INTRACRANIAL PRESSURE SENSOR:

DETECTION OF SHUNT MALFUNCTION IN HYDROCEPHALUS PATIENTS

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ABSTRACT

Currently, our client, Dr. Medow is working with Professor John Webster and Elena Bezrukova in developing a sensor that would monitor pressure inside the skull of hydrocephalus patients. This sensor will potentially notify medical personnel when a cerebral spinal fluid drainage shunt has failed.

Our team contributed to this project by designing a phantom testing device that will be used to calibrate and test sensor specifications (drift stability, accuracy, etc.)

The final design is an upright standing tank comprised of five sections of clear PVC tubing. During a testing procedure the sensor is placed at the base of the structure, and pressure is generated from the water pressure above. The pressure can easily be altered by changing the height of the water.

Following testing we concluded that our device can supply the appropriate consistent positive pressures, permits drift stability testing, and is physically stable.

INTRODUCTION

Hydrocephalus is a condition characterized by excessive accumulation of fluid in the brain. Cerebrospinal fluid (CSF) surrounds the brain and spinal cord cushioning the brain. The excessive accumulation of CSF results in an abnormal widening of spaces in the brain called ventricles which are connected by narrow passages shown in figure 1.a. Normally, CSF flows through the ventricles, exits into cisterns. Hydrocephalus impedes this process.

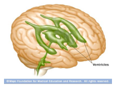

Figure 1.a Ventricles

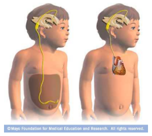
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Figure 1.b Shunt System

Hydrocephalus is most often treated by surgically inserting a shunt system consisting of the shunt, a catheter, and a valve. This system shown in figure 1.b diverts the flow of CSF to another area of the body, normally the stomach or the heart, to be reabsorbed into the circulatory system.

Shunt systems are not perfect devices. Complications include infections, obstructions, and outgrowing the shunt. Within the first 2-3 years of implantation, 50% of shunt systems fail leading to invasive procedures. To successfully monitor the shunt system, a pressure sensor can be used to detect an increase/decrease in intracranial pressure. Our clients are currently working on designing a sensor (Figure 1.c) for this specific purpose.

The phantom tester is the focus of our project and caters to the capabilities of the pressure sensor. Pertinent sensor design criteria follow:

- Reliability: within 0.1% error
- Range: -30 to +100 mmHg
- Drift stability: 2 to 3 mmHg

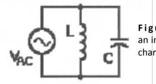


Figure 1.c (Left) An LC circuit has an inductor and a capacitor and has a characteristic resonant frequency

FINAL DESIGN

PHANTOM TESTER DESIGN CRITERIA

- Reliability: within 0.1% error
- Able to calculate drift stability
- Range: -30 mmHg to +100 mmHg
- Not interfere with telemetry signal
- Able to take readings at any interval
- User friendly
- Accommodates water and vacuum conditions
- Mimic intracranial environment for testing

PHANTOM TESTER

Figure 2.a Final Design (left)

- Pressure generated from water height
- Change in water height correlates to change in pressure
- 0.305 m sections of clear PVC pipe
- Adjustable for user
- Maximum height: 1.37 meters
- Rubber fittings connect tubes and prevent leakage
- Wide inner diameter (15.31 cm) reduces meniscus; allows more accurate measurements
- Large (.305 m x .305 m) polyurethane base prevents leaking and provides stability

Figure 2.b (right) Near the base of the bottom tube, a rubber stopper was installed into the wall of the plastic tubing. A section of polyurethane tubing runs through this plug and into a drainage container. A clamp was placed on the polyurethane tube to keep water inside the tube during testing. This design can also accommodate vacuum conditions. Once the column is empty, it can be capped at the top. The drainage tube is then connected to a vacuum trap which forms a vacuum inside the sealed column.

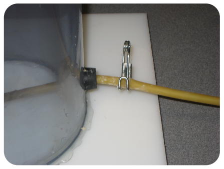
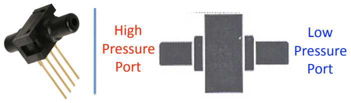


Figure 2.c Differential Pressure Sensor (right) A differential pressure sensor was utilized to verify calculated measurements in pressure. This device works by measuring pressure difference between opposite terminals of the sensor. The pressure is then converted to a voltage and read by an oscilloscope. The actual measurements from the new sensor will be correlated to the resonant frequency of the pressure sensor built. This sensor is only able to detect pressures between about 0 and 2 psi. Negative pressure readings from vacuum conditions will be measured by a vacuum pressure gauge.



PROTOCOL

Equipment

- Pressure sensor
- Differential pressure sensor
- Voltage amplifier
- Vacuum pressure gauge
- Water source
- Vacuum trap
- Aspirator
- Phantom tester

Testing for Negative Pressures

- Place pressure sensor on the base and secure tubing and cap
- Connect to vacuum trap and aspirator
- Vary the negative pressures within the column by changing the rate of water flow of the aspirator
- Record data using negative pressure gauge
- Record resonance frequency from telemetric output

Testing for Positive Pressures

- Place pressure sensor on the base
- Connect tube at base of phantom tester to voltage amplifier and differential pressure sensor
- Calculate density of water used to fill water column
- Make sure the differential pressure sensor and voltage amplifier are of the same height of the cut out hole of the tube
- Fill column with water to reach height that correlates with desired increment in pressure
- Record voltage from oscilloscope
- Record resonant frequency from telemetric output

Use correlation equation shown in figure 3.a to relate resonant frequency to voltage. Take multiple readings to create correlation table relating the two measurements.

TESTING

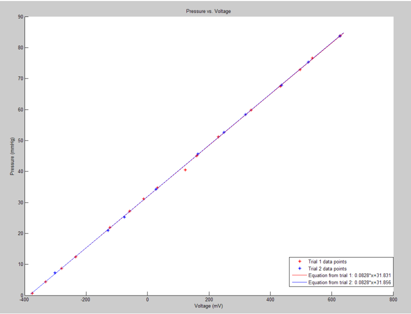


Figure 3.a Final Curve (above) Data collected from testing during two separate sessions. The conversion factor from voltage to pressure was consistent in both trials (0.0828 mmHg/mV). There is a slight variation between the Y-intercept of each trial due to a small change in initial pressure.

- Maximum pressure: 100 mmHg
- Minimum pressure: -12 mmHg
- Evaporation in 12 hours: 0 cm
- 100 different data points collected
- Consistent readings
- Accuracy ($r^2 = 0.997$)
- No leaks
- Physically stable

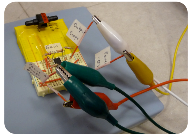


Figure 3.b Circuit containing amplifier used for calibration

CONCLUSION

- ✓ Positive pressure range met
- ✗ Unable to meet negative range
- ✓ Correlated voltage to pressure
- ✓ Design protocol for pressure sensor
- ✓ Can measure drift
- ✓ Simple user interface
- ✓ Easy to transport
- ✓ Easy learning curve

A phantom tester was developed that will be sufficient in testing various sensor prototypes throughout the course sensor development.

FUTURE

Immediate Future

- Provide better sealing system to measure in vacuum conditions
- Incorporate a clear attachment method between detachable columns
- Increase draining rate
- Modify protocol as the sensor changes

Future Semester(*s*)

- Miniaturize prototype sensor
- Implement biomaterial casing for miniature sensor
- Testing device should be applicable for all stages of sensor development, but can be easily modified

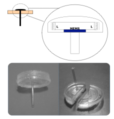


Figure 3.c Biomaterial Casing (above) Integration of our circuit design on small scale with a previously manufactured casing developed by a BME 301 class in spring of 2008 would complete this prototype.

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