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Electromagnetic Blood Flow meter: Review

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Abstract: Currently, there are many widely used methods for measuring blood flow. However, this report focuses on one such technique: electromagnetic blood flow meters (specifically alternating current electromagnetic blood flow meters). It begins by looking in to the brief theoretical overview followed by the explanation of the two most common electromagnetic blood flow meters: sine wave electromagnetic blood flow meters and square wave electromagnetic blood flow meters. After dictating the probe design limitations and possible sources of errors, the paper compares electromagnetic blood flow meters with other methods. It highlights the physiological and medical correlations.It also elucidates the use and application of electromagnetic blood flow meters and finally concludes that, if used properly, electromagnetic blood flow meters are one of the most reliable blood flow measurement techniques.

Keywords:*Blood Flow, Flow measurement, Electromagnetism, Probe design, physiological parameters*.

I. INTRODUCTION

The free medical dictionary defines blood flow as “the movement of blood in the blood vessel” (The Free Medical Dictionary). For many reasons like technical and clinical requirements, measuring (quantification) of blood flow accurately is very difficult. Besides the average velocities of blood flow vary over a wide range in vessels with diameters ranging from 2 centimeters to few millimeters [4].

Blood flow is the continuous running of blood in the cardiovascular system. The blood flow is pulsating in the large arteries, diminishing in amplitude as it approaches the capillaries. In the veins, it is none pulsating. The flow in arteries is the result of ventricular ejection; in the veins, it is a result of a number of factors including respiratory movement, muscle compression and the small residuum of arterial pressure [3, 8].

The laminar blood flow is blood flow through a large blood vessel moves forward in a series of concentric laminae that slide over each other like a telescoping radio aerial [3, 7]. The other type of blood flow is turbulent blood flow, experienced when blood flows through a small caliber orifice, which is the cause of murmurs in the heart and large arteries [2, 3].

The two factors that determine the flow of blood through blood vessels are the pressure gradient (∂P) between two points in the blood vessels and the resistance (R) because of friction; blood flow is measured in litters per minute or milliliters per minute and referred as cardiac output [8].

William Harvey was the first person to estimate the cardiac output in 1628. In 1886, Grehart and Quinquardt [9] measured the cardiac output of dog using Fick’s method, whichstated, “the amount of a substance taken up by an organ is the product of blood flow to the organ and the concentration difference of the substance between the arterial and venous systems”. The concept of electromagnetic flow measurement was the successor of Fick’s method. Fabre was the first person to use the electromagnetic flow meter noninvasively, where as Kolin and Wetterer initially use the same technique for invasive measurement [9].

The operation principle behind the electromagnetic blood flow meters is Faraday’s law of electromagnetic induction, which states that if electrical current carrying conductor moves at right angle through a magnetic field, an electromotive force is induced in the conductor. In the case of electromagnetic blood flow meters, while the blood flows between forces of magnetic field, which are provided by the electromagnetic blood flow meters, voltage is induced in the blood stream. The induced voltage is perpendicular to the magnetic field and the direction of the flow of blood. Then this voltage is picked up by the blood flow transducer probes placed 90 degree to the direction of the blood flow [4, 10, 11].

The magnitude of voltage induced in the blood stream is proportional to the volume and velocity of the blood flow [5] and can be given by the following formula [10]:

$$e = \int_0^L u x B . dL$$

Where e = induced voltage (V), B = strength of the magnetic field (T), **u** = instantaneous velocity of blood (m/s), **L** = length between electrodes (m)

In early models, magnetization in was possible by a direct current or merely using permanent magnets. However, due to high noise vulnerability and polarization of electrodes these models were unsatisfactory [5, 11]. To mitigate the problems experienced by direct current electromagnetic blood flow meters, scholars device another solution i.e. using alternating current as means of magnetic field production. The two most commonly used alternating current electromagnetic blood flow meters are sine wave electromagnetic blood flow meters and square wave electromagnetic blood flow meters.

II. ELECTROMAGNETIC BLOOD FLOW METERS

One of the electromagnetic blood flow meters, the sine wave electromagnetic blood flow meter uses wave alternating current to generate the required magnetic field. The flow voltage (induced voltage) is also sinusoidal. Even if for lower frequency application, the circuit becomes complex and high frequency application results a problem of stray capacitance effect [10], it can be used for a wide range of frequency values.

The main interfering input for the sine wave electromagnetic blood flow meter is the induction of transformer voltage. The blood vessel and the blood that flows through it act as the secondary winding of the electromagnetic circuit, which in turn generates the transformer voltage. Its magnitude is by far larger than the magnitude of the flow voltage and 90^o out of phase.

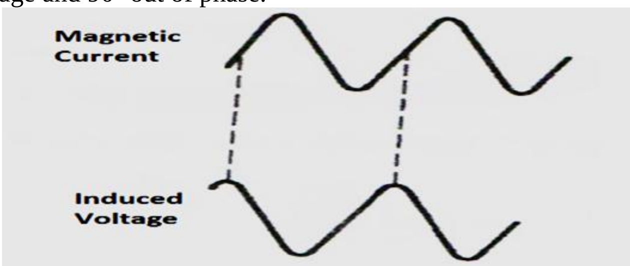

Figure 1: Sine wave form excitation current and error signal induced by the current [2]. (Cromwell, et al., 1973, p. 122).

Different compensation mechanisms are used to eliminate this high amplitude voltage. One of the techniques is injecting equal magnitude voltage with reversed polarity or a signal exactly equal in magnitude but 1800 out of phase with the transformer voltage [4]. The other alternative is using gated sine wave amplifier. Full wave peak detection gated sine wave amplifier samples the flow voltage around a point where the transformer voltage is zero. On the other hand, the full wave phase sensitive peak demodulator samples the induced voltage twice per each cycle at zero transformer voltage and produces the average sample.

As long as the original phase stability criteria is maintained, superior result can be achieved by using automatic quadrature suppression that adjusts the amount of supplied inverted signal automatically based on the magnitude of the transformer voltage. The effect of the inverted signal is to cancel out the transformer voltage so that the final read of the instrument is within the acceptable range [1, 10].

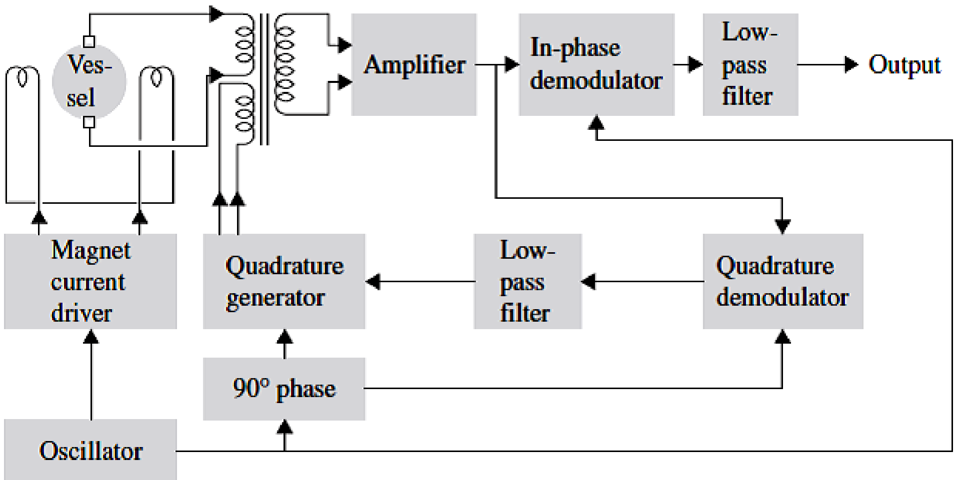

Figure 2: The quadrature-suppression electromagnetic blood flow meter detects the amplifier quadrature voltage. The quadrature generator feeds back a voltage to balance out the probe-generated transformer voltage [10].

Although the sine wave electromagnetic blood flow meter requires a complicated circuit to remove the transformer voltage, with proper design, it results a good signal to noise ratio [4, 10].

In the square wave electromagnetic blood flow meter, the excitation is square wave alternating current, and the induced voltage is square wave too. One advantage of the square wave electromagnetic blood flow meter over the sine wave counterpart is the magnetization process. If the magnetization flux gets its maximum value, it does not need the application of any further potential difference (voltage) until the next transition occurs, which is impossible for sine wave excitation [1].The other interesting point is the width and duration of the transformer voltage. In the square wave electromagnetic blood flow meter, the transformer voltage appears as a spike at the beginning of each transition for a short period of time, which can be easily circumvented by using gated amplifier [4].

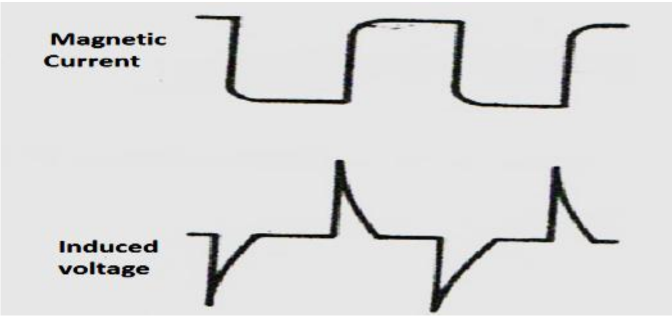

Figure 3: Square wave excitation current and transformer voltage induced by the current [3].

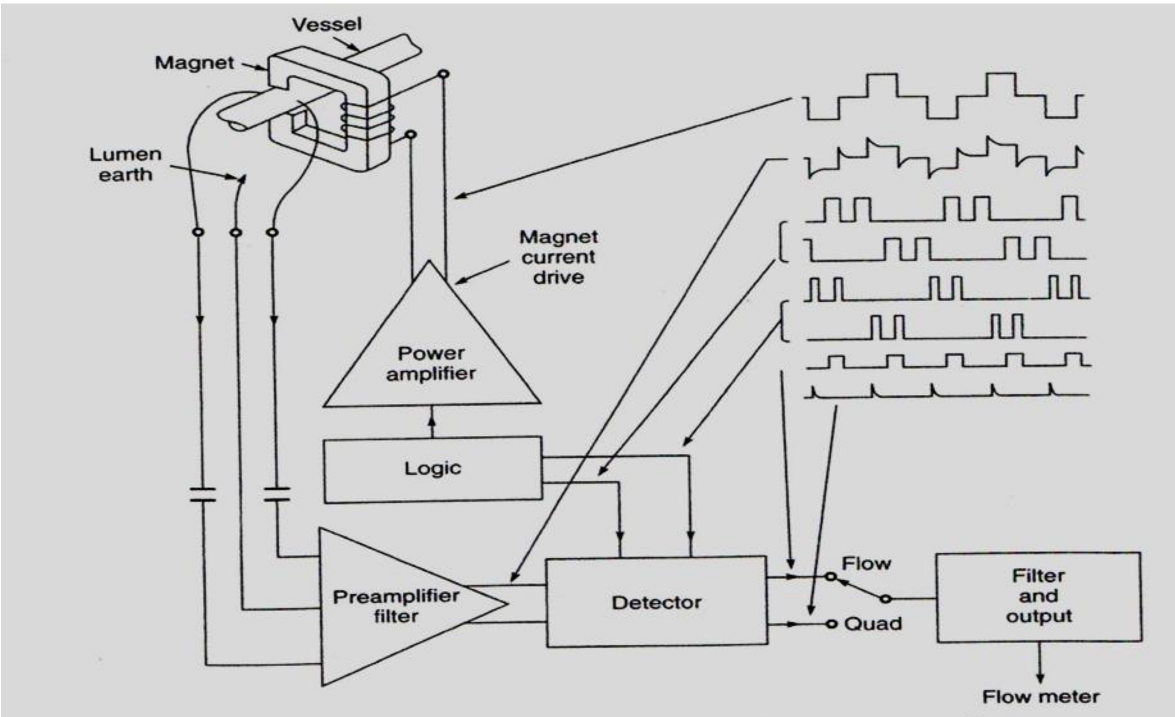

Figure 4: Block diagram of square wave electromagnetic blood flow meter [4].

Though square wave excitation has less stringent phase stability requirements [4] (Khandpur, 2009, p. 329), also it has shortcomings, which arise from the high amplitude (spike) transformer voltage. This high peaked transformer voltage causes different problems on the blood flow meter circuitries. One of the drawbacks is amplifier-overloading [10]. (Webster, 1998, p. 342). Where the amplifier is overloaded, it causes significant voltage change across the coupling and biasing capacitors. This in turn leads to a long time recovery and distortion of the flow signal. To get the correct reading, it requires reduction of the amplifier gain to unity so that there is no amplifier saturation. The transformer voltage also causes polarization potential change between the electrolyte and the electrodes leading to application of special pre-amplifier circuit or bootstrap arrangement [1].

III. PROBE DESIGN LIMITATIONS AND POSSIBLE SOURCES OF ERRORS

The probes consists of electromagnet coil with appropriate electric current to produce the required magnetic field, and two point electrodes which are made up of mainly stainless steel or platinum. To protect the probes from chemical corrosion, they are encapsulated in a biologically inert material like silicone rubber [4].

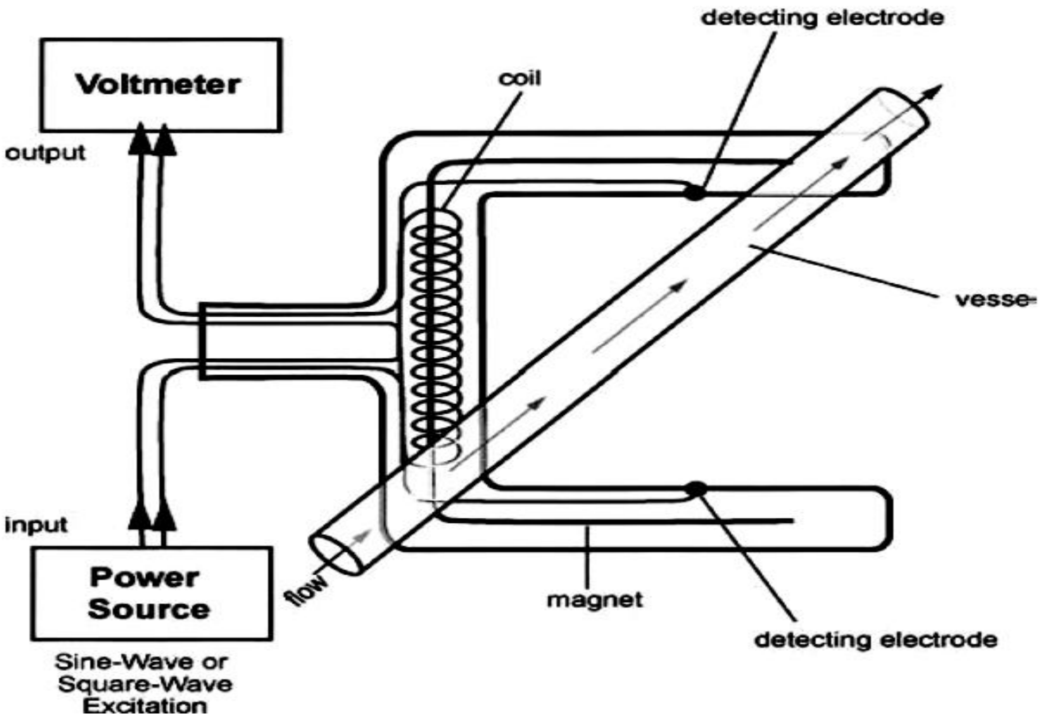

Figure 5: Schematic of electromagnetic blood flow probe consisting of an electromagnet, a coil, and detecting electrodes, as well as input and output systems [9].

In alternating current electromagnetic blood flow meters, design of blood flow transducers is of great importance. It is because accuracy of blood flow measurement is highly dependent on the magnitude of flow voltage (induced voltage). If error occurs at the stage of the transducer, it propagates through the following stages to the final out- put which results false reading. It is also important to design the pickup electrodes in such a way that there are minimum interfering inputs like generation of noise and leakage of the induced voltage [4, 10, 11].

For cuff type flow meters, placement of the cuff may generate error, which is the result of blood vessel wall conductivity and the nature of the intracellular fluid [9]. (Tabrizchi & Iida, 2003, p. 58). None uniformity of the magnetic field causes hysteresis. Assumuption in electromagnetic blood flow meter is that blood flow in circular vessel is dependent only on the distance from the center of the vessel, but if the flow is asymmetric, it may result false read out. The other point worth to mention is the effect of hematocrit (volume percentage of red blood cells in blood) and rate of flow. Increasing the hematocrit or the flow rate decrease the sensitivity of the probe [1, 9, 10].

IV. COMPARISON WITH OTHER BLOOD FLOW METERS

Indicator-dilution method is one of the techniques used to measure blood flow, which can be continuous infusion, dye dilution or thermos-dilution. Unlike the electromagnetic blood flow meter that measures the instantaneous blood flow, indicator-dilution method measures the average flow [10].

Compared to electromagnetic blood flow meters, ultrasonic blood flow meters (Doppler blood flow meters or transient-time flow meters) also measure blood flow profiles [4, 10]. (Khandpur, 2009, p. 331; Webster, 1998, p. 344). In electromagnetic blood flow meters, magnetic field is applied to the blood vessel. On the other sound energy is the source of measurement in ultrasonic blood flow meters. Branching of blood flow from the direction of the applied sound beam introduce significant error especially in Doppler blood flow meters. Additionally the flow disturbance causes dynamicity and none stationary property in the spectrum of Doppler flow meters. This in turn contributes blood flow measurement error in ultrasound blood flow meters [9].

Nuclear magnetic resonance (NMR) blood flow meters are other alternatives to measure flow velocity or flow rate [4] (Khandpur, 2009, pp. 340 - 341). Change of volume can also be measured by Plethysmographs that can be chamber Plethysmographs, electric - impedance Plethysmographs or photo – Plethysmographs [10].

V. MEDICAL AND PHYSIOLOGICAL PARAMETERS

Blood flow is one of the physiological parameters to be measured in cardiovascular system. The proper functioning of our body like metabolism and nutrient exchange is dependent on adequate blood flow throughout the cardiovascular system [8]. (Silverthon, 2007, pp. 458-460). In view of this, it is crucial to quantify the blood movement through blood vessels so that early diagnosis and treatment can be available for circulation related problems like stroke and heart attack [2]. (Cromwell, et al., 1973, pp. 75 - 79).

Generally the blood flow rate which can be measure by the electromagnetic blood flow meter ranges from 1ml/sec to 300ml/sec in aorta or venous. According to Webster (1998, p. 10) the frequency of aortic or venous blood flow varies from dc to 20 Hz where as Khandpur [4], (2009, p. 68) states that the maximum frequency can be extended to 100Hz. Electromagnetic blood can measure a cardiac output of 4l/min to 25l/min with a frequency range of dc to 20 Hz [10]. (Webster, 1998, p. 10). The frequency can also be as high as 60 Hz [4].

VI. BLOOD FLOW MEASURMENT

Blood flow is a time varying quantity and important parameter to be measured. Electromagnetic blood flow meters are one of the methods used to measure blood flow clinically or experimentally. In humans, electromagnetic blood flow meters are used to diagnose pathophysiological conditions and to assess the impact of drug in the cardiovascular system. They are also used study the effect of altered physiological conditions in experimental animals. Electromagnetic blood flow meters are capable of measuring bit-to-bit blood flow. As a benchmark of precise blood flow measurement, electromagnetic blood flow meters are used to calibrate other blood flow meters [9].

Blood flow measurement in electromagnetic blood flow meters can be invasive or noninvasive. Perivascular sensors or intravascular sensors are used for in vivo (internal) measurement to measure regional blood flow [1, 9]. In vitro (external) measurement is possible through surface electrodes [9].

Signal from any cardiovascular parameter requires appropriate signal conditioning [9]. (Tabrizchi & Iida, 2003, p. 55). In view of this, for simplified electromagnetic flow meters, the induced voltage, which is picked up by the point electrodes, is fed to preamplifier for amplification. Then it is forced to pass through a band pass filters to limit the upper and lower frequency ranges. Following the band pass filter there is a detector, which is phase sensitive and used to recover the original signal. The final stage is the low pass filter that is a capacitor – resistor (RC) filter used to remove the high frequency components of the output signal is then fed to display unit [4].

VII. CONCLUSION

To sum up, there is no doubt that physicians need to measure the blood flow to acquire quantitative blood flow and blood velocity data from patients. The two most commonly used electromagnetic blood flow meters are: sine wave electromagnetic blood flow meters and square wave electromagnetic blood flow meters. It can be clearly seen that, the major setback, which results circuit complexity in alternating current electromagnetic blood flow meters, is the induced transformer voltage. In the square wave electromagnetic blood flow meters, the transformer voltage can be avoided easily. In contrast, the sine wave electromagnetic blood flow meters can be optimally designed to give a good signal to noise ratio.

Electromagnetic blood flow meters can measure blood flow at any given time invasively or noninvasively. They are used clinically to diagnose flow related problems and experimentally to study blood flow profile. For proper usage, electromagnetic blood flow meters are one of the most accurate blood flow measurement techniques. Finally, calibration of other blood flow measuring instruments can be done using electromagnetic blood flow meters as a benchmark.

REFERENCES

[1]. Cobbold, R. (1974). *Transducers for biomedical measurements: principle and applications*. Toronto: a Wiley – International Publication.

[2]. Cromwell, L., Weibell, F., Pfeiffer, E., & Usselman, L. (1973). *Biomedical instrumentation and measurements*. Englewood Cliffs: Prentice – Hall Inc.

[3]. The Free Medical Dictionary. Retrieved March 20, 2012, from <http://medical-dictionary.thefreedictionary.com/blood+flow>.

[4]. Khandpur, R. (2009). Hand book of biomedical instrumentation. New Delhi: Tata McGraw-Hill Publishing Company Limited.

[5]. Kolin, A. (1959). Electromagnetic blood flow meters: implantable flow transducers facilitate circulatory studies in conscious and free-moving animals. *Science, 130*.

[6]. Kolin, A., & Kado, R. (1959). Miniaturization of the electromagnetic blood flow meter and its use for the recording of circulatory responses of conscious animals to sensory stimuli. *Proceedings of the National Academy of Sciences of the United States of America, 45*.

[7]. Schmid-Schonbein, H. H., Grunau, G., & Brauer, H. *The flow behavior of blood* (Vol. 2). Frankfurt: Hoechst.

[8]. Silverthon, D. U. (2007). *Human physiology: an integrated approch* (4 ed.). San Francisco Pearson Education, Inc.

[9]. Tabrizchi, R., & Iida, N. (2003). Electromagnetic blood flow measurements. In J. Moore & G. Zouridakis (Eds.), Biomedical technology and devices handbook. New York, London: CRC Press LLC. Retrieved from <http://www.crcnetbase.com/doi/abs/10.1201/9780203491492.ch3>. doi: 10.1201/9780203491492

[10]. Webster, J. G. (Ed.). (1998). *Medical instrumentation: application and design* (3 ed.). New York: John Wiley & sons, Inc.

[11]. Woodcock, J. (1975). *Theory and practice of blood flow measurement*. London: Butterworth & Co (Publishers) Ltd.