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Electric Currents and Modulation

FATIH CETISLI

Electric Currents

There are two opposite electric charges, namely "positive and negative charges". An atom is neutral if the number of positively charged protons and negatively charged electrons are equal. The amount of positive or negative charge that a substance carries due to the unequal number of protons and electrons is called "electric charge" (Coulomb).[1]

If there is a difference in electric charge at two points on a conductive object, the substance tries to go to the neutral state by displacing electrons from the point where the negative electric charge is high to the point where the positive electric charge is higher, which causes the force to be replaced by the electromotive force or electrical potential difference (Electromotive Force) [voltage (Volt-V)]. The number of electrons displaced due to the potential difference differs with the conductivity of the object, and the number of electrons displaced in one second is defined as the current amplitude [Ampere (Amp)], while the resistance to the force that makes it difficult for the electrons to move is defined as resistance (Ohm). The resistance and conductivity are inversely proportional, as the resistance increases, the conductivity decreases.

While the positively charged protons do not have the ability to move due to their high mass and due to their sticking to each other, the negative charge electrons have the ability to move freely and displace, and the electric current, which is also known as electron current, manifests itself with some effects. It is possible to summarize these effects as electrolytic, magnetic and heat that arises depending on the resistance of the conductive medium through which it passes.[2]

Substances such as rubber are defined as non-conductive objects because of the impossibility of the displacement of electrons in these materials. It is possible for conductive objects to be solid, liquid, or gaseous. In liquid conductors, electrolytes that are called anions with negative charges and cations with positive charges conduct current. The formation of anions and cations is provided by water-soluble salts, bases, and acids. Fluids in the human body appear to be good conductors because they contain acids, bases, and salts.[1]

The direction of the electric current may remain constant or change periodically. In "Direct current", which is also called "Monophasic or Galvanic current" in the literature, the direction of the current is fixed. The current that does not change direction for more than one second is physiologically accepted as Direct current.

If the direction of the electric current changes regularly, the current is defined as "Alternating current", and there are also "Biphasic or Faradic current" characterizations in the literature (Figure 1). In Alternating current, after the current amplitude rises from zero point to the highest positive value, it decreases to zero value again, then reaches the largest negative value and returns to zero value again. The time elapsed in this process is defined as a period, and the number of repetitions

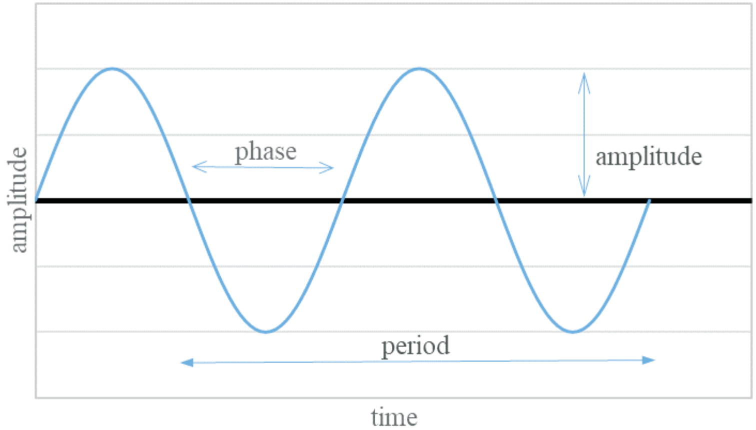

Figure 1 Characteristics of alternating current.

in 1 s is defined as frequency (Hertz-Hz) (Figure 2). The process of reaching the peak value from the zero point and returning to the zero value is called as "phase". Therefore, within a period of time, the current consists of two opposite phases and is biphasic (Figure 3). If these phases, which can be sine waves, triangles, and rectangulars, have the same shape in opposite directions, it is possible to talk about symmetrical alternating current (Figure 4). If the amplitude, frequency, or both characteristics of the alternating currents are different, a phase difference occurs between the two currents.[3]

Considering the clinical or electrophysiological effects, it is possible to talk about three types of currents.

High Frequency Currents: Currents with a frequency of more than $1x10^6$ Hz are defined as High Frequency Currents and the current sense is not perceived in such currents. In this type of current, the effect of heat and vibration comes to the fore.

Medium Frequency Current: This is the type of current that is between $1x10^3$ and $1x10^6$ Hz, but frequencies between $4x10^3$ and $20x10^3$ Hz are widely used. Most notably, Interferential currents can be given as an example of such currents. An asynchronous action potential is obtained with the impulse of the electrical stimulus.

Low Frequency Current: This is the type of current that is between 1 and $1x10^3$ Hz, but frequencies between 1 and 200 Hz are commonly used. Most notably, Faradic, Exponential, Diadynamic, and Transcutaneous Nerve Stimulation (TENS) currents are examples of such currents. In this type of current, which is also called "Excitatory or Im-

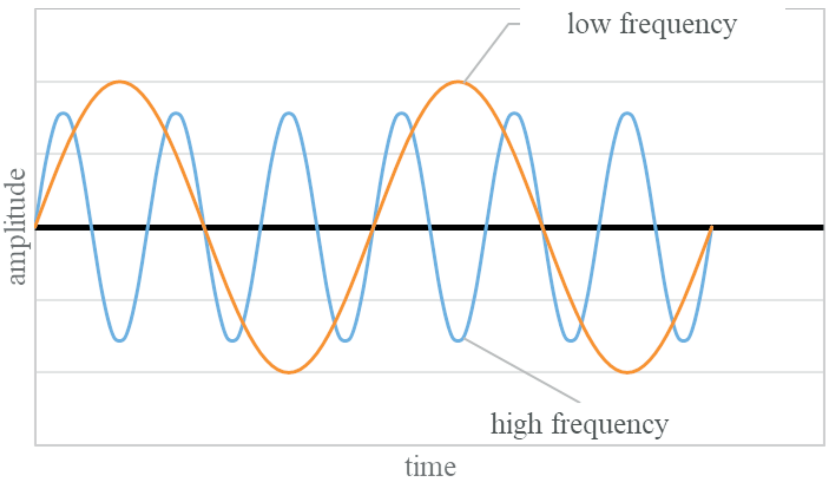

Figure 2 Effect of frequency on alternating current / sinusoidal.

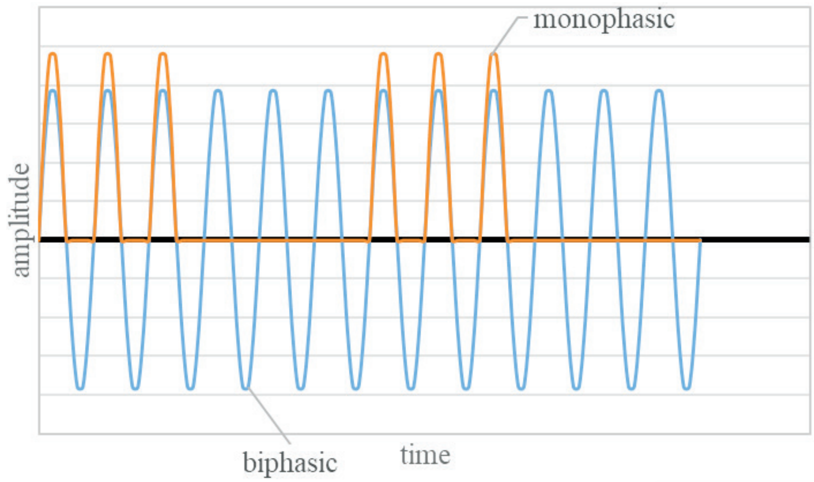

Figure 3 Biphasic and monophasic currents.

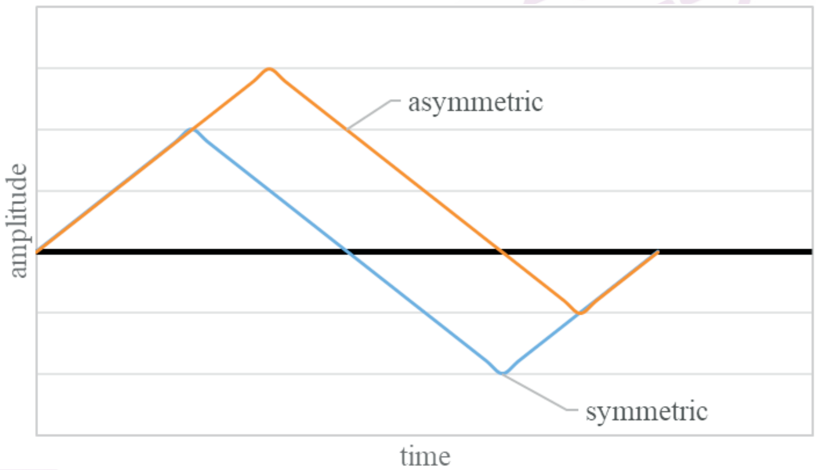

Figure 4 Effect of symmetry on alternating current / triangular.

pulse Currents", synchronous action potential is obtained with the impulse of the electrical stimulus.

Modulation

The clinician modulates the current to obtain the weakest current that can stimulate the tissue in the shortest time in order to increase the physiological efficiency. During the modulation of the current, it is possible to prevent the development of accommodation, which reduces the efficiency with polarization, which has side effects. Modulation is achieved by changing the pulse duration, shape, frequency, and direction of the current through the tissue.[4]

It is possible to talk about three types of modulation in Direct current.

Intermittent Direct Current: The direction of the applied current remains constant for not less than 1 second (s), and the current is interrupted at regular intervals (usually 50-60 s). Denervated Muscle Stimulation is the most common use of intermittent Galvanic current.

Reversed Direct Current: It is a type of modulation in which the current changes direction continuously, as in alternating current, with the duration of each phase more than 1 s.

Surrounded Direct Current: It is similar to the intermittent Galvanic current, but differently, the current amplitude is increased from 0 to the peak value in a few seconds, not less than 0.5 s. Monophasic or biphasic application can be performed as well as sudden or slow reduction of the current from its peak value to zero.

In the modulation of the Alternating current, changes are made in the duration and amplitude of the current. There is no known physiological or clinical superiority of modulation processes over each other according to duration or amplitude.

Explosive (Burst) Type Modulation: The passage of alternating current is interrupted for a few milliseconds and lasts for a few milliseconds during the periods when the current passes. The alternating current modulation obtained in this way is also known as "Russian Current".

Intermittent Alternating Current: It is a modulation type where the interruption lasts longer than 1 s and the current lasts for a few seconds. The most obvious difference from the explosive type of modulation is that it provides sufficient resting time for muscle relaxation after muscle contraction.

Amplitude Modulation: It is obtained by simultaneously giving two alternating currents with different frequencies to the tissue. In this way, two different currents are combined with each other to create a single current effect. It is also known as Interferential current.

Pulsed Currents

In clinical applications, when current direction is taken into account, the use of Direct or Alternating current, and when frequency is considered, the use of modulations of high, medium or low frequency currents has come to the fore rather than the use of plain ones. The concept of pulsed current has been defined because modulations have led to the emergence of new parameters in the definition of currents and subsequently to terminological confusion.[5] It is also possible to define pulsed current as the electrical current transmitted in the form of short-term signals. Current ramp-up time, pulse duration, and pulse frequency are the parameters that determine the characteristics of these currents.

- Current Ramp-up Time: The time for the pulse amplitude to rise from zero to the peak value.
- Pulse Duration: The time during which the minimum electrical energy required to stimulate the nerve is obtained, equal to the chronaxie of the nerve to be stimulated [between a few microseconds (µs) and a few ms).
- Interpulse time: 10-999 ms
- Pulse frequency: The numbers of beats per 1 s [pulse per second (pps) or Hz]

The muscle contraction with the electrical stimulation occurs when the current amplitude increases or decreases. Therefore, the current rise time should be shorter than 60 µs in order to prevent the development of accommodation. There is no difference between triangular and rectangular currents for impulse durations shorter than 10 ms, and the motor effect comes to the fore when the impulse duration is shorter than 1 ms. Accommodation in muscle fibers develops more slowly than in nerve fibers.

Sensory stimuli such as stinging, burning and tingling occur during the beat period, where the amplitude remains constant. These effects become more pronounced when the amplitude remains constant for more than 20 ms. The phase duration should be less than 200 s in order to reduce or eliminate the sensory effects because it can become painful.

In order for the stimulated tissues to rest, the interval between beats should be kept long in a way that does not cause a continuous stimulation.

The pulse frequency can be changed between 1 and 100 Hz (low frequency stimulation) in the stimulators used today. Safe and comfortable stimulation can be performed because the total amount of current passing to the tissue in 1 s is low.

Pulsating currents can be monophasic or biphasic, with pulsed phases in square/rectengular, triangular, or sinusoidal forms. However, it is possible for biphasic pulsed currents to be symmetrical or asymmetrical. Biphasic symmetrical pulsed currents are important because they do not create polarization in the tissue under the electrode and are preferred to asymmetrical pulsed currents. In this context, Faradic current is a type of asymmetric biphasic pulsed current. The Neo Faradic current, which has replaced the Faradic current, is a monophasic pulsed current type.

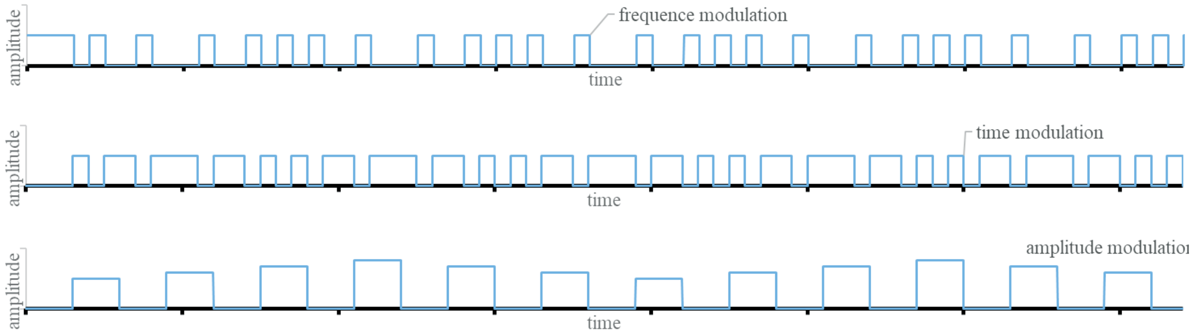

Figure 5 Types of modulation in pulsed current / rectangular.

Modulation in Pulsed Currents

A very short current ramp-up time is used to prevent accommodation, and a rectangular phase shape is used to achieve optimal effect with the smallest electric current amplitude. The ideal pulse duration is determined to be equal to the chronaxie of the nerve to be stimulated, and biphasic current is applied to eliminate the polarization effect. Symmetrical biphasic pulsating currents are more effective than asymmetric biphasic pulsating currents in motor nerve stimulation. In this context, modulations such as pulse and current are implemented (Figure 5).[1]

Pulse Modulation: Delaying accommodation is the main goal. The duration, amplitude, or frequency of the pulsating current automatically increases and then decreases.

Current Modulation: The current phase as a whole is modulated, not just the duration, amplitude, or frequency of the current. Three different types of modulation can be performed as intermittent type, explosive (package) type, and ramp type.

Intermittent Type: A few seconds of rest period followed by a current that lasts for a few seconds.

Impulsive (Package) Type: A different application of pulsed current in which the current transition and subsequent rest times are a few milliseconds.

Ramp Type: Unlike the intermittent pulsed current, the current amplitude is gradually increased (1-5 s) and gradually decreased. There is a rest period of a few seconds as in pulsed current.

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