Pressure Meter

Engineering World Health

Midsemester Report

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Abstract

The pressure of the gasses provided by anesthesia machines, ventilators, and other similar hospital equipment must be measured in order to avoid unsafe conditions for patients. Generally this is done with an internal gas pressure meter, but in third world countries the machines are not always advanced and may require an external device to read the pressure. Engineering World Health (EWH), an organization that provides medical equipment to underserved areas of the world, is in need of a device for this purpose. It is necessary to build a pressure meter that will satisfy the specifications – especially with a limited budget. Once some background research was completed, several different designs were considered. These designs included devices containing piezoelectric material, a propeller and a strain gauge. In order to decide which design would be the most appropriate, a design matrix was constructed. This led to a final choice of a device containing a strain gauge. Lastly, future work was considered – improving upon the design of the strain gauge circuit, design of the interface to connect the strain gauge and the digital readout, writing of the proposal for EWH, construction of the prototype, and finally testing and improvement of the device.

Background Information

Engineering World Health (EWH) is an organization of engineers, scientists, doctors, students, and other people who are interested in making a difference in disadvantaged areas of the world. It supplies appropriate medical technology to third world countries and other underserved areas in order to provide adequate medical care for the people living in these regions. (Engineering World Health (1), n.d.)

EWH has a program in which it sets specifications for certain devices that would be useful in medical care in these areas, and then accepts designs for these devices. If the designs meet all the requirements and are approved, EWH provides $150 for prototype production. Eventually, if the device is mass-produced for use in a third world country, the design group can accompany EWH members to distribute the device. (Engineering World Health (2), n.d.)

The Engineering World Health website (http://ewh.org) has specifications for each of the devices, including the gas pressure meter. The limiting factor of the design for this device is going to be the cost, which tends to be the case for most of the EWH projects. Also, generally gas pressure is measured with a pressure meter found within the machines, but in third world countries the machines are not always advanced and may require an external device to read the pressure

Problem Statement

Our task is to design a gas pressure meter to be used in third world countries and to be distributed by Engineering World Health. The pressure meter will be used to measure the pressure of oxygen, medical air, and carbon dioxide and must be compatible with several different machines, including ventilators and anesthesia machines. The pressure leaving the machines will be measured and displayed in a digital readout. Generally ventilators and anesthesia machines used in hospitals today contain an internal device that makes the pressure measurement, but since this device will be used in a different setting, the machines may not be as “up-to-date” and may require an external device to read the pressure. (Backes, W., personal communication, February 28, 2007).

Constraints

This device must abide by several constraints in order to be a plausible solution. Several of these constraints were explicitly defined by EWH, and the rest were left to the group to research.

With regards to functionality, EWH has specified that the device must be able to measure pressure to within at least 10% of its true value, while 1% is optimal. The device needs to have a continuous readout, which means that the measurement system must be continuous as well. Also, the readout must be digital, which could be beneficial to the accuracy of the device by removing random error produced by the person reading the display. Dimensions must be 4 inches by 4 inches by 1 inch for a device with only one segment, or 1 inch by 4 inches by 1 inch for a device with several segments.

EWH has specified that the device will be used to measure medical gasses, such as O_2, CO_2, and medical air. However, the range of pressures that the device will be required to measure was not defined. With the help of clinical engineers from the University of Wisconsin Hospital, the group decided that pressures between -35 mm of Hg and +75 mm of Hg would be optimal. This will be the pressure of the gas just before it enters the patient.

Since the device will potentially be used with technologically "out-of-date" machines, there is no specific form factor to reference for the design. The device must therefore be flexible in its ability to compensate for different connections (e.g. hose barb, locking ring, quick release). The device must also be reusable and autoclave compatible, though this method of sanitation may not be necessary and will be discussed with EWH later. The final specification is the cost; in quantities of 500, the devices needs to cost less than two dollars each, including packaging, but not including the cost of manufacturing.

Several other safety requirements were not specified but EWH, but should still be taken into consideration when designing the device. The materials that are used, along with being autoclavable, must be nontoxic and should not shed any sort of debris. Also, since the device will be directly linked to the airflow going to the patient, the design of the device should not block the airways in the case of a malfunction. Weight was not specified, and will probably not pose a significant constraint on the design.

Current Technology

There are many forms of pressure measurement in use today for many applications. These tools are known as pressure or gas gauges. Pressure is most commonly thought of as the relationship between the amount of force and the area on which it is exerted. This is the basis for the equation Pressure = Force/Area. Most measurement devices incorporate this concept in some way, and make measurements with some reference to a zero point (usually atmospheric pressure). There are also two types of pressures considered – static pressures and dynamic pressures. Static pressures are exerted in all directions, like from gas and fluids. Flow produces pressures parallel to its direction and is usually referenced as dynamic pressure. These two differ in the way that they are measured. Since static is constant in all directions, the measurement device may be positioned anywhere. Dynamic pressures are measured in a more complex fashion, using references to other pressures. However, since dynamic pressures are less important in this design, they will not be considered in depth.

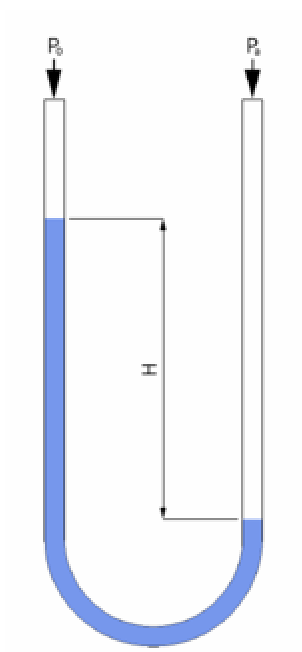

Figure 1: Diagram of a monometer. Pa represents the unknown pressure, and Po represents the reference pressure.

One of the most primitive forms of pressure measurement is the monometer. It utilizes a U-shaped column filled with some liquid, typically mercury or water (Figure 1). The pressure of one side of the column is used as a reference and compared to the pressure of the other side, using the difference in heights as a measurement. The pressure displaces the liquid until the liquid's weight compensates and reaches equilibrium. This is a superior method for analog analysis.

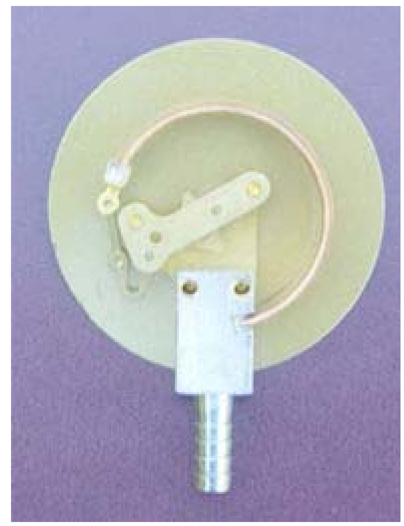

Figure 2: Backside view of a Bourdon Gauge.

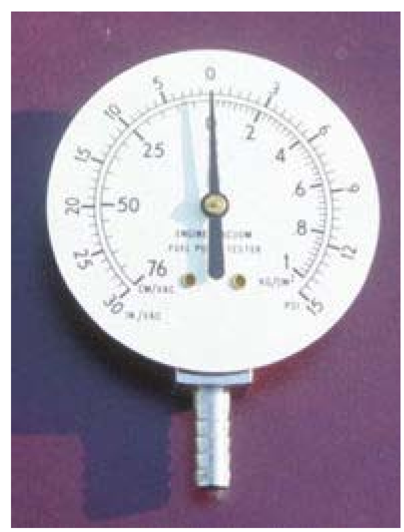

Figure 3: Frontside view of a Bourdon Gague.

Another common form of measurement is called the bourdon gauge. It involves a coiled tube connected to a port that's exposed to a changing pressure (Figures 2 and 3). As the pressure increases, the tub straightens out, rotating a gear train connected to a dial. The stronger pressure extends the tube farther and the dial is rotated. This is another gauge that is primarily used in analog pressure analysis.

The most commonly used digital pressure detector is a strain gauge. An example is the foil strain gauge. As the foil is deformed by pressure, the resistance across it changes. Using a Wheatstone bridge, this unknown resistance can be measured and converted into a voltage. With a gauge factor and the change in voltage, different pressures can be analyzed digitally.

Propeller design

This design uses the relationship between the velocity of flow, its density, and the area of a cylinder as described by Bernoulli's equation. The main part of the design consists of a cylinder of known diameter with an axial fan mounted to its center. It is important that the cylinder is long enough so that moving air has enough time to stabilize after experiencing turbulence from the change in tube diameter between the medical equipment and the device. Each device will be calibrated with various known pressures throughout the range of the required pressures outlined in the constraints section. Once a calibration curve is created, a known voltage will indicate an unknown pressure.

One of the pros of this device is its simple design. It will not be complicated to produce, and the components should be relatively easy to find. None of the pieces are excessively expensive.

One of the cons of this design, however, is that it requires flow. Pressure does not necessarily require flow, so in some cases this design might not function properly. Also, each device will need to be calibrated separately. One final downside is the possibility of the blockage of a patient's airway due to malfunction of the fan.

Piezoelectic Design

This design is based on the utilization of a special material that is able to transduce a mechanical signal into an electrical signal. The material that can accomplish this is a piezoelectric material. This material responds to a mechanical stimulus with a voltage output and to an electrical signal with a mechanical change in shape. A flap of this material would be placed on the interior of a tube that is connected to the machine in which we need to measure pressure. When the gas from the machine flows through the tube the pressure from the gas will deform the material, outputting a voltage which we could convert to a pressure through calibration.

Figure 4: Depiction of the piezoelectric material behavior. As material is deformed there is a change in voltage. (Design inSite, n.d.)

One of the pros of this design are that it would be more accurate than the propeller design. Also, it would reduce the number of circuitry components because it acts as its own transducer, meaning that it would only be necessary to digitize the voltage output *and* display the results.

The biggest problem with this design is that it will be very expensive because the piezoelectric material can be very costly, at least $100, which is far from our budget constraints. Also, the piezoelectric material can only detect changes in pressure, and would not be able to measure static pressures.

Strain Gage

This design is based on basic principles of circuitry and is able to use mechanical pressure to transducer and electrical signal. The basic circuit component at the heart of the strain is the wheatstone bridge shown below in figure 5. Using known resistances of three resistors, an unknown voltage can be found over the fourth resistor, labeled Rc in figure 5 below. Through calibration with known pressures a voltage output can be equated to pressure.

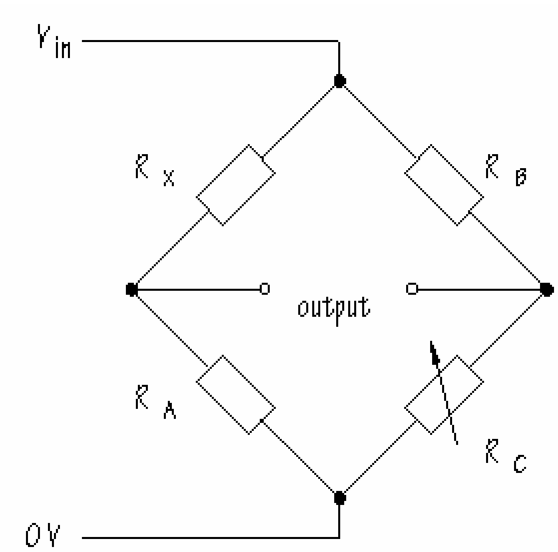

Figure 5: Depiction of a wheatstone bridge. Using three known resistors, a change in voltage can be determined off of a fourth resistor based on the mechanical stimulus it receives. (Westminster School Intranet, n.d.)

One advantage of this design is that it is very accurate. This would provide the best chance of reaching the goal of 1% of the true value of pressure. Also, this design can be relatively inexpensive compared to the other two because these pressure transducers are already commercially available. Furthermore, this is the only design that is able to measure static pressure, which is a major advantage over the other designs.

The major con of this design is that it has a lot of circuitry components, which increases the probability of failure in any single component of the circuit.

Design Matrix

Once the designs were narrowed down to final three options – piezoelectric, propeller, and strain gauge – they were evaluated using a design matrix. Each design was evaluated in six different categories, which included patient safety, cost, size, ease of production, durability and client requirements. Since three of these categories – patient safety, cost and client requirements – are the most important, they were weighed on a scale from 1 to 10 (1 being the worst to 10 being the best). The rest of the categories – size, ease of production and durability – were considered on a scale from 1 to 5 (1 being the worst and 5 being the best). The piezoelectric design came out with 27, the propeller design came out with 31, and the strain gauge design came out with 40 points. Based on this evaluation, the design chosen for further pursuit was the strain gauge design. Figure 6 shows this design matrix.

Design	Piezoeletric	Propeller	Strain gauge
Patient safety (10)	**8**	**6**	**8**
Cost (10)	**4**	**8**	**10**
Client requirements (10)	**6**	**6**	**10**
Size (5)	3	3	4
Ease of production (5)	3	3	4
Durability (5)	3	5	4
Total (45)	**27**	**31**	**40**

Figure 6: Design matrix of our three design alternatives. The strain gauge design won out getting 40 total points.

Potential Problems and Future work

Even though the strain gauge design has numerous superior qualities to the alternative designs, there are still several drawbacks. Primarily, since there are a myriad of electronic components of the Wheatstone bridge circuit, the design has a high risk of malfunctioning. This also means that due to such a high number of parts, identifying and fixing the problems will be more difficult. Also, this design requires the most calibration of the three, which can become a problem as well.

In the future, the current strain gauge design will be updated and improved. The current design (fig #7) consists of a voltage divider which ensures that the right amount of current goes through the circuit, a Wheatstone bridge, used to measure the unknown resistance, and finally an inverting operational amplifier which amplifies the voltage difference created by the Wheatstone bridge. Once the strain gauge circuit is finalized, the interface will be designed between the strain gauge and the digital display. This will be necessary in order for the digital display to be dependant on the change of voltage in the strain gauge. After the entire design is completed, a proposal will be written for EWH. If the proposal is accepted, the team will be given $150 to build a prototype for testing. At completion of the prototype, a testing procedure will be designed. The procedure will include measures to calculate the calibration curve, which is important in ensuring that the device works accurately. After testing, the accuracy of the prototype will be improved. Finally, the goal will be to lower the cost of the design in order to satisfy the given price specifications.

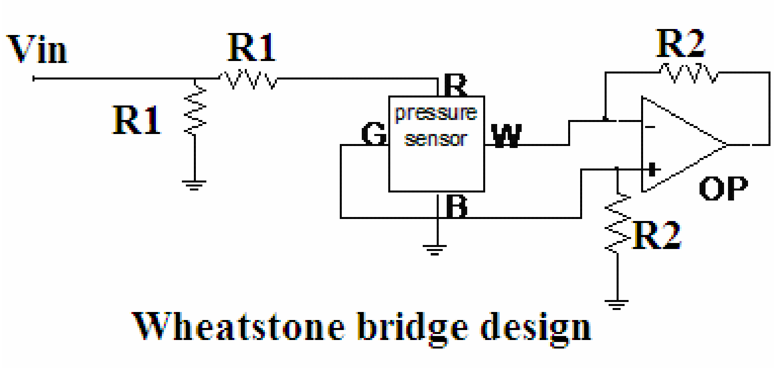

Figure 7: Preliminary circuit design for utilization of a strain gauge.

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