

[54] **ELECTRONIC MONITORING CONTROL AND DISPLAY APPARATUS FOR BREATHING GAS SYSTEM**

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[51] Int. Cl. **G05d 11/00**

[58] Field of Search **98/1.5; 128/142, 142.2, 2 L; 137/87, 88, 93; 340/248 A, 236; 328/127, 128**

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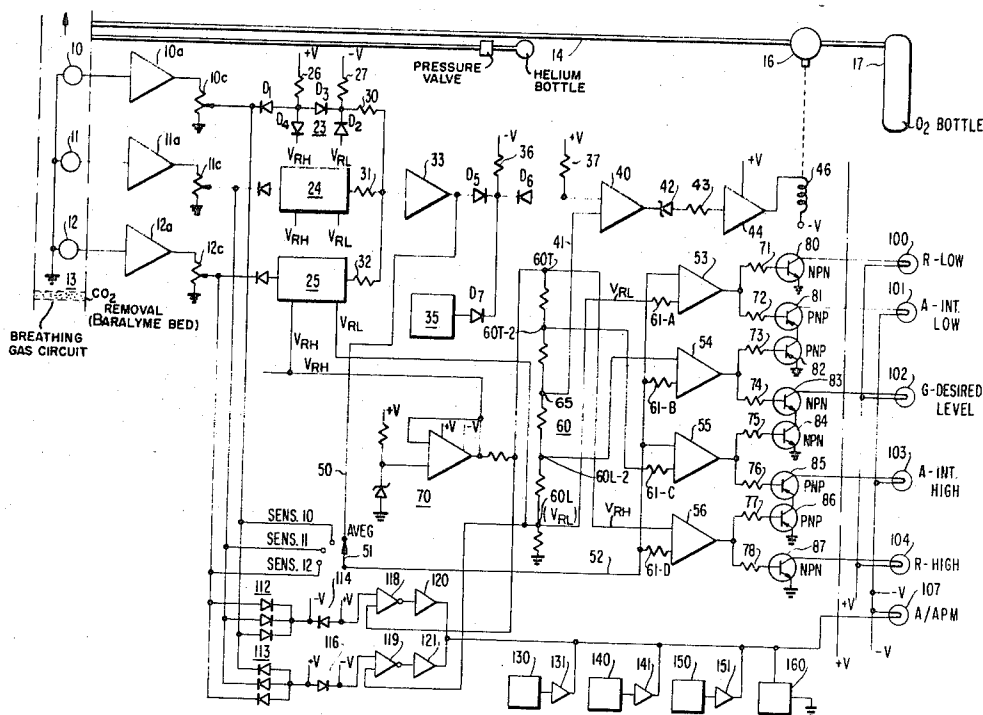
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[57]

ABSTRACT

There is disclosed an electronic monitoring, control and display system for breathing gas system, as for example, in a self-contained underwater breathing apparatus. The output voltage of one or more galvanic partial oxygen pressure sensors, after being compensated for temperature variation, is amplified, limited and averaged and (1) periodically compared with a first reference voltage level to determine whether make up oxygen is to be supplied to the breathing system and (2) compared with a plurality of stepped reference voltage levels, an intermediate level in the steps being the said first reference voltage level. Such plurality of stepped voltage levels are used in a plurality of comparator circuits along with logic circuitry and a bank of display lamps to digitize the conditioned signal voltage from the sensors, the logic circuitry permitting the energization of only one lamp to the exclusion of all others (except an alarm lamp) to eliminate any ambiguity or need for interpretation in the display to the user. In a preferred arrangement a plurality of lamps of the miniature type are housed in a straight row within a waterproof housing which is adapted for securement to the wrist of the diver.

8 Claims, 5 Drawing Figures



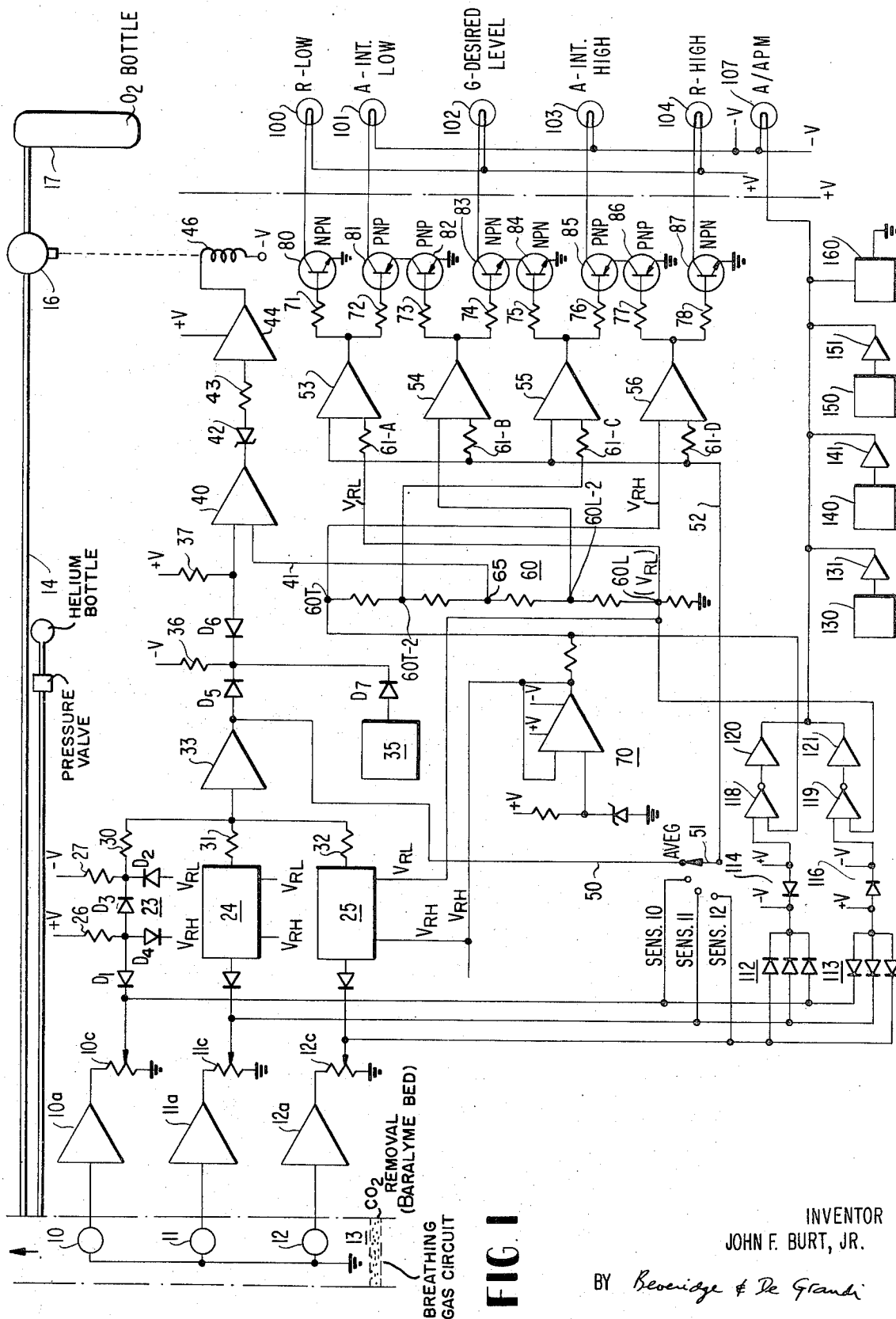


FIG 1

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ATTORNEYS

FIG. 3

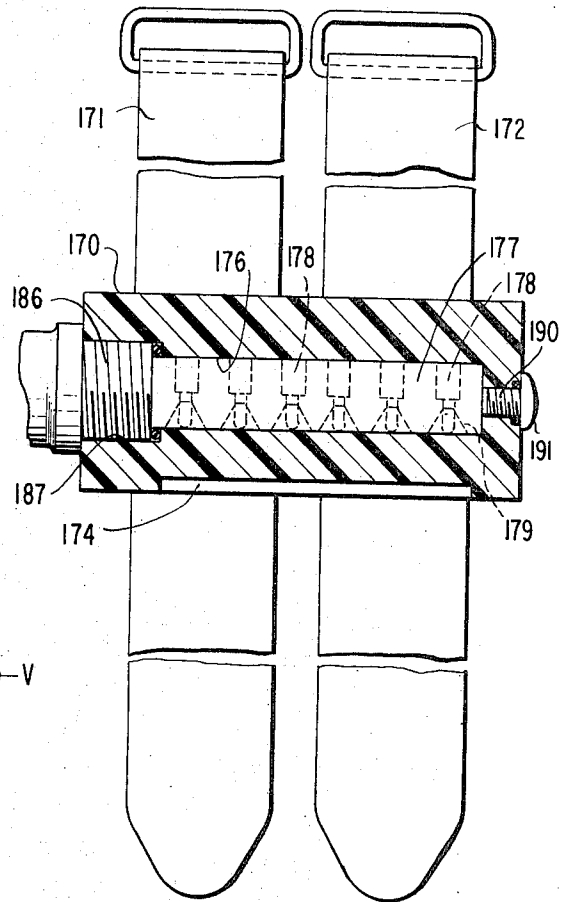


FIG. 2

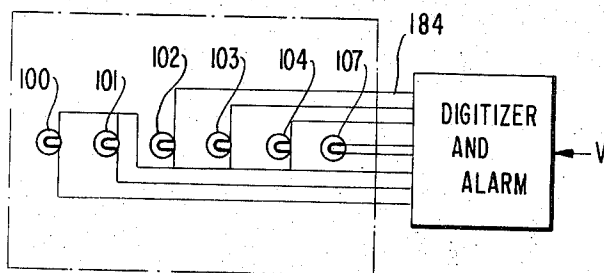


FIG. 4

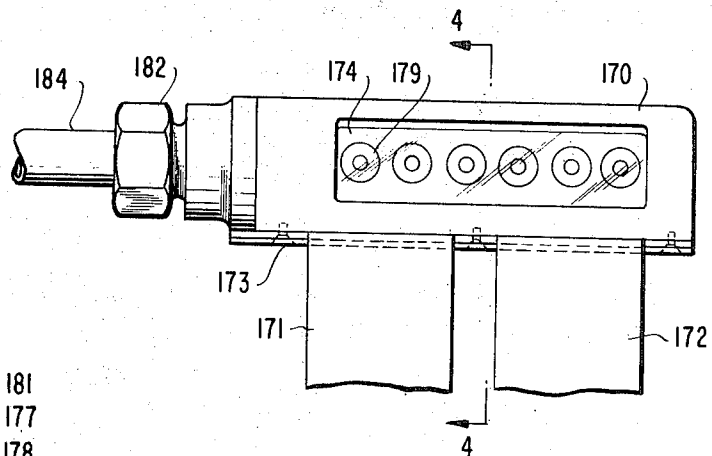
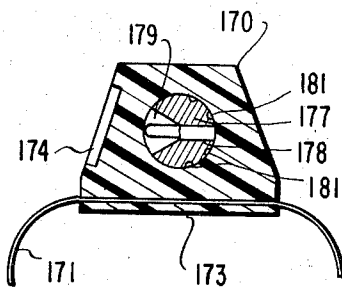


FIG. 5



ELECTRONIC MONITORING CONTROL AND DISPLAY APPARATUS FOR BREATHING GAS SYSTEM

BACKGROUND OF THE INVENTION

Conventionally, systems for displaying conditions of vital gas parameters in closed and semi-closed breathing systems have been by means of analog meters, usually of the mechanical type but more recently, with the advent of improved partial oxygen pressure sensor and electrical control systems and improvements in batteries for supplying power, electrical meters have been used for presenting to the user the vital oxygen parameters as measured by improved partial oxygen pressure sensors. Other gas parameters, such as pressure of oxygen at the oxygen bottle, pressure of diluent gas at the diluent gas bottle measured by conventional pressure gauges which are suitably located for observation by the user. The present invention is directed to improvements in the display of vital data in breathing gas systems to eliminate ambiguity in such displays; to present all vital data concerning the breathing gas system to a user in a manner such that the user may quickly and easily isolate dangerous conditions for corrective action; to provide an alarm system which is operable when any of a plurality of vital parameters in the breathing gas system may be at a dangerous condition or level or at least when the output signals of sensors or transducers are such as to signify a dangerous condition; to provide the user with such information without the need of any significant interpretation by the user; to provide an improved automatic control system for the makeup oxygen supply to the breathing gas circuit which conserves the use of oxygen and hence extends the uninterrupted time period a user may use the system; and to provide an electrical system for such control which is relatively simple and economical.

The above and other objects, advantages and features of the invention will become more apparent from the following description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is an electrical block diagram incorporating the invention.

FIG. 2 is a more simplified block diagram of a digital lamp display circuit as used in the invention,

FIG. 3 is a top view of a digital wrist display device as embodied in the invention, and

FIG. 4 and 5 are side and end elevational views, respectively, of the wrist display device as embodied in the invention.

Referring now to FIG. 1 of the drawings, a plurality of sensors, as for example three galvanic partial oxygen pressure (PO_2) oxygen sensors 10, 11 and 12 of the type generally disclosed in Rutkowski application Ser. No. 831,152 filed June 6, 1969, now U.S. Pat. No. 3,711,395 and assigned to the assignee of the present invention, for example, it being understood that any other type of oxygen sensors may be used in place of the type disclosed in the above-referenced patent application. Such sensors 10, 11 and 12 are shown included within a breathing gas circuit designated generally by the numeral 13 which may, in general, be either a closed semi-closed or open circuit breathing system, and as an example, will be described in connection with a closed circuit breathing system for underwater breathing apparatus in which the breathing gas circuit

includes a carbon dioxide removal unit, (not shown) with a mouthpiece (not shown) for supplying the conditioned gases moving in breathing gas circuit 13 to a user. In addition, such a breathing gas system may include pressure control diaphragm means (not shown) as well as diluent oxygen control and supply means, likewise not shown. Such apparatus, for the purposes of this invention, are deemed to be conventional. Reference, however, is made to the application of Frederick Parker et al., Ser. No. 6,387 filed Jan. 28, 1971, now U.S. Pat. No. 3,710,553 and assigned to the assignee of the present invention for a detailed disclosure of such an underwater breathing system for which the invention is particularly well adapted, such application being incorporated herein in its entirety.

As diagrammatically shown in FIG. 1, the breathing gas circuit 13 has connected thereto a pipe 14 which leads from a normally closed oxygen control valve 16 which, in a manner to be described more fully hereinafter, controls the periodic supply of oxygen, when needed, from oxygen bottle 17 to breathing gas circuit 13 via pipe 14.

THE CONTROL CIRCUIT

The output voltages from galvanic oxygen sensors 10, 11 and 12 are amplified by conventional differential amplifiers 10a, 11a, and 12a, respectively, the gain of such amplifiers being fixed at a selected level. Sensors 10, 11 and 12 are each individually calibrated by potentiometer means 10c, 11c and 12c respectively, and if it is not possible to calibrate a given sensor, this is an indication that such sensor must be replaced.

The amplified and calibrated signals appearing at the wipers of potentiometers 10c, 11c and 12c, respectively, are passed to limiting circuitry 23, 24 and 25, respectively with the details of one such limiting circuitry being shown at 23. The limiting circuitry 23 comprises resistors 26 and 27 and diodes D_1 , D_2 , D_3 and D_4 . As illustrated, the cathode of diode D_2 is connected to a voltage V_{RL} representing the lowest possible oxygen level voltage. If any of the sensor voltages are lower than the lowest permissible voltage, they are rejected in favor of the lower limit. If any of the voltages are higher than the highest permissible voltage limit, the higher voltage is rejected in favor of the higher limit. In between these two voltage limits, e.g., the high voltage limit as established by V_{RH} and the low voltage limit as established by V_{RL} , the conditioned sensor voltage output is unchanged. Thus, this limiting circuitry limits the condition sensor outputs between fixed levels. The circuitry in blocks 24 and 25 is identical to the circuitry shown in for limiting circuitry 23 and is not described in detail. The outputs of the limiting circuitry is coupled through resistors 30, 31 and 32, respectively, to an averaging amplifier 33 which averages the voltage output of limiting circuitry 23, 24 and 25 so that the output of amplifier 33 is a voltage which represents the average voltage of oxygen sensors 10, 11 and 12.

The average voltage as appearing at the output of amplifier 33 is sampled periodically. This is done by a free running multivibrator 35 which supplies sampling pulses to sampling circuit which comprises diodes D_5 , D_6 and D_7 and resistors 36 and 37 which have applied thereto the relative potentials illustrated in FIG. 1. Functionally the sampler circuit is a gate circuit which is gated on by an output pulse from free running multivibrator 35 and in the absence of a pulse from free run-

ning multivibrator 35 the averaged voltage of the PO₂ sensors appearing at the output of amplifier 33 is blocked. Free running multivibrator 35 may be adjusted to have a rate of one gate pulse output every selected time interval and in the present case, the sampler applies or passes the averaged sensor voltage at the output of amplifier 33 to comparator amplifier 40 every 5 seconds. It will be appreciated that this time interval may be increased or decreased according to the desired discipline of the oxygen supply system to the breather. In addition, a reference voltage is applied via line 41 to comparator amplifier 40 and constitutes the control point. In the event the average voltage from amplifier 33 is less than this reference voltage, there is an output voltage from comparator amplifier 40 which is coupled through zener diode 42 and current limiting resistor 43 to driver amplifier 44 which turns on or energizes solenoid 46 which in turn controls solenoid valve 16. The zener diode keeps the driver amplifier from turning on with a negative comparator output. The solenoid is designed to remain energized for about one-half a second which admits one-half a liter slug of oxygen into the breathing mixture in breathing gas circuit 13. The sampling circuitry then turns off a solenoid driver 44, waits another five seconds and then repeats the comparing process. Thus, oxygen is admitted to the breathing gas circuit only if the level of oxygen as measured by sensors 10, 11 and 12 is below a selected level. Moreover, Fluctuations in oxygen partial pressure are minimized by use of sample data control e.g., the periodic sampling and introduction of fixed pulses of oxygen when necessary reduces fluctuations by reducing mixing and transportation time relays in the small volume (the pipe 14 being diagrammatic). In addition to providing closer control of oxygen, battery power consumption is greatly reduced.

DIGITIZER AND DISPLAY

As shown in FIG. 1, the output from averaging amplifier 33 is applied by lead 50 to selector switch 51 which may be used to select any one of the voltages from the sensor 10, 11, or 12, respectively or the averaged voltage from averaging amplifier 33. Normally, as shown in FIG. 1, the switch 51 is in the position to select the averaged voltage from averaging amplifier 33 which voltage is applied over line 52 as one of the inputs to a plurality of operational or comparator amplifiers 53, 54, 55 and 56. The second input to amplifier 53, . . . 56 is derived from a voltage divider 60. To the top or upper end 60T of voltage divider 60, is applied a calibrated or reference voltage from precision reference voltage source 70 which, as shown, is conventional using a zener diode as a precision reference device. (The reference voltage V_{RH} is obtained from this source as well as the reference voltage V_{RL} .)

It will be noted that the precision or calibrated voltage from source 70 that is applied to voltage divider 60 is also applied as one input or one comparison input to comparator 56. Similarly, the voltage from the lower level 60L of the voltage divider 60 is applied through a resistor 61 as a second input to comparator amplifier 53. Similarly, the next highest level 60T—2 on voltage divider 60 is applied as an input to comparator amplifier 55 whereas the intermediate point 65 on the voltage divider is applied on line 41 as an input to comparator amplifier 40 which is used to establish the set point or control point for the admission of oxygen into the

breathing gas circuit 13. Finally, the second level from the bottom 60L—2 on voltage divider 60 is applied as a second input to comparator amplifier 54.

If the applied signal voltage from averaging amplifier 33 is lower than the step voltage applied to comparator amplifier 53, the output of comparator amplifier 53 is positive. The output of each of the comparator amplifiers is applied via series resistors 71—78 to AND logic circuits which are comprised of alternate NPN, PNP transistor units, with the alternate PNP or NPN transistor driving output indicator lamps 100, 101, 102, 103, 104, respectively.

If the applied signal voltage from averaging circuit 33, for example, or from any one of sensors 10, 11 and 12 as determined by the position of switch 51, is lower than the step voltage level applied to comparator amplifier 53, the output of this amplifier is positive so that the NPN transistor 80 is turned on or rendered conductive and the PNP transistor 81 is turned off. Thus, the "low" light is 100 is turned on or illuminated. The "AND" circuits formed by transistors 81, 82, 83, 84, 85, 86 and 87, in the examples shown, keep the remaining lights 101—104 off.

When the signal level just exceeds this low step value, the output of comparator amplifier 53 becomes negative which turns off transistor 80 and turns on transistor 81. Since the output of comparator amplifier 54 is also negative, the transistors 81 and 82 (both of which are PNP) are "on" so that lamp 101 (intermediate low) is on and the remaining lights 100, 102—104 are off. When the signal level reaches the step value applied to comparator 54 (the voltage at point 60—L—2), the output thereof becomes positive and transistor 81 and transistor 82 turn off and transistor 83 then turns on because of the positive potential on its base, to energize or illuminate the lamp 102 (the desired level) turns on and transistor 82 turns off thus extinguishing the lamp 101. In between this value of set voltage and the next highest level is the control point voltage as applied to comparator 40. Thus, the control point is exactly in the middle of the desired level band.

The meter-light electronics continues to sequence the lights as the signal voltage increases with the same control as exercised by the AND logic circuitry as described above. Electrical energy to operate the circuitry may derive from battery packs, not shown, which may constitute both positive and negative powers supplies.

ALARM CIRCUITS

The sixth lamp 107 illustrated in FIG. 1 is an alarm lamp. As illustrated, the output voltages from the PO₂ sensors 10, 11, and 12 are coupled through coupling diode set 112 and coupling diode set 113 (connected in opposite polarity to diode set 112) to limit selection circuitry 114 and 116 which, in turn, select the highest and lowest oxygen sensor readings and applies same to comparators 118 and 119, respectively, and which, in turn, operate driver amplifiers 120 and 121 respectively. These amplifiers 120 and 121 are simply switches which operate or energize alarm lamp 107 and alarm buzzer 160 as illustrated. The circuitry comparator consisting of diodes 113 and limiting low level selecting diode circuitry 116 operate in a similar manner, it being noted that the high level comparison voltage is selected from the upper end 60T of voltage divider 60

whereas the low level is selected from the lower end 60L of the voltage divider 60.

As illustrated, a plurality of additional sensors 130, 140, and 150 are connected to driver amplifiers 131, 141, 142, respectively to sense various other conditions, as for example the battery voltage, to provide an alarm whenever the battery voltage is low, and/or sense the oxygen pressure at an oxygen bottle 17 and operate the alarm when the contents or pressure of the oxygen in oxygen bottle 17 is low or, to sense the pressure of the diluent gas and provide an alarm when the diluent pressure becomes low. These and other conditions may be sensed to provide an alarm at low level or high level conditions whenever it is necessary to warn the user of a dangerous or impending dangerous situation. At the same time that the alarm light is 107 is illuminated or energized, an audible alarm or buzzer 160 may be energized to provide both simultaneous visual alarm by the illumination of lamp 107 audible alarm by buzzer 160.

DIGITAL WRIST DISPLAY ASSEMBLY

The digital wrist display assembly (FIGS. 3-5) includes a main elongated body or housing member 170, one or more wrist straps of fastening assemblies 171, 172 (which may be Velcro, snap fasteners, buckles, etc.) secured to the base by plate 173. Body member 170 is preferably made of a transparent plastic material (Lexan, for example) and has a transparent elongated viewing window, 174 which may be separate, but is preferably formed integral with body member 170 so as to avoid the necessity of forming a water tight seal for the window. An elongated chamber 176 is formed in body member 170 and chamber 176 is sized so as to snugly receive miniature lamp carrier member 177.

Lamp carrier member 177 has a plurality of spaced transverse bores 178, each bore 178 ending in a conically or parabolically shaped opening or bore 179, the bores 178 being adapted to receive the base of miniature lamps 100, 101 . . . 104, 107, with the filament portion of the lamp bulbs being in the conically enlarged bore portion 179 and opposite the viewing window 174. The individual lamps 100, 101 . . . 104, 107, may be frictionally secured in the bores 178 and wired by means of wires seated in longitudinal grooves 181 to a connector member 182 at the end of flexible conductor cabling 184 which is supplied with operating current by digitizer and alarm circuitry as described above.

Connector 182 is provided with a threaded portion 186 for threadably engaging internal threads 187 on the interior of housing member 170. Sealing washers or "O" rings (not shown) provide a water tight seal for the chamber. After assembling the lamp carrier 177 and connector 182 with body member 170, the chamber is filled with a non-conductive liquid, such as mineral oil, through a filling port 190 which is sealed by a sealing screw 191.

Various modifications may be made to the invention as disclosed herein and still be within the scope of the claims appended hereto.

What is claimed is:

1. In a closed circuit breathing system constituted by a breathing gas circuit including sensor means for producing electrical signals proportional to partial oxygen pressure, and means for displaying the signals produced by said sensor means, and including a breathing gas regenerator means and a supply of regenerating gases in-

cluding an oxygen supply and a normally closed oxygen solenoid control valve,

means for limiting signals from said sensor means to a selected range of amplitudes,

means for producing a reference signal having an amplitude intermediate said selected range,

first comparator means for comparing said sensor signals limited to said selected range with said reference signal,

said display means including a plurality of light emitting elements operated by said comparator means, each said light emitting element corresponding to a selected sub-range of amplitudes within said selected range, and operated by said comparator means when the amplitude of said sensor signals is within a selected sub-range, respectively,

second comparator means,

means for periodically producing a control signal for said second comparator means whereby the comparing of said sensor signals with said reference signal by said second comparator means is made on a periodic basis, and,

means for opening said solenoid control valve on said periodic basis only when sensor signals are below said reference signal.

2. The invention defined in claim 1 wherein said means for periodically producing a control signal for said comparator means is a timing circuit means and the period of said control signal is once about every 5 seconds.

3. The invention defined in claim 2 wherein said normally closed oxygen solenoid valve when energized is adapted to remain opened for about one half second and admit about one half liter of oxygen into the breathing mixture in said breathing gas circuit.

4. The invention defined in claim 3 wherein said means for producing a reference signal having an amplitude intermediate said selected range includes

means for producing a fixed reference voltage,

voltage divider means for stepping said fixed reference voltage into a plurality of discrete levels constituting a subrange, respectively, and there being an intermediate voltage level to constitute said reference signal;

said comparator means including

a plurality of comparator circuits, one for each discrete voltage level on each side of said intermediate voltage level,

means for applying each discrete voltage level to a corresponding comparator, respectively, each of said corresponding comparators including an amplifier,

means for applying the limited signals in said selected range of amplitudes to each said amplifier,

AND logic circuit means connected to the outputs of said comparators,

and means in connecting said AND logic circuit means to said light emitting elements so that only the one light emitting element corresponding to the subrange in which said voltage proportional to a variable lies is energized through said AND logic circuit means to emit light.

5. The invention defined in claim 4 wherein said "AND" logic circuit means is constituted by a series of pairs of transistors of alternate conductivity types and connected to receive signals from said comparator means, the transistor pair connected to a higher level

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comparator having one of said pair connected to a corresponding transistor in the next lower level comparator.

6. In a breathing system constituted by a breathing gas circuit including a plurality of independent galvanic oxygen pressure sensor means for producing electrical signals proportional to partial oxygen pressure, said breathing system includes a breathing gas regenerator means and a supply of regenerating gas including an oxygen supply and a normally closed oxygen control valve controlling the supply of oxygen to said breathing system, and means for displaying the signals produced by said sensor means, improvements comprising:

means associated with each of said sensors for limiting signals to a selected range of amplitudes, means for producing a reference voltage having an amplitude intermediate said selected range, first comparator means for comparing said sensor signals limited to said selected range with said reference signal, means for averaging the signals of said partial oxygen pressure sensor means to produce a voltage proportional to the average output voltage of said sensor means,

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said display means being a digital display including a plurality of light emitting elements operated by said comparator means, each said light emitting element corresponding to a selected sub-range of amplitudes within said selected range, and operated by said comparator means when the amplitude of said voltage is within a selected sub-range, respectively,

a second comparator means for comparing the said voltage proportional to the average output voltage of said sensors with said reference voltage and, means for opening said control valve to supply oxygen to said breathing gas system when said voltage proportional to the average output voltage of said sensors is below said reference voltage.

7. The invention defined in claim 6 including a zener diode connected to the output of said second comparator.

8. The invention defined in claim 6 including means for producing a periodic control signal for said second comparator means whereby the comparing of said averaged sensor voltage signals with said reference in said second comparator means is on a periodic basis.

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