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Equivalent Electrical & Mechanical Networks of Human Body

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Abstract. Using the model, we explain a basic principle of electric-field communication that uses the human body. Although it is well known that electricity easily passes through the human body. In this we have given equivalent mechanical & electrical networks (Models) of human body. For this purpose we have used Force current (F-I) analogy & Force Voltage (F-V) analogy. In this paper we examine the physical justification for these analogies to improve mutual understanding. A simple way to relate analogies to common physical intuition is proposed. The 'mass-inductor' (F-V) analogy reflects a real-world distinction between equilibrium energy-storage phenomena and steady-state energy-storage phenomena. After comparison between these two analogies. We conclude that electrical network theory (from which the force-current analogy is derived) is an inappropriate basis for a general representation of physical system.

Keywords: Physical systems, Force current (F-I) analogy, Force Voltage (F-V) analogy, electric-field communication.

1. Introduction

The human body can be regarded as a conductor covered by skin, clothing, shoes, and other insulators. Researchers using bond graphs to communicate their models frequently encounter resistance and in comprehension due to an unresolved explanation about the most appropriate analogy between electrical circuits and mechanical systems i.e., the force-voltage analogy vs. the force-current analogy. The force current analogy requires equations of steady-state energy storage phenomena while the constitutive equations of equilibrium force voltage analogy (energy storage phenomena) do not. In this way, the mass inductor (force voltage analogy) analogy is more consistent with fundamental physics than the mass-capacitor analogy. All introductory bond graph literature uses the force-voltage analogy, thereby erecting a barrier for researchers more familiar with the force-current analogy. In this paper we examine the physical justification for these analogies to improve mutual understanding. More specifically, when modelling physical system dynamic behaviour in multiple domains (e.g., mechanical, electrical, fluid, etc.) it is important to establish a rational basis for analogies between the corresponding variables and phenomena. However, the most appropriate analogy between electrical circuits and mechanical remains unresolved, a matter of open explanation. This paper will attempt to explore the physical basis for analogies that are in common use.

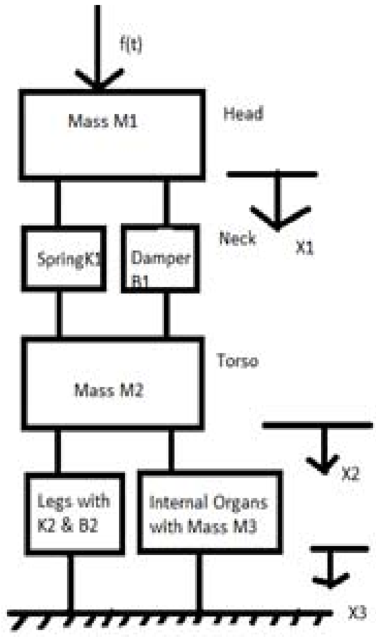


Fig.1: Body structure of Human being

2. Importance of Equivalent Networks

Different currents and voltage have different effect to human being. Generally the current is what determines the danger to human. The used voltage with some other things (for example skin resistance) generally determines what is dangerous and what not. It is often helpful to consider our models of the physical world as describing systems of particles distributed in space. The particles may have properties such as mass, charge, motion, etc., though in a given context we will deliberately choose to neglect most of those properties so that we may concentrate on a single physical phenomenon of interest. Thus to describe electrical capacitance we consider only charge while to describe translational inertia we consider only mass and so forth. From this perspective, all quantities based on the motion of particles may be considered as analogous to one another; thus velocity, current. It is interesting to note that it has only been that heating tissue for control of cancer has become widely used in clinics, hospitals, and cancer research centers. Yet, the first use of electric-field heating for control of cancer occurred in 1800. This application' of electric current for destroying cancer through heat was demonstrated by Recamier and Pravaz in the destruction of uterine cancer.

3. Effects of 50 Hz Electric and Magnetic Fields on Health

Generally the AC voltage in 40-50 Hz is very dangerous to human. A current that is less that 10 mA is not dangerous to most people. Alternating current (AC) in range of 70-110 mA and direct current (DC) in the range of 200-250 mA is considered to be very dangerous and lethal if it goes through the chest (where the heart is). In the following pages, we will analyse risks associated with our "Electricity" fairy, especially the potential effects of exposure to 50 Hz electric and magnetic fields. Well known effects depend on the local intensity of the induced current in every tissue. It explains why the reference unit is the induced current density expressed in a thousandth ampere per square meter (mA/m^2). 50 Hz electric fields do not penetrate the human body, but rather cause the migration of electric charges (ions) towards the surface of the body. This charge displacement generates a current that circulates from the body surface towards the ground. 50 Hz magnetic fields do penetrate the human body and induce electromotive forces that generate currents called "Eddy currents". These currents form closed loops perpendicular to the direction of the magnetic field. As regards to health effects, here are presented current density values relevant to known effects:

- Between 1 and 10 mA/m^2 : no known effect on health
- Between 10 and 60 mA/m^2 : well established effects are observed including visual (flashes of light, called magnetophosphenes) and nervous system effects.

- Between 100 and 1000 mA/m^2 : a stimulation of excitable tissue is observed, and there are possible health hazards

Above 1000 mA/m^2: one observes problems of extra systoles and ventricular fibrillation, i.e., acute hazards to the health.

From 100 mA/m^2, current induced by fields exposure are higher than endogenous currents and involve an electric stimulation of excitable tissues, as for example a cardiac muscle.

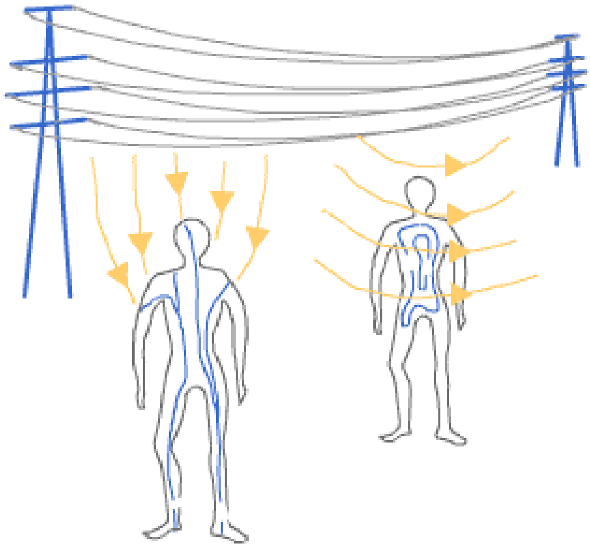


Fig.2: Effect of 50 Hz Fields on health.

3.1. Examples of measurement of these natural currents

Electricity produced by brain neurons is recorded with electrodes placed on the scalp. An electroencephalogram is the trace of electric activity of the brain.

Fig.3: Subjects during EEG (Left) &ECG (Right)

The heart is a muscle which, just like every muscle, emits a certain amount of electricity when it is working. The electricity emitted can be recorded with the help of electrodes. An electrocardiogram is the trace of electric activity of the heart.

An induced current higher than 100 mA/m^2 can lead to a stimulation of nervous and cardiac tissues. To assure the well-being for people, recommendations incorporate safety factor regarding the induced current density of 100 mA/m^2.

4. Theoretical modelling

Reconstitution of electrical properties of the human body on computers. From this model, computers calculate with precision the distribution of currents induced by an external field and other electrical parameters.

Fig.4: Reconstitution of electrical properties of the human body on computer

5. Equivalent Mechanical Network

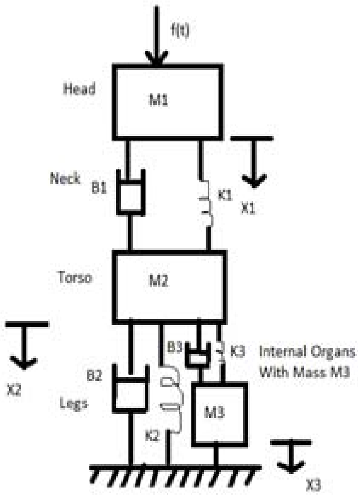


Fig.5: Mechanical Network of Human being

Equilibrium Equation at Mass M_1

$$f(t) = M_1 \frac{d^2 x_1}{dt^2} + B_1 \frac{d(x_1 - x_2)}{dt} + K_1(x_1 - x_2) \quad (1)$$

Equilibrium Equation at Mass M_2

$$\frac{B_2\, dx_2}{dt} + K_2 x_2 + \frac{M_2 d^2 x_2}{dt^2} + B_3 \frac{d(x_2 - x_3)}{dt} + K_3(x_2 - x_3) + \frac{B_1 d(x_2 - x_1)}{dt} + K_1(x_2 - x_1) = 0 \quad (2)$$

Equilibrium Equation at Mass M_3

$$\frac{M_3 d^2 x_3}{dt^2} + \frac{B_3 d(x_3 - x_2)}{dt} + K_3(x_3 - x_2) = 0 \quad (3)$$

5.1. Modeling Using Force Voltage Analogy (Kirchhoff's Voltage Law)

Modeling using force voltage analogy gives the Kirchhoff's Voltage circuit means satisfies the Kirchhoff's Voltage Law equations. The constitutive equations of steady-state energy storage phenomena require an inertial reference frame while the constitutive equations of equilibrium energy storage phenomena do not. In this way, the mass inductor analogy is more consistent with fundamental physics than the mass-capacitor analogy. The considerations of the analogy are given below-

$$f(t)=V \quad (4)$$

$$B=R \quad (5)$$

$$M=L \quad (6)$$

$$K=1/C \quad (7)$$

$$X=q \quad (8)$$

$$i = \frac{dq}{dt} \tag{9}$$

After putting the values from above equations into equations (1), (2), (3)

$$V = L_1\frac{dI_1}{dt} + R_1(I_1 - I_2) + \frac{1}{C_1}\int (I_1 - I_2)dt \tag{10}$$

$$R_1(I_2 - I_1) + \frac{1}{C_1}\int (I_2 - I_1)dt + R_2 I_2 + \frac{1}{C_2}\int I_2 dt + L_2\frac{dI_2}{dt} + R_3(I_2 - I_3) + \frac{1}{C_3}\int (I_2 - I_3)dt = 0 \tag{11}$$

$$L_3\frac{dI_3}{dt} + R_3(I_3 - I_2) + \frac{1}{C_3}\int (I_3 - I_2)dt = 0 \tag{12}$$

5.2. Modeling Using Force Current Analogy (Kirchhoff's Current Law)

Modeling using force current analogy gives the Kirchhoff's Current circuit means satisfies the Kirchhoff's Current Law equations. Assigning force as analogous to current implies that an elemental mass is analogous to an elemental capacitor. This 'mass-capacitor' analogy has a venerable history. To our knowledge, it was first introduced by Firestone in 1933(Firestone, 1933). It was initially motivated by the problem of building equivalent electrical network models with dynamic behavior analogous to mechanical systems, which at that time may have had considerably more practical importance than it has today. The 'force-is-like-current' classification may be justified physically by reference to measurement procedures: both velocity and voltage are classified as 'across' variables because they may be measured as differences between values at two points (i.e., across two points); force and current are classified as 'through' variables that may be measured by a sensor in the path of power transmission between two points. The considerations of the analogy are given below-

$f(t)=I$ (13)

$B=1/R$ (14)

$M=C$ (15)

$K=1/L$ (16)

$X=\phi$ (17)

$$V = \frac{d\phi}{dt} \tag{18}$$

$$I = C_1\frac{dV_1}{dt} + \frac{V_1 - V_2}{R_1} + \frac{1}{L_1}\int (V_1 - V_2)dt \tag{19}$$

$$\frac{V_2}{R_2} + \frac{1}{L_2}\int V_2 dt + \frac{C_2 dV_2}{dt} + \frac{V_2 - V_3}{R_3} + \frac{1}{L_3}\int (V_2 - V_3)dt + (V_2 - V_1)/R_1 + \frac{1}{L_1}\int (V_2 - V_1)dt = 0 \tag{20}$$

$$C_3\frac{dV_3}{dt} + \frac{(V_3 - V_2)}{R_3} + \frac{1}{L_3}\int (V_3 - V_2)dt = 0 \tag{21}$$

6. Equivalent Electrical Network

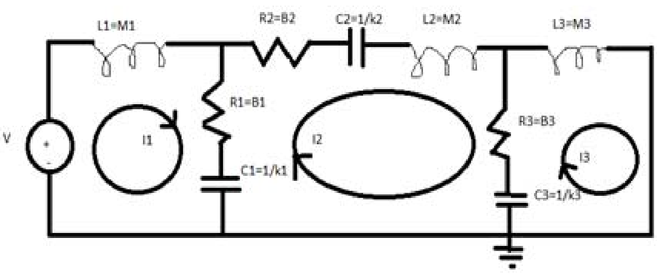
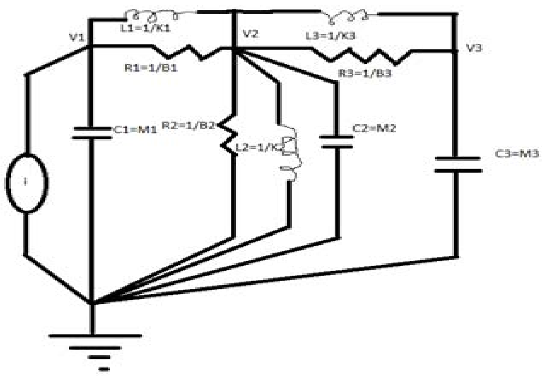


Fig.6: Electrical Network of Human being using
(a) Force-Voltage Analogy



(b) Force-Current Analogy

Electricity kills a great many people worldwide every year. A current of 50mA (barely enough to make a low wattage lamp even glow) is sufficient to send your heart into a state called "ventricular fibrillation", where the heart muscles are all working out of synchronisation with each other. Little or no blood is pumped, and you will die within about 3 minutes unless help is immediately at hand. To avoid this kind of things to happen, the electrical installations and devices should be built in such way that people don't come in touch with the dangerous voltages. Different safety measures and standard exist for this. Insulation and grounding are two recognized means of preventing injury during electrical equipment operation. Conductor insulation may be provided by placing nonconductive material such as plastic around the conductor. Grounding may be achieved through the use of a direct connection to a known ground such as a metal cold water pipe.

7. Conclusion

This paper provides some important considerations in the choice of analogies between variables in different domains of physical system dynamic behavior. Obviously, we feel that the ‘mass-inductor’ analogy is significantly superior though we do not doubt that proponents of the ‘mass-capacitor’ analogy could mount opposing arguments that we have not considered.

8. References

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