zeolite. For this purpose, the minerals are placed into a container known as molecular

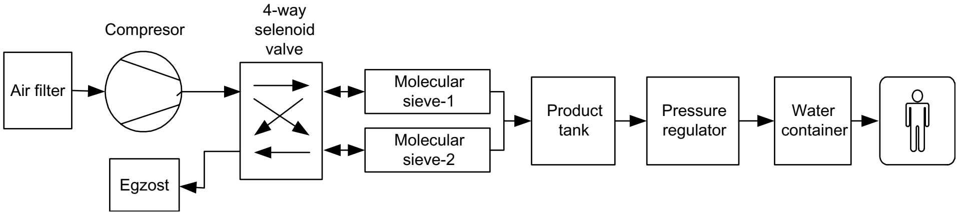

Fig. 2. Block diagram of the oxygen concentrator.

or zeolite bed. When the ambient air is applied to this structure with a specific pressure, the oxygen passes through it into the output with the applied pressure while the nitrogen molecules in the air are absorbed with the minerals in the bed. Block diagram of the designed oxygen concentrator using the pressure swing absorption technology is shown in Fig. 2. The concentrator device consists of an air filter, a compressor, a four-way selenoid valve, a molecular sieve, a product tank, a pressure-regulator, a water container and an exhaust component.

In this system, the air taken from the atmosphere is passed through the air filter, and then sent to the first molecular sieve with the pressure provided by compressor. While the pressurized nitrogen which enters into the molecular sieve is being held in the zeolite bed, the oxygen is allowed to pass through unrestricted into the product tank. When the pressure in the product tank reaches 23 PSI, the zeolite in the first molecular sieve is completely saturated with nitrogen. Thus, the compressed air is given to the second sieve by changing the valve position so that oxygen production can continue. Meanwhile, the first molecular sieve is depressurized and regenerated by the removal of the absorbed nitrogen, carbon dioxide and water vapor. When the zeolite in the second sieve is saturated with the nitrogen, the pressurized air is given to the first sieve again and the nitrogen in the second sieve starts to be thrown out by the egzost system. The pressurization and depressurization cycle proceeds alternately during the system operation. The oxygen which is brought into a suitable pressure and a purity of 90−95% in the product tank is passed through into the pressure regulator and the flow meter respectively. Then, it is given to the patient with a nasal canola or an oxygen mask.

The molecular sieves which contain a chemical called "5A molecular sieve" are one of the most important components that affect the device performance. Two molecular sieves are used to supply the oxygen continuity in the designed system, because this chemical is quickly saturated with nitrogen. The design of each molecular sieve depends on basic parameters such as the bed length, the bed diameter, the package type of the bed and the air pressure fed to the bed. Two types of packaging are used in the production of molecular sieves: conventional packaging and multilayered packaging. The conventional one is a uniform packaging type made by using only one kind of molecular sieve. In other words, one kind of molecular sieve with the same diameter is uniformly distributed in the adsorption column. One of the most significant problems faced with this type packaging is that the flow velocity in the central core of the column is much higher than the velocity in the outside of the central core. As a result, while the molecular sieve in central core is firstly saturated by adsorbing enough nitrogen, the outside of the central core is still not saturated. Thus, the molecular sieves in the whole column are not sufficiently used in this type packaging. The drawbacks of the conventional packaging can be eliminated by reducing the flow velocity in the central core. This function can be achieved by using a multi-layer arrangement called multi-layered packaging instead of using a single-type molecular sieve in the whole column. In the multi-layered packaging, the small diameter of molecular sieves is packed in the central core while the larger diameter of sieve lies in the outside of the central core.[25] Two-layered packaging containing central core and outer core are used in this study. The dimensions of molecular sieves in the central and outer ones are 1.6 mm and 2.1 mm, respectively. The diameter of each cylinder is 82 mm, with heights of 650 mm each.

The compressor used to provide the necessary pressure to the molecular sieves is a dry-air compressor which comprises a single electric motor and two reciprocating piston mechanisms driven from opposite ends of the motor shaft. Each mechanism contains a piston which is reciprocated in a cylinder by the motor. The two cylinders are connected together to provide the required air flow and pressure used to produce oxygen at a desired purity. The experimental studies show that an electric motor of 330 W/1.5 A can obtain the pressure of 3 bar, which provides oxygen at a purity of about 95–82% from the oxygen concentrator output at a flow velocity of 1–5 L/min.

Another factor that affects the oxygen purity in the system output is the volume of the product tank used for storing the oxygen from molecular sieves. The use of a large volume tank in the oxygen concentrator causes the decrease of the oxygen purity in the output of device while a small volume tank increases the fluctuations in oxygen flow. Therefore, the tank volume in the design of oxygen concentrator is determined in accordance with the dimension of molecular sieves and the compressor power. An air filter, which filters all particles including harmful substances such as dust, humidity and pollen caused by the environmental conditions until a minimum of 0.3 microns, is used in concentrator input. A pressure regulator that decreases the pressure of approximately 23 PSI in product tank to 5–10 PSI is connected to the tank output to minimize the flow imbalances in flow meter input. Then, the oxygen is given to the patient over the water container with a 9 PSI-valve security by setting the flow meter to the flow velocity desired.

3.2. *Control of proposed system*

A control card that consist of sensing circuits, a motor-driving circuit, a selenoid valve-driving circuit and a microcontroller is designed to control the proposed system and a GPRS based fault transfer module, send faults occurring in the oxygen concentrator to technical service and hospital authority, is integrated to the control card. Sensing circuits on the designed card consists of a pressure-sensing circuit, a temperature-sensing circuit and an oxygen-sensing circuit. The output data of pressure-sensing circuit is used for both the controlling of the system and fault transfer. On the other hand, the output data of temperature and oxygen-sensing circuits are only used for fault transfer. The motor-driving circuit connects the electric motor in the air compressor to the AC line or cuts from it depending on the data from the sensing circuits. If the data from the sensing circuits shows a kind of fault case for the system, the compressor is stopped by cutting the triggering signal from controller to driving circuit. Then, faults are sent to fault transfer system through the input/output port of controller to be sent to technical service staff and hospital authority. Otherwise, the necessary air pressure for oxygen purity is

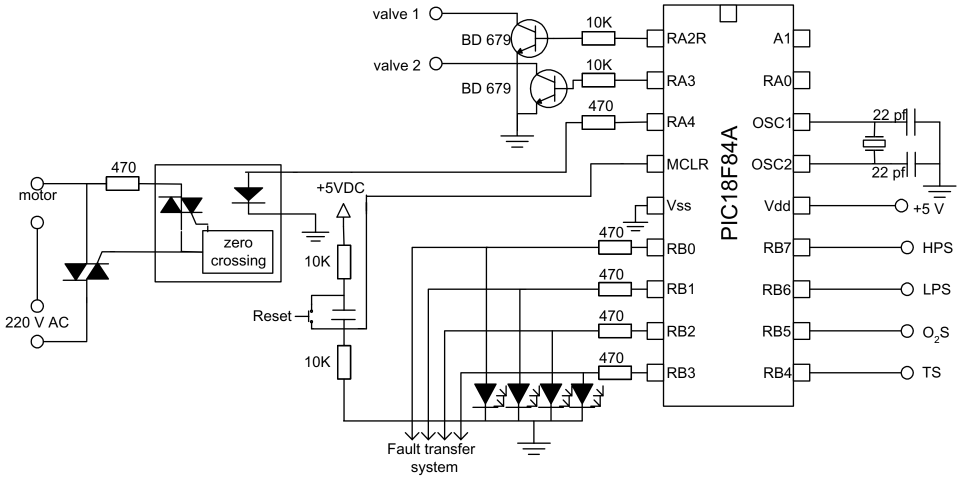

Fig. 3. Circuit diagram of the control card used to control the whole system.

supplied by connecting the compressor to the AC line on the driving circuit. The valve driving circuit is used to change the position of selenoid valve in accordance with the pressure data in product tank. The position of the valve with four-way and two-positions decides that the air pressure from compressor will go to which one of the two molecular sieves in system. Figure 3 shows the circuit diagram of the control card used in the oxygen concentrator.

The sensing circuits are designed in such a manner that the outputs will give 0 V or 5 V so that it is not required additional a digital to analogue converter. While the pressure data measured from product tank decides which cylindrical bed the air from the compressor will be sent via the solenoid valve on the one hand, it allows the detection of high pressure or low pressure faults. Figure 4 shows the circuit diagram of the pressure-sensing circuit used to measure the pressure in product tank.

To measure the pressure sensitively in the product tank is important for the system performance. Thus, a silicon piezoresistive pressure sensor providing a high accuracy and linear voltage output directly proportional to the applied pressure is used in the pressure-sensing circuit. When examining the characteristic curve showing the change of the output voltage in accordance with the differential pressure of the sensor, the output voltage is changed linearly between 0 mV and 40 mV in the change of pressure between 0 PSI and 29 PSI. The function of the increasing differential voltage at the sensor output is performed with an instrumentation amplifier which is a circuit configuration commonly used in pressure sensors. While the first two operational amplifiers are used to increase the differential signals from the sensor, the third operational amplifier sends to the output by taking the difference of the amplified signals. The gain of the sensing circuit can be changed by adjusting resistance R3. The common mode rejection ratio (CMRR) is set by the

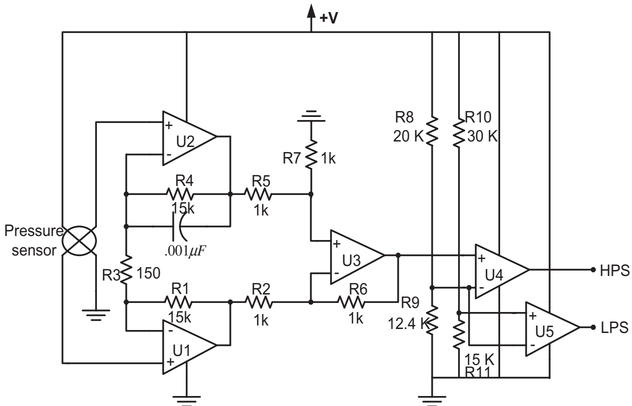

Fig. 4. Pressure-sensing circuit.

resistor matching between R2, R5, R6 and R7. Extremely low tolerance resistors or precision resistor trimming is required to achieve high CMRR. The Formula between the input and output of the amplifier is obtained as follows by using the super position law.

$$v_{C1} = v_1.[1 + (R1/R3)] + v_2.[-(R1/R3)], \tag{1}$$
$$v_{C2} = v_1.[-(R4/R3)] + v_2.[1 + (R4/R3)], \tag{2}$$
$$v_C = v_{C1}.[-(R6/R2)] + v_{C2}.[1 + (R6/R2)].[R7/(R5 + R7)]. \tag{3}$$

The pressure of 0−29 PSI sensed by the pressure sensor is scaled with 0−4 V in the output of the amplifier. The values of the resistors connected to the comparator are equally chosen as 1 K to achieve high CMRR. Therefore, the maximum value of the differential voltage obtained from the outputs of operational amplifiers U1 and U2 is 4 V. When it is considered that the maximum value of the differential signal taken from the pressure sensor is 40 mV, it can be concluded that the signal applied to the inputs of both operational amplifiers should be amplified 100 times. If the resistors R1 and R4 are chosen as 15 K, the resistor R3 can be calculated as 150 Ω from Eqs. (1) and (2). The signals of the instrumentation amplifier output is transformed into a digital signal to be applied to the external interrupt input of the micro-controller by using two comparator circuits called the window detector. The detector separates the pressure in product tank into three zones as high pressure, normal pressure and low pressure. On the pressure-sensing circuit, the pressure values above 23 PSI and under the 10 PSI are classified as high pressure and low pressure, respectively. This function is accomplished with the reference voltages supplied by using R8, R9 voltage divider for high pressure output (HPO) and R10, R11 voltage divider for low pressure output (LPO). The reference voltages are 3.17 V (23 PSI) for high pressure comparator U4 and 1.55 V (10 PSI) for low pressure comparator U5. On the other hand, the pressure values between 23 PSI and 10 PSI are coded as

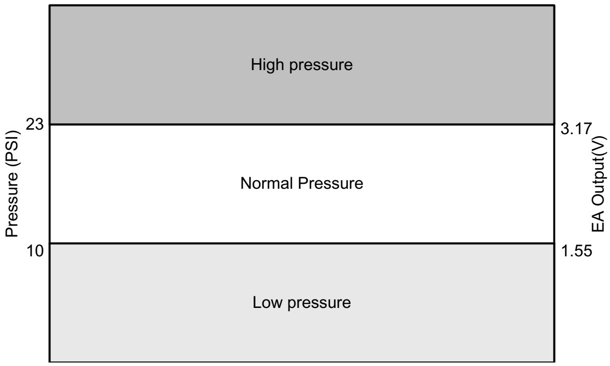

Fig. 5. Classfication of the pressure in product tank.

normal pressure according to the program written in microcontroller. The classified pressure zones and the sensing outputs are shown in Fig. 5 and Table 1, respectively.

As shown in Table 1, the sensing circuit outputs contain three different states in the digital form which are 1−0 for high pressure zone, 0−0 for normal pressure zone, and 0−1 for low pressure zone in accordance with the pressure value in product tank.

The decrease at the oxygen purity produced by the device can result from various causes such as the pressure decrease in product tank, the chemicals in molecular sieves losing their futures, the lack of control resulting from controller and the fault case occurring in selenoid valves. Although the system has a pressure-sensing circuit, the other causes creating this decrease, especially the fault case arising from the molecular sieves can be detected by using an oxygen-sensing circuit. The principle circuit diagram belonging to the oxygen-sensing circuit is given in Fig. 6.

The galvanic cell oxygen sensor with a measurement range of 0−100%, an accuracy of ±2% in full scale and a linear output voltage with respect to the partial pressure of oxygen is used to sense the oxygen purity in product tank output. The signal at the millivolts level taking from oxygen sensor is amplified to the level of 4 V by using the instrumentation amplifier. Similar to the pressure-sensing circuit, the values of resistors R2, R5, R6 and R7 are equally selected as 1 K to get high CMRR. When the magnitude of the signal obtained from the oxygen-sensor output for oxygen at the purity of 100% is though to be approximately 50 mV, it is concluded that the gains of operational amplifiers U1 and U2 will be 80 to increase this value to 4 V. If the values of resistors R1 and R4 are chosen as 10 K, the value of resistor R3 is

Table 1. According to pressure zones, sensing circuit outputs.

	High pressure output	Low pressure output
High pressure zone	1	0
Normal pressure zone	0	0
Low pressure zone	0	1

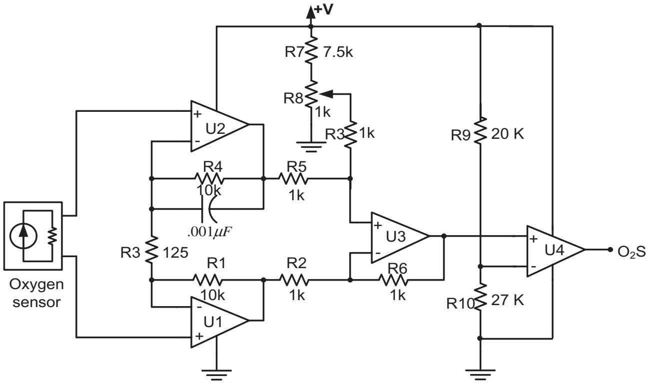

Fig. 6. Oxygen-sensing circuit.

calculated as 125 Ω from Eqs. (1) and (2). The resistor R8 is used to adjust the zero-offset voltage of instrumentation amplifier. The decrease of the oxygen purity in oxygen concentrator output to 85% for the flow velocity of 1−3 L/min means that sufficient oxygen purity needed for the patient is not reached. This is determined by comparing with the output signal of instrumentation amplifier and the reference voltage of 3.4 V, which is equal to the oxygen at purity of 85%, and obtained from source voltage by using voltage divider resistor R9, R10. The comparator output is a digital signal, where "0" and "1" data indicate to be the oxygen at low-purity and sufficient purity in the device output, respectively.

Increasing the ambient temperature to 60−70°C means that the compressor motor is excessively loaded. This case can cause a fault in motor during long-term operation. The overload of motor can resulted from dusting on pistons and the problems of other components in the device. The temperature fault happening in such a case is sent to the input/output ports of microcontroller by using a 60°C limit-thermostat.

3.3. *GPRS-based fault transfer system*

A fault transfer system (FTS) is designed for monitoring of an oxygen concentrator used at home. It is possible to examine the FTS in two parts: hardware and software. The hardware part is composed of a fault-sensing module integrated to an oxygen concentrator and a GPRS modem connected to fault-sensing module. The software part is divided into two parts: PIC microcontroller software and the Graphical User (GUI) Interface software prepared for the server where data are stored. The general schema of the realized remote monitoring system is shown in Fig. 7.

3.3.1. *Software*

Fault transfer system was implemented using a fault-sensing module connected to an oxygen concentrator and GPRS modem. Four fault cases are represented with 4-bits.

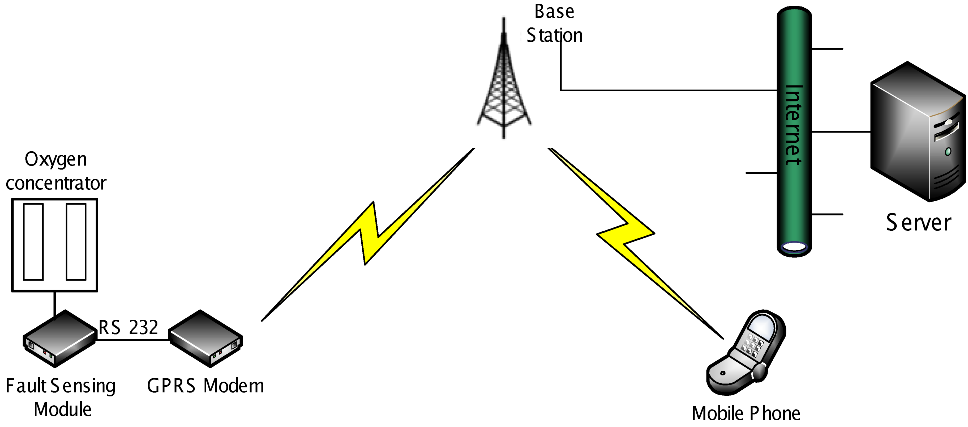

Fig. 7. General schema of the realized remote monitoring system.

The fault-sensing module senses these faults and sends them to the GPRS modem. As detecting the change in any bit of 4-bits, the fault-sensing system transmits the data of 4-bits to GPRS modem using serial communication protocol. In GPRS modem, data is transmitted to assigned mobile telephone such as SMS and to accessing server using GSM network. Figure 8 shows flowchart of the program, which is downloaded in PIC18F452 microcontroller. The microcontroller programs are written in Visual Basic programming language by using proton development suite program.

Server side software application has three separated software and each of them is a part of entire solution because of using the same sources. All three applications have been developed using Microsoft Visual Studio. Net 2008 IDE and chosen C#. Net 3.5 programming language.

Windows Service Application

General purpose of the Windows service developed for the FTS is to take the data sent to the specified TCP/IP port of the server from fault-sensing module via GPRS by listening port continuously and write it to the database. Because of the data come to the port is binary formatted, Windows service analyses the data according to the meaning of each bit specified, considering the database structure and converting the data utilizable format for the web and WAP application, and then write it to the database.

Web Application

There are two user types as administrator and hospital authority for both Web and WAP applications. Administrator can monitor and manage all faults of the devices for each hospital, add/edit devices and hospitals and their user accounts but hospital authority can only monitor faults of devices of their own hospital. After logging in to the web application with the correct username and password as administrator, all continuing faults are list by grouping hospitals and devices as

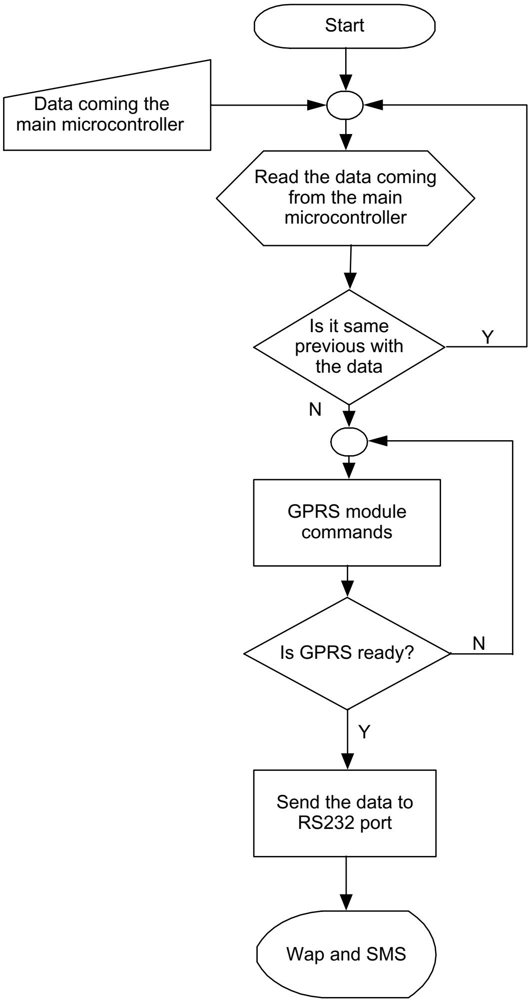

Fig. 8. Flowchart of the program written in PIC 18F452 microcontroller.

shown in Fig. 9. In this page, faults can be monitored easily, changed their conditions and written note for each devices.

There are three fault conditions; Continuing, Servicing and Fixed. If a fault's condition set as "Servicing", it can be monitor under "Servicing faults" page any-more. Device conditions can also be monitored and managed by each hospital. If a device has one or more faults, its condition is shown as "Faulty" or if a device has no fault, its condition is shown as "Working". When hospital authorities logged in to web application, the related hospital's devices are listed in order to show their conditions. Thus, devices can be monitored both the administrator and hospital authorities.

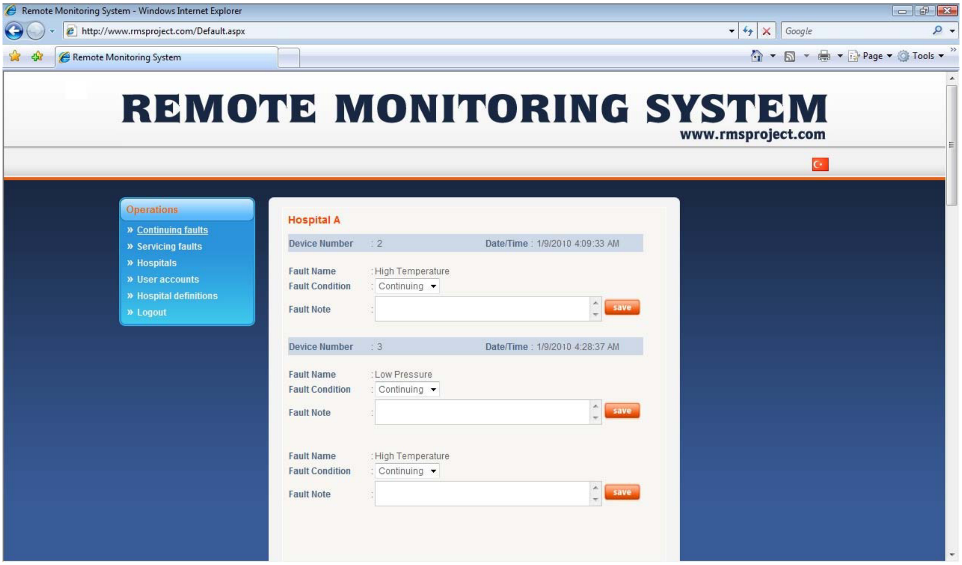

Fig. 9. Screenshot of the Web application for continuing faults.

WAP Application

Wireless Application Protocol (WAP) is an enabling technology based on the Internet client server architecture model, for transmission and presentation of information from the World Wide Web (WWW) and other applications utilizing the Internet Protocol (IP) to a mobile phone or other wireless terminal.[26]

WAP is essentially a wireless equivalent to the Internet protocol stack (TCP/IP).[27] Purpose of the WAP application for the FTS is to have mobility for monitoring the machine conditions.

3.3.2. *Hardware*

The hardware of fault transfer system consists of two parts. First one is the fault-sensing module which collects fault case from the oxygen concentrator. Second one is GPRS modem which receives fault data from the fault- sensing module and sends these data to mobile phone and to accessing server using GSM network. Circuit schema of fault sensing module is shown in Fig. 10. In the fault sensing module, there is a serial port output that supplies the communication with GPRS modem. PIC 18F452 is used as a microcontroller and a 14 MHz crystal is used as oscillator. The data transmission rate is chosen as 19,200 bps. The fault sensing module and GPRS modem are connected each other with the RS232 communication protocol. Connector type of RS-232 is D9-pin female, baud rate from 300 to 115.200 bit/s, auto-bauding (300 to 38.400 bit/s), short circuit (to Ground) protection on all outputs. The EZ10 terminal (named as GPRS modem) provides low-pass RF suppression circuits and level conversion to the GM862 engine inside.

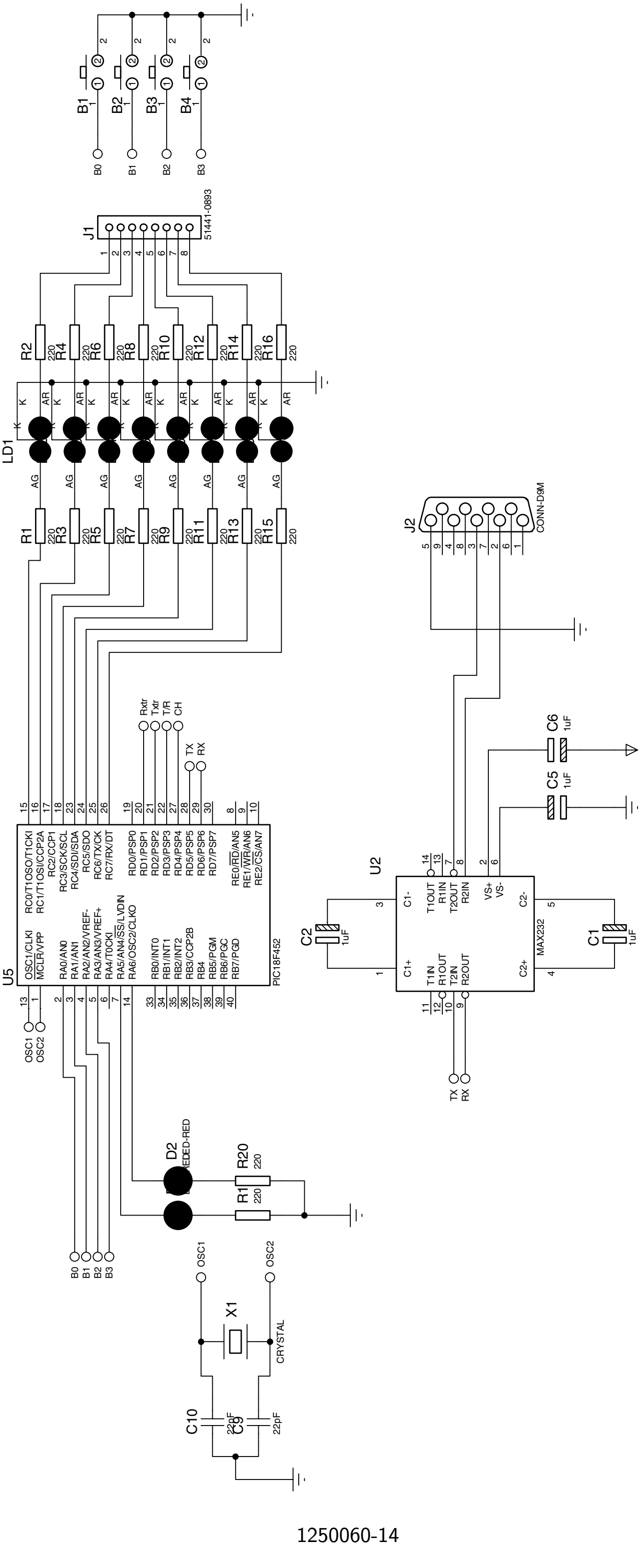

Fig. 10. Circuit schema of the fault-sensing module.

GPRS modem used in this study goes to the IP and port number and tells that it wants to communicate with it. If that port of the server is open, GPRS modem gives CONNECT warning. This warning shows that modem has connected to the server. After this point whatever we send through the connection will go to the server. In this application, we get the data and replace it into the database. For this reason, a program runs for listening the port in the server side. This program reads and records the data whenever data received.

4. Experimental Results

The experimental studies of the oxygen concentrator with a GPRS-based fault transfer system are carried out on a prototype shown in Fig. 11. The system test for fault cases is realized by artificially creating high temperature, low pressure, high pressure, and low oxygen purity faults which are possible to occur in the system. Whereas high pressure fault is organized by closing the air output of the system, low

Fig. 11. Photograph of the proposed oxygen concentrator.

pressure and low oxygen purity faults are created by removing the air carrier pneumatical hoses from their beds. On the other hand, high temperature fault is achieved by making short-circuit of the limit thermostat. The control of oxygen concentrator and sending the faults to the related technical service and hospital authority are performed with a program downloaded into the microcontroller. The

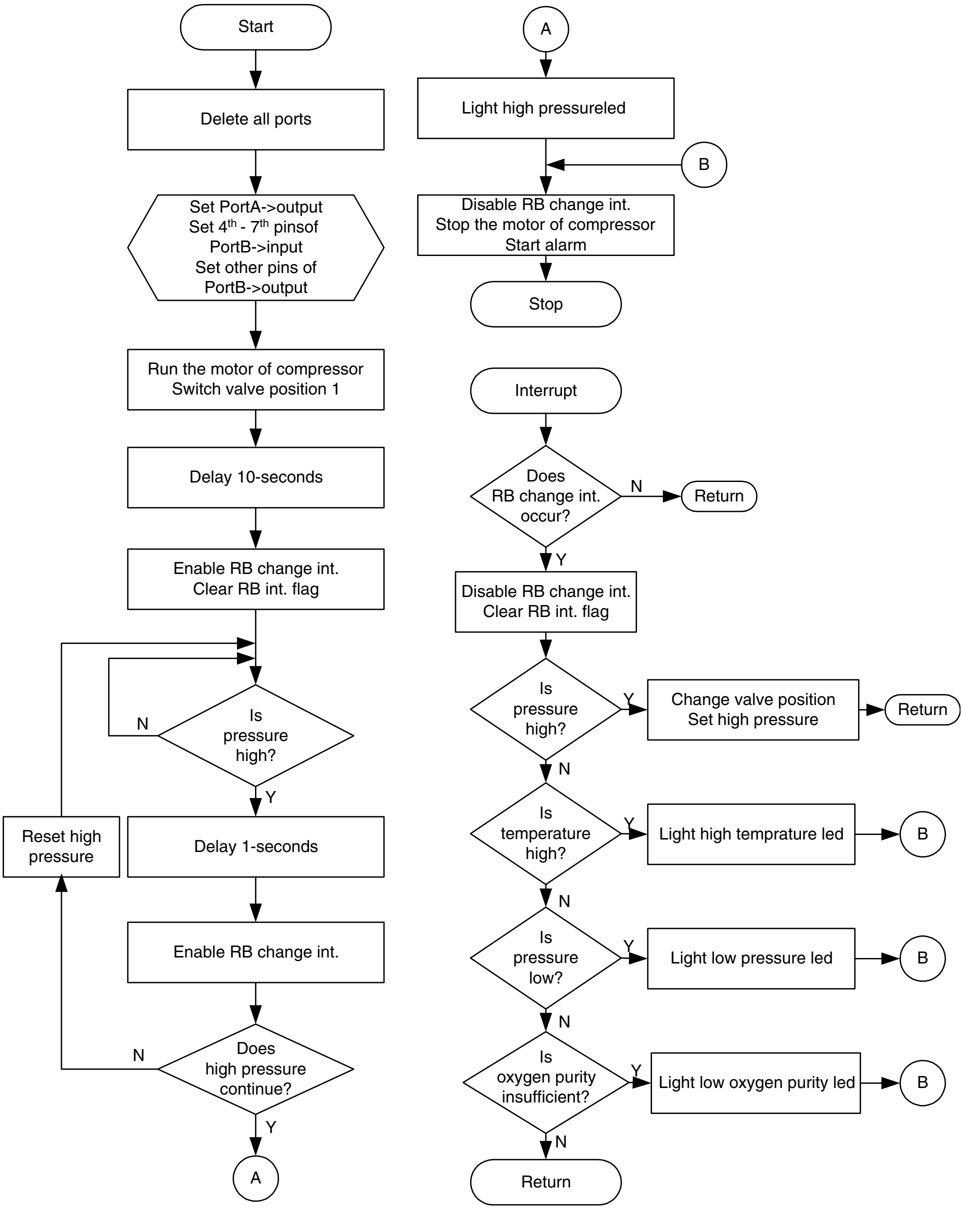

Fig. 12. Flowchart of the program used in control of proposed system.

flow chart of the program used to carry out this function is shown in Fig. 12. The program both controls the system and detects the faults simultaneously. When a fault occurs in the system, it stops the system, and then sends the faults to the related technical service and hospital authority through a GPRS based fault transfer system.

As understood from the flowchart shown in Fig. 12, selenoid valve is set to the position 1 by involving compressor in the circuit at the first run-time, and then the system is being run for a period of 10 s, which is necessary to form a pressure of 23 PSI in the product tank. During this running period of the system, the problem of self-shutting down automatically is solved by disabling the error of low pressure and insufficient oxygen purity. The faults related to the system are sensed by using Port B logic level change interrupt. When a change in the logic signal level applied to the PB4−PB7 pins of Port B from the sensors occurs, the interrupt flag belong to the interrupt sets to 1 and program branches to interrupt subroutine from the left off. The change in the sensor output is determined by disabling Port B change interrupt in the interrupt subroutine. If a high pressure interrupt occurs, it is changed the valve position and skipped to the main program. It is queried whether the high-pressure state continues by re-enabling Port B change interrupt after a delay of 1 s. If the high-pressure state is going on, the fault led of high-pressure lights on, and then the fault case is sent to the GPRS based fault transfer system. Afterwards, the motor used in the oxygen concentrator is stopped and the patient is alerted on an alarm. Otherwise, the system goes on running normally. When a low-pressure, a low-oxygen purity and a high temperature faults occurs in the system, the fault information is sent to the GPRS based fault transfer system by lighting on the fault case leds and patient is warned after stopping motor.

In the realized system, the gas flow analyzer device produced for biomedical purposes is used to monitor the changes in the oxygen purity going to the patient and the changes in the pressure of product tank at different flow velocities. For the first-run and steady state run states of system, the pressure changes in product tank for different flow velocities (1−4 L/min) are shown in Fig. 13.

As understood from the waveforms shown in Fig. 13, the reaching the pressure in product tank to the peak value (23 PSI) takes 10 s for the first run time. In the steady-state run of the oxygen concentrator, the fluctuations in the pressure of product tank at the flow velocities of 1 L/min, 2 L/min, 3 L/min and 4 L/min are measured as 3.01 PSI, 5.27 PSI, 6.58 PSI and 7.69 PSI, respectively. The correction time of the system for these flow velocities are 2.6 s, 4.1 s, 4.9 s and 5.3 s, respectively. The pressure regulator is a device used to reduce changes in the pressure of product tank and its output can be adjusted from 5 PSI to 9 PSI. Figure 14 shows the output waveform of the regulator whose pressure set to 8.4 PSI. From the output waveform, it can be seen that the pressure change of 5.27 PSI in product tank is lowered to 0.2 PSI in the regulator output for the flow velocity of 2 L/min.

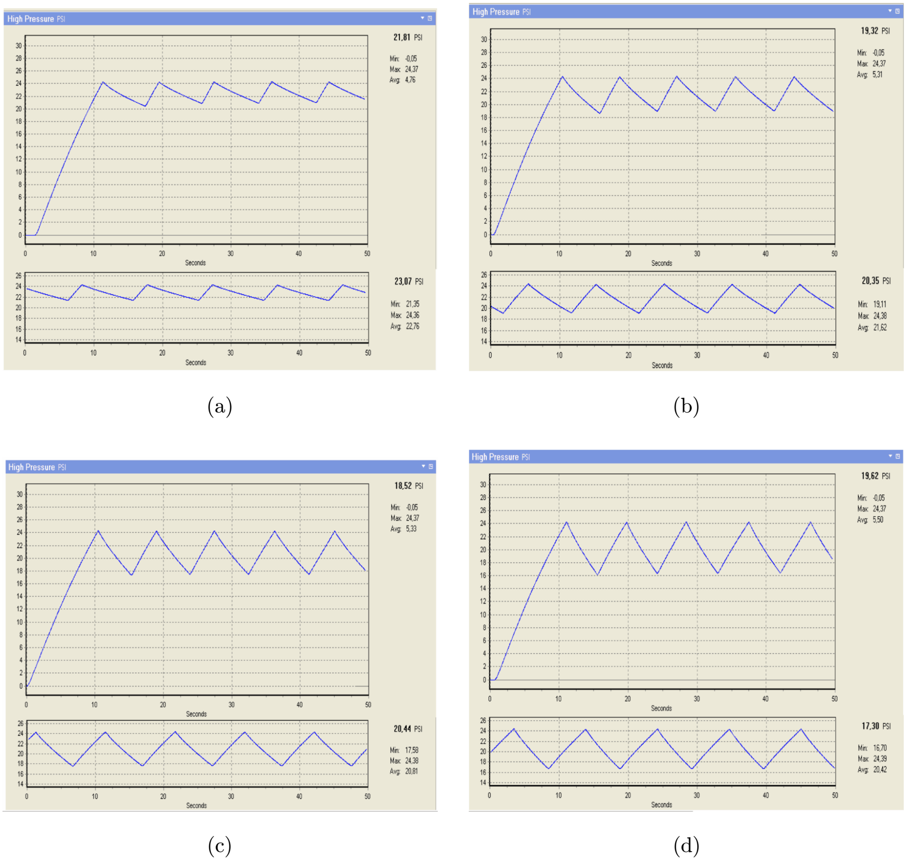

Fig. 13. Changes in the pressure of product tank: (a) change in the pressure for flow velocity of 1 L/min. (b) Change in the pressure for flow velocity of 2 L/min. (c) Change in the pressure for flow velocity of 3 L/min. (d) Change in the pressure for flow velocity of 4 L/min.

Figure 15 shows the oxygen purities obtained from the flow meter output at the flow velocity range of 1–5 L/min. It can be seen from the figures that the realized system provides the oxygen at the purity of about 94.7% ± 0.2 to the patient at the flow velocity range of 1–3 L/min. When the flow velocity increases to 4 L/min and

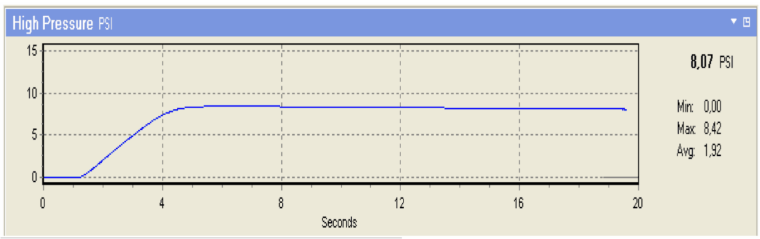

Fig. 14. Pressure changes in the regulator output for the flow velocity of 2 l/min.

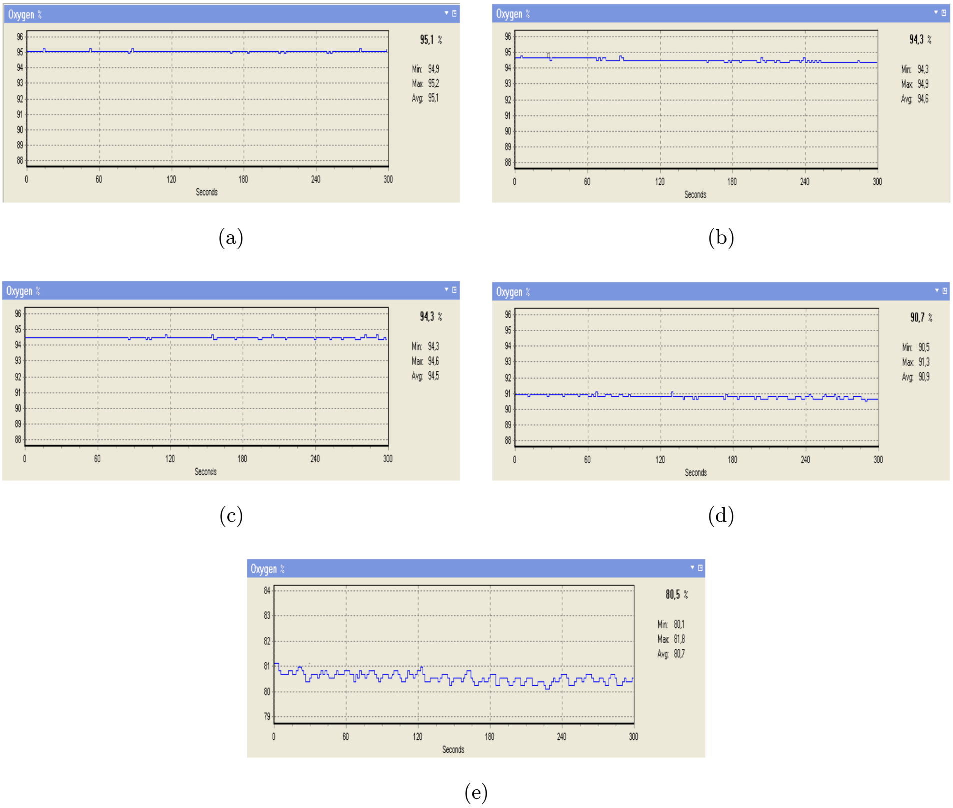

Fig. 15. Changes in the oxygen purity measured from flow meter output at different flow velocities: (a) Oxygen purity at the flow velocity of 1 L/min. (b) Oxygen purity at the flow velocity of 2 L/min. (c) Oxygen purity at the flow velocity of 3 L/min. (d) Oxygen purity at the flow velocity of 4 L/min. (e) Oxygen purity at the flow velocity of 5 L/min.

Table 2. Sensor outputs and the response times of the system in accordance with the fault cases.

Sensor name	Organized faults	Sensor outputs	System response time (s)
	The air output of the system is closed (HPS)	10	24
Pressure sensor	The air carrier pneumatical hoses are removed from their beds (LPS)	01	29
Temperature sensor	The limit thermostat is made short-circuit	1	1
Oxygen sensor	The air carrier pneumatical hoses are removed from their beds	1	9,60

5 L/min., it is observed that the oxygen purity in the flow meter output decreases to respectively 90.9% ± 0.4 and 80% ± 0.85.

Table 2 shows the sensor outputs and the response time of the system in accordance with artificially creating faults.

These results show that when a fault is occurred in the system, it is stopped after a delay of maximum 29 s and the related technical and hospital authorities are informed about the faults in a short time period. From the experimental results, it is shown that the proposed system supplies the desired oxygen purity at the flow velocities of 1–3 L/min.

5. Conclusions

In this study, a low cost oxygen concentrator was designed and its practical application was realized on a prototype. A GPRS based fault transfer system for the proposed oxygen concentrator was developed to eliminate the problems arising from the information relying on patient's statement. In this way, it was aimed to minimize the delays that may occur during the treatment period. The sensing circuits on the control card were arranged in such a manner that gives a digital output for eliminating the analog digital converter and providing the fault detection with short program codes. The experimental results showed that the proposed system supplied the oxygen at the purity of about 94.7% for the flow velocities of 1–3 L/min. It is concluded that the system provides a good performance when considered that a patient with the COPD should take the oxygen at the purity of 90% or more for the flow velocities of 2–3 L/min.

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