2. DESIGN CONSTRAINTS

The electromagnetic flow meter developed in this project provides a replacement for the flow meters used by the University of Mississippi Medical Center (UMC). The new flow meter uses UMC's original flow meter, which is no longer available, as a reference. Therefore, the new device provides similar results. The flow meter is designed to measure the volumetric flow rate of a conductive fluid through a pipe. The device is later calibrated using a saline solution to simulate the electrical conductivity of blood. The new electromagnetic flow meter is designed with constraints that allow UMC to continue researching with cheap, accurate equipment. This portion of the document is divided into two major sections: technical design constraints and practical design constraints.

2.1 Technical Design Constraints

The technical design constraints are listed in Table 1.

Table 1. Technical Design Constraints

Name	Description
Measurement Accuracy	The flow meter is capable of measuring flow rates from 0.1-1 m/s within 1 cm/s of the actual values.
Maximum Fluid Velocity	The flow meter measures data within the targeted accuracy range for fluid velocities up to 1 m/s.
Conductivity	The flow meter is calibrated to match the electrical conductivity of blood, which varies from 60-80 Siemens per centimeter.
Size	The inner diameter of the flow probe must be 22 mm.
Display Precision	The Display shows fluid flow rates of ±315 mL/s.

2.1.1 Measurement Accuracy

This flow meter is used in applications where measurement accuracy takes precedence over all other constraints. The flow meter is designed so measurements taken from 0.1-1 m/s are within 1 cm/s of the actual values. Therefore, the maximum deviations between the actual and measured fluid velocities at 0.1 m/s and 1 m/s are approximately 10 percent and 1 percent, respectively. Lower fluid velocities are more difficult to measure since the induced voltage is smaller and more susceptible to noise and interference. The accuracy is also affected by stray magnetic fields, turbulent fluid flow, non-homogenous fluid, non-uniform magnetic field, voltage loss through the pipe, etc. However, most of the error is eliminated through calibration by accounting for the voltage drift and other effects caused by most of the problems listed above.

2.1.2 Maximum Fluid Velocity

The maximum fluid velocity of the flow meter is based on the maximum fluid velocity through a cow's aorta. Based on measurements taken from 30 cow specimens, the ascending aorta has a maximum fluid velocity of 89 ± 8.5 cm/s during contraction of the heart and 36 ± 6.0 cm/s between contractions [1]. Since the flow meter must measure the fastest fluid velocity but still accurately record low fluid velocity, the flow meter will be calibrated to measure a maximum fluid velocity of 1 m/s.

2.1.3 Conductivity

The conductivity range of the flow meter is designed to handle the conductivity of blood, which is typically 70 Siemens per centimeter [2]. However, the flow meter handles a broader range of conductivities, 60-80 Siemens per centimeter, since the blood's conductivity varies in different parts of the body.

2.1.4 Size

The flow meter probe must securely fit around a cow's aorta, but the size of the different specimens' aortas varies from 21 mm to 35 mm [3]. The diameter of the aorta also decreases along its path, which means even a 35 mm aorta eventually reaches a diameter of 21 mm. The sponsor requested the inner diameter of the probe be exactly 22 mm. This allows the probe to fit around the aorta of most cows.

2.1.5 Display Precision

The flow meter must display all of the flow rates seen in its working environment. The cow's aorta has negative velocities as well as positive. During a heart beat, the maximum negative blood velocity is not as great as the positive velocity, so the meter must be capable of displaying negative numbers as well as positive. The flow meter must also account for accidentally placing the probe backwards on the blood vessel. Thus, it is necessary for the meter to be capable of measuring negative fluid flow rates equal in magnitude to the maximum positive flow rates. The maximum magnitude in flow rate is equal to the cross-sectional area of the inner diameter of the tube multiplied by the fluid velocity. Therefore, the flow meter must measure fluid flow rates of ±315 mL/s.

2.2 Practical Design Constraints

The practical design constraints are listed below in Table 2.

Table 2. Practical Design Constraints

Type	Name	Description
Sustainability	Durability	The probe is designed to remain implanted for two to three months.
Manufacturability	Size and Weight	The flow sensor box has dimensions of a typical bench laboratory instrument.
Health and Safety	Safety	The voltage generated by blood flowing through the electromagnetic field must be small enough that it does not harm the host.
Economic	Cost	The flow meter has a purchasing cost of less than $700.
Ethical	Misuse	The flow meter is only designed for use with cow arteries and not for human use.

2.2.1 Sustainability

The research being conducted by the UMC requires the probes remain implanted for two to three months at a time. In order to fulfill this requirement, the probe must be designed to last a minimum of three months. The probe's encasing protects the magnetic core and wire coil. The electrodes, although exposed, come into contact only with the outer wall of the aorta and experience little corrosion. The probe's wire leads are exposed outside of the cow's body. For this reason, they are wrapped in protective material to prevent environmental damage.

2.2.2 Manufacturability

The electromagnetic flow meter consists of a probe and a flow sensor box. The wire leads that connect the probe to the box are two feet in length. The dimensions of the sensor box will reflect the dimensions of a typical bench laboratory instrument.

2.2.3 Health and Safety

Since the probe of the electromagnetic flow meter is designed to be implanted inside a living organism, safety is a major concern. The voltage generated by blood flowing through the probe's magnetic field is small enough that it does not harm internal organs. The probe's design and size ensure that, once implanted, the cow experiences no discomfort.

2.2.4 Economic

The magnetic core, wire coil, and encasing of the probe give it an approximate manufacturing and labor cost of $400. The circuitry and functionality of the flow sensor box give an estimated manufacturing and labor cost of $300. The fully packaged flow meter has a purchasing price of less than $700.

2.2.5 Ethical

The probe is not designed to be used in humans. It is designed specifically for use in cow test subjects. Using the probe for other purposes may prove harmful, or it may lead to equipment failure or malfunction.

References

[1] Braun, U., and vetJosef, F., “Duplex ultrasonography of the common carotid artery and external jugular vein of cows,” *American Journal of Veterinary Research*, vol. 66, no. 6, pp. 962-965, 2005.

[2] Shercliff, J.A., *The Theory of Electromagentic Flow-Measurement*. Cambridge: University Press, 1962, p. 125.

[3] Khan, S. R., and Islam, M. N., “Studies on the prospect of bioprostheses by cow aortic valve for human use,” *Bangladesh Med Res Counc Bull*, vol. 17, no. 2, pp. 75-80, 1991.