Physiotherapy and Electrotherapy Equipment

29. Physiotherapy and Electrotherapy Equipment

29.1. HIGH FREQUENCY HEAT THERAPY

Physical stimulus commonly employed in the practice of physiotherapy is in the form of heat, either by simple heat radiation or by the application of high frequency energy obtained from special generators. The use of high frequency energy in thermotherapy has the advantage of considerable penetration as compared with 'simple' heat application. Thus, with high frequency energy, deeper lying tissues, e.g. muscles, bones, internal organs, etc. can be provided heat.

High frequency energy for heating is obtained by various ways. It may be from the short-wave therapy unit making use of either the condenser field or the inductor field method. Microwaves and ultrasonic waves are also used for heating purposes in special cases.

29.2. SHORT-WAVE DIATHERMY MACHINE

The term 'diathermy' means 'through heating' or producing deep heating directly in the tissues of the body. Externally applied sources of heat like hot towels, infrared lamps and electric heating pads often produce discomfort and skin burns long before adequate heat has penetrated to the deeper tissues. But with the diathermy technique, the subject's body becomes a part of the electrical circuit and the heat is produced within the body and not transferred through the skin (Yang and Wang, 1979).

Another advantage of diathermy is that the treatment can be controlled precisely. Careful placement of the electrodes permits localization of the heat to the region that has to be treated. The amount of heat can be closely adjusted by means of circuit parameters. The heating of the tissues is carried out by high frequency alternating current which generally has a frequency of 27.12 MHz and a wavelength of 11 m. Currents of such high frequencies do not stimulate motor or sensory nerves, nor do they produce any muscle contraction. Thus, when such a current is passed through the body, no discomfort is caused to the subject. The current being alternating, it is possible to pass through the tissues currents of a much greater intensity to produce direct heating in the tissues similar to any other electrical conductor.

The method consists in applying the output of a radio frequency (RF) oscillator to a pair of electrodes which are positioned on the body over the region to be treated. The RF energy heats the tissues and promotes healing of injured tissues and inflammations.

Circuit Description: The short wave diathermy machine consists of two main circuits: an oscillating circuit, which produces a high frequency current and a patient circuit, which is connected to the oscillating circuit and through which the electrical energy is transferred to the patient.

Earlier models of diathermy machines employed single-ended or push-pull power oscillators operating from unfiltered or partially filtered power supplies. They usually made use of a valve circuit, a typical example of which is shown in Fig. 29.1. Transformer T_1, the primary of which can be energized from the mains supply, is a step-up transformer for providing EHT for the anode of the triode valve. A second winding can provide heating current for the cathode of the triode valve. The tank (resonance) circuit is formed by the coil AB in parallel with the condenser C_1. The positive feedback is generated by coil CD. There is another coil EF and a variable condenser C_2 which form the patient's resonator circuit due to its coupling with the oscillator coil AB.

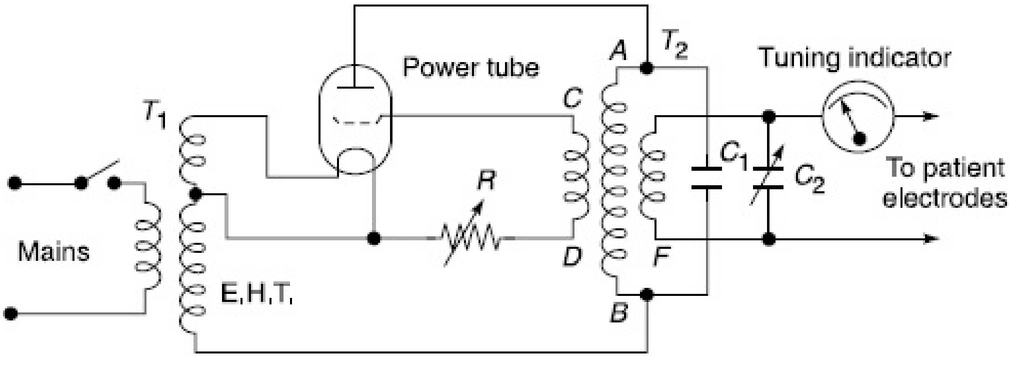


Figure 29.1. Simplified circuit diagram of a short wave diathermy unit

The anode supply of such a circuit is around 4000 V. The conduction in the triode takes place during the positive half-cycle and the high frequency is generated only during this period. More usually, the supply voltage is rectified before supplying to the anode of the oscillator valve. In such a case, the oscillations produced are continuous and more power thus becomes available. In order to ensure that the oscillator circuit and the patient's resonator circuit are tuned with each other, an ammeter is placed in series with the circuit. The variable condenser C_2 is adjusted to achieve a maximum reading on the meter, the needle swinging back on either side of the tuned position. The maximum power delivered by these machines is 500 W.

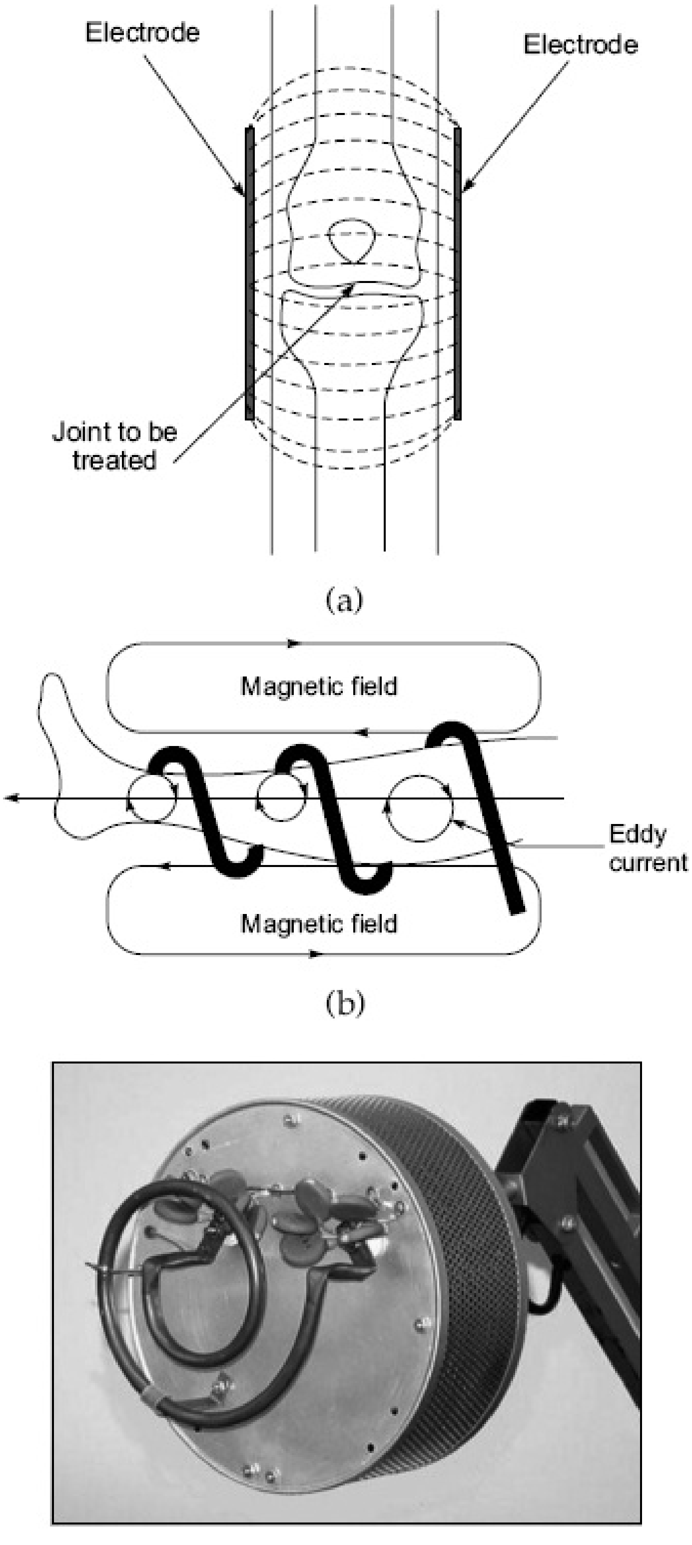
A thermal delay is normally incorporated in the anode supply which prevents the passage of current through this circuit until the filament of the valve attains adequate temperature. The patient circuit is then switched on followed by a steady increase of current through the patient. A mains filter is incorporated in the primary circuit to suppress interference produced by the diathermy unit itself.

There are several ways of regulating the intensity of current supplied to the patient from a short-wave diathermy machine. This can be done by either (i) controlling the anode voltage, or (ii) controlling the filament heating current, or (iii) adjusting the grid bias by change of grid leak resistanceR1, or (iv) adjusting the position of the resonator coil with respect to the oscillator coil. However, the best way of finely regulating the current is by adjusting the grid bias, by putting a variable resistance as the grid leak resistance.

Automatic Tuning in Short-wave Diathermy Machines: Any short-wave therapy unit would give out the desired energy to the patient only if and as long as, the unit is correctly tuned to the electrical values of the object (part of the body). Therefore, tuning must be carefully carried out at the beginning of the treatment and continuously monitored during the treatment. There is a possibility of the tuning getting affected due to unavoidable but involuntary movements of the patients and the resultant fall of dosage.

In order to overcome the problem of making tuning adjustments during the course of treatment, an additional circuit is fitted in the machine. The RF current in the patient circuit changes a capacitor to a voltage, whose polarity and magnitude is a measure of the detuning of the patient circuit. This voltage accordingly moves a servo-motor, adjusting the tuning capacitor so that resonance is restored.

Application Techniques of Short-wave Therapy: The pattern of tissue heating is greatly affected by the method of short-wave diathermy delivery. The two most common forms of application include the capacitor plate method and the inductive method (Fig. 29.2).



(a)

(b)

(c)

Figure 29.2. Methods of applying electrodes in shortwave diathermy treatment (a) condenser method (b) inductive method (c) Inductive heating by a coil housed in a drum.

In the capacitor plate method, the output of the short-wave diathermy machine is connected to metal electrodes which are positioned on the body over the region to be treated (Fig. 29.3). These electrodes are called 'PADS' in the terminology of the diathermy. These pads or electrodes do not directly come into contact with the skin. Usually layers of towels are interposed between the metal and the surface of the body. The pads are placed so that the portion of the body to be treated is sandwiched between them. This arrangement is called the 'Condenser Method' [Fig. 29.2(a)] wherein the metal pads act as two plates while the body tissues between the pads as 'dielectric' of the capacitor. When the radio frequency output is applied to the pads, the dielectric losses of the capacitor manifest themselves as heat in the intervening tissues. The dielectric losses may be due to vibration of ions and rotation of dipoles in the tissue fluids (electrolytes) and molecular distortion in tissues which are virtually insulators like fats.

Figure 29.3. Shortwave diathermy (with capacitive electrodes) in use (`http://www.holistichealthpc.com/services/procedures/`)

There are two types of electrode arrangements for condenser method. In the *Contraplanar technique* , the electrodes are placed over the opposite aspects of the trunk or limb, so that the electric field is directed through the deep tissues. On the other hand, in the coplanar technique, the electrodes are placed side by side on the same aspect of the part, provided there is an adequate distance between them. Fig. 29.3 shows a shortwave diathermy in use with coplanar electrodes.

Alternatively, the output of the diathermy machine may be connected to a flexible cable instead of pads. This cable is coiled around the arm [Fig. 29.2(b)] or knee or any other portion of the patient's body where plate electrodes are inconvenient to use. When RF current is passed through such a cable, an electrostatic field is set up between its ends and a magnetic field around its centre. Deep heating in the tissue results from electrostatic action whereas the heating of the superficial tissues is obtained by eddy currents set up by a magnetic effect. This technique is known as 'inductothermy'.

Another form of inductive heating is by a coil which is housed within a drum. The current flowing within the coil produces a rotating magnetic field, which in turn produces eddy currents in the tissues. Due to the friction caused by the Eddy currents, heat is produced in the tissues. The configuration of the coil is shown in Fig. 29.2 (c).

Although most short-wave diathermy machines have an output power control, yet there is no indication of the amount of converted and absorbed heat within the body tissues. Therefore, the intensity of treatment is dependent on the subjective sensation of warmth felt by the patient.

29.2.1. Pulsed Shortwave Therapy

A severe limitation of diathermic machines is that they direct continuous high frequency radio waves, and if a high enough output of energy is sustained for even a brief time, they can cause burns. As a consequence, the wattage has to be lowered to tolerable limits. Also, the heat resulting from diathermy has many contra-indications and limitations because the heat limits the amount of energy that can be used. The increase in energy output, while avoiding the dangers of heat, has been achieved in a machine called 'Pulsed Shortwave Therapy' (PSWT).

Pulsed therapy apparatus also works at 27.12 MHz, the frequency of short-wave diathermy machine. However, the energy is delivered in the form of pulses of 65 ms with an interval between pulsations at a maximum setting of 1600 ms. The rate of pulsations is adjustable in steps from 80 to 600 pulses per second. Even at this setting, power is provided no more than 4% of the total time that the machine is in operation. The peak instantaneous wattage can be varied from 290 to 975 W. The effect of the rest periods is to reduce the output to a maximum average of only 40 W. The result is an intermittent, relatively athermic, electrotherapy (Fig. 29.4). Therefore, despite the high energy pulses, all the heat is dissipated during the rest period, and as a consequence, there is no danger of burns or hyperthermic complications. The depth of penetration depends upon the peak energy delivered, which is adjustable on the machine. Tuning adjustment is provided to obtain maximum efficiency at each wattage setting. The control offered by the machine will enable the user to vary (a) the mean power delivered to the patient and (b) the pulsing parameters governing the mode of delivery of the energy. Studies show that *mean power* is probably the most important parameter for treatment.

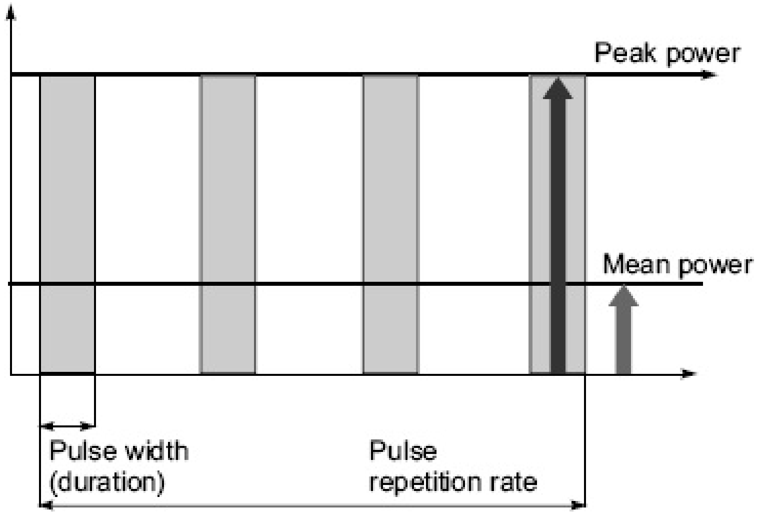


Figure 29.4. Peak power vs mean power in a pulsed shortwave therapy machine

There are two basic types of output from these machines, the *electric* field, comparable to the condenser (capacitor) field in traditional shortwave diathermy and secondly, the *magnetic* field, comparable to inductothermy. Some machines offer the facility to pulse either output, with the magnetic field being delivered via a drum containing a coiled conductor housed in some form of 'monode' or 'drum' applicator (Fig. 29.5). Manufacturers include a special screen in the face of the drum to eliminate most, if not all of the electric field.

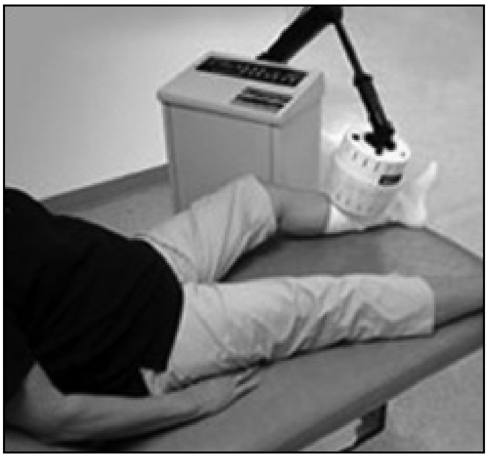


Figure 29.5. Pulsed shortwave diathermy machine with monode applicator

The output of the monode applicator can be thought of as a form of pulsed inductothermy. The pulsed electromagnetic field which is emitted from the applicator will be transmitted through the tissues, and will be absorbed in those of low impedance i.e. the conductors which are tissues like muscle, nerve, those which are highly vascular, tissues in which there is oedema, effusion or recent haematoma.

The mean power table that is provided with each machine is the critical piece of information when it comes to clinical decision making and patient doses. The table identifies all the potential combinations of pulse repetition rate and pulse durations, and therefore how the machine can be 'set' to deliver a specific mean power. The tables are not interchangeable between models and it is important that the correct table is used for the machine available or else an incorrect clinical dose could be applied.

The physiological effects of pulsed therapy are not fully understood. Cells in vitro become aligned within a diapulse field as iron filings follow the lines of force around a magnet, and the orientating effects of the electromagnetic waves seem to be important. Perhaps the most exciting possibility with pulsed-electromagnetic waves is that they may enhance the rate at which peripheral nerves, particularly the smaller diameter fibres, re-generate.

29.3. MICROWAVE DIATHERMY

Microwave diathermy consists in irradiating the tissues of the patient's body with very short wireless waves having frequency in the microwave region. Microwaves are a form of electromagnetic radiation with a frequency range of 300-30,000 MHz and wavelengths varying from 10 mm to 1 m. In the electromagnetic spectrum, microwaves lie between short waves and infrared waves. The most commonly used microwave frequency for therapeutic heating is 2450 MHz corresponding to a wavelength of 12.25 cm. The heating effect is produced by the absorption of the microwaves in the region of the body under treatment.

Microwave diathermy provides one of the most valuable sources of therapeutic heat available to the physician. However, in many conditions, though the therapeutic effects of microwave diathermy are similar to short-wave diathermy, yet in others, better results are obtained by using microwave.

The technique of application of microwave diathermy is very simple. Unlike the short-wave diathermy where pads are used to bring in the patient as a part of the circuit, the microwaves are transmitted from an emitter, and are directed towards the portion of the body to be treated. Thus, no tuning is necessary for individual treatments. These waves pass through the intervening air space and are absorbed by the surface of the body producing the heating effect. The special design of the treatment heads and shapes focuses the field directly at the target area. The whole device is used to direct the waves onto the tissues. This device is sometimes termed the emitter, the director or the applicator. In this kind of treatment, the patient does not form a part of the circuit, so no tuning is necessary as in short wave application. Generally, two designs of applicators are common:

i. ***Circular:*** In which heat is denser at the periphery more than at the center. Different sized applicators are used for small or large areas.

ii. ***Rectangular:*** for elongated areas.

So, the applicator selection depends upon the shape and the anatomical configuration of the treated area.

Microwave penetrates more deeply than infrared rays but not deeply as shortwave diathermy, so microwave is not suitable for deeply placed structures (Cameron, 2009). The effective depth of microwave penetration is about 3 cm so the depth of heating is intermediate between that of infrared radiation and short wave diathermy. As the microwaves are strongly absorbed by water, tissues with high fluid content are heated most, while less heat is produced for tissues with low fluid content as fat. Moreover, there is an appreciable heating of tissues having good blood supply such as muscle. Fig. 29.6 shows comparison of heat distribution in the body-tissues with shortwave and microwave diathermy.

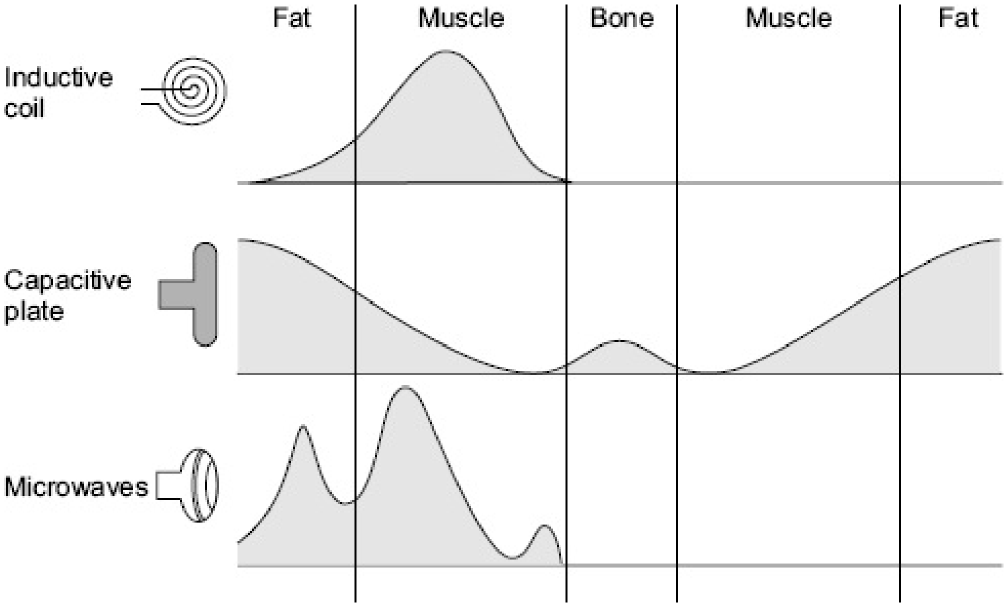


Figure 29.6. Comparison of the heat distribution in the body tissues with the shortwave inductive diathermy, capacitive plate of diathermy applicator and microwave diathermy. (Adapted from Cameron, 2009)

Production of Microwaves: Microwaves are produced by high-frequency currents and have the same frequency as the currents which produce them. Such currents cannot be produced with oscillators using ordinary vacuum tube valves or solid-state devices. A special type of device called 'magnetron' is used for the production of high frequency currents of high power.

The magnetron consists of a cylindrical cathode surrounded by an anode structure that contains cavities opening into the cathode-anode space by means of slots. The output energy is derived from the resonator system by means of a coupling loop which is forced into one of the cavities. The energy picked up on the coupling loop is carried out of the magnetron on the central conductor of a co-axial output tube through a glass seal to a director. The director consists of a radiating element of antenna and a reflector which directs the energy for application to the patient. The electrical current is transformed into electromagnetic radiation on passing through the antenna.

The reflector then focuses this electromagnetic energy and beams it to the tissues where it is subsequently absorbed, reflected or refracted, according to the electrical properties of the tissue. Tissues of lower water content (i.e., subcutaneous) are penetrated to a greater depth but little is absorbed, whereas tissues of high water content (i.e., muscle) absorb more of the electromagnetic energy but allow little penetration.

The output power of a magnetron depends upon anode voltage, magnetic field and the magnitude and phase of the load impedance to which the magnetron output power is delivered. Therefore, the cable used to carry the energy from the magnetron to the director is always of a definite length for a particular frequency. A part of the energy fed to the magnetron is also converted into heat in the anode on account of the collision of the electrons with the anode so that the output energy is considerably less than the input energy. The efficiency of a magnetron is usually 40 to 60%. The heat produced at the anode must be removed which is usually done by using water or air as a means of cooling.

Schematic Diagram of a Microwave Diathermy Unit: The essential parts of a microwave diathermy unit are shown in Fig. 29.7. The mains supply voltage is applied to an interference suppression filter. This filter helps to bypass the high frequency pick-up generated by the magnetron. A fan motor is directly connected to the mains supply. The fan is used to cool the magnetron.

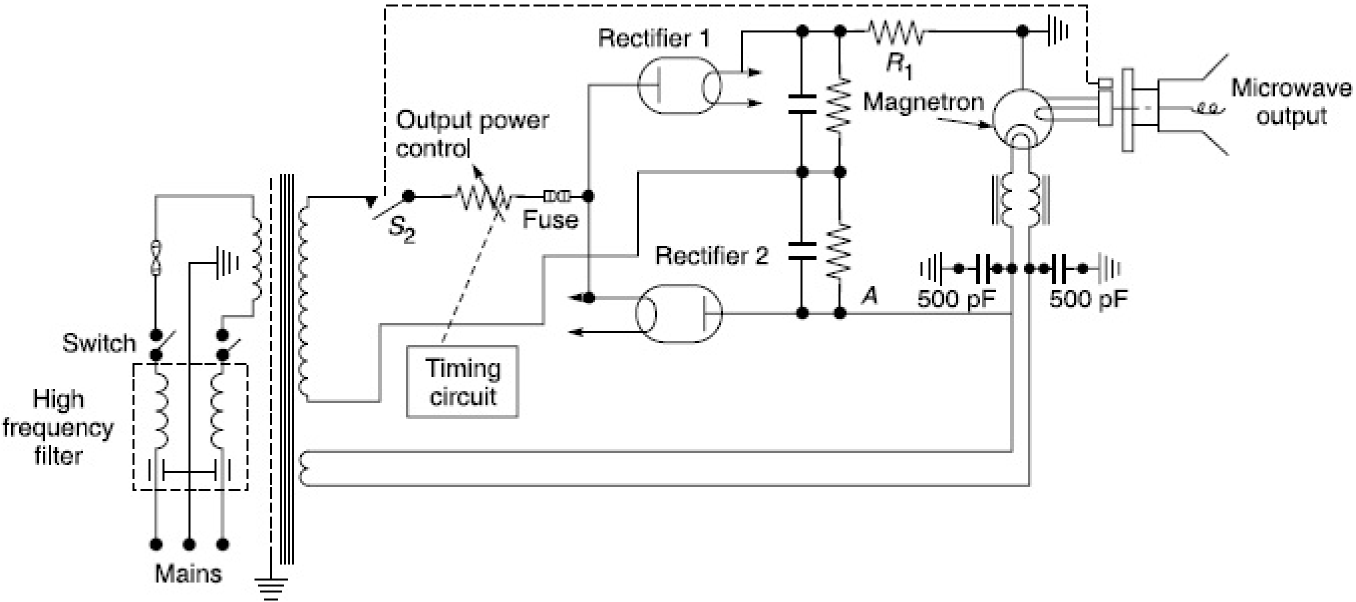


Figure 29.7. Simplified circuit diagram of a microwave diathermy machine

The Delay Circuit: It is necessary for the magnetron to warm up for 3 to 4 minutes before power may be derived from it. A delay circuit is incorporated in the apparatus which connects the anode supply to the magnetron only after this time elapses. The arrangement is such that a lamp lights up after 4 minutes indicating that the apparatus is ready for use.

The Magnetron Circuit: The magnetron filament heating voltage is obtained directly from a separate secondary winding of the transformer. The filament cathode circuit contains interference-suppression filters. The anode supply to the magnetron can be either DC or AC. A DC voltage is obtained by a full wave rectifier followed by a voltage doubler circuit. A high wattage variable resistance is connected in series which controls the current applied to the anode of the magnetron.

When using AC, the voltage is applied to the anode of the magnetron through a series connected thyratron so that the AC voltages of both tubes are equal in phase. By shifting the phase of the control grid voltage with respect to the phase of the anode voltage, the amount of current through the magnetron can be determined and thus the output power can be varied. The phase shift can be achieved by using a capacitor resistor network.

Safety Circuits: There are chances of the magnetron being damaged due to an excessive flow of current. It is thus protected by inserting a fuse (500 mA) in the anode supply circuit of the magnetron. The protection of both the patient and the radiator is ensured by the automatic selection of the control range depending on the type of the radiator used.

The considerable interference produced by the apparatus necessitates the use of large self- inductance coils in the primary supply. Since the cores are likely to become saturated in view of the small dimensions, the coils are split up and fitted in such a way that no magnetization occurs.

Excessive dosage can cause skin burns and in all cases, the sensation experienced by the patient is the primary guide for application. The skin should be dry as these waves are rapidly absorbed by water. The duration of irradiation generally ranges from 10 to 25 minutes.

29.4. ULTRASONIC THERAPY UNIT

Ultrasonics are used for therapeutic purposes in the same manner as a short-wave diathermy machine is used. The heating effect in this case is produced because of the ultrasonic energy absorption property of the tissues. The property of specific heat distribution in tissue and the additional effect of a mechanical component have given rise to a number of special therapeutic applications of ultrasonics. The effect of ultrasonics on the tissues is thus a high speed vibration of micro-massage. Massage as a modality in physical medicine has been used in the treatment of soft tissue lesions for centuries. Ultrasonic energy enables this massage to be carried out, firstly to a greater depth than is possible manually, and secondly at times (in acute injuries) when pressure cannot be exerted by hand because of intolerable pain caused to the patient. The thermal effects of ultrasound are dependent on the amount of energy absorbed, the length of time of the ultrasound application and the frequency of the ultrasound generator. The electrical power required in most of the applications is usually less than 3 W/cm^2 of the transducer area that is in contact with the part of the body to be treated.

Ultrasonic generators are constructed on the piezo-electric effect. A high-frequency alternating current (e.g., 0.75-3.0 MHz) is applied to a crystal whose acoustic vibration causes the mechanical vibration of a transducer head, which itself is located directly in front of the crystal. These mechanical vibrations then pass through a metal cap and into the body tissue through a coupling medium. The therapeutic ultrasonic intensity varies from 0.5 to 3.0 W/cm^2. Applicators range from 70 to 130 mm in diameter. The larger the diameter of the applicator, the smaller would be the angle of divergence of the beam and the less the degree of penetration.

Circuit Description: The equipment required for ultrasonic therapy is electronically very simple. Fig. 29.8 shows the block diagram. The heart of the system is a timed oscillator which produces the electrical oscillations of the required frequency. The oscillator output is given to a power amplifier which drives the piezo-electric crystal to generate ultrasound waves. Power amplification is achieved by replacing the transistor in typical LC tuned Colpitt oscillator by four power transistors placed in a bridge configuration.

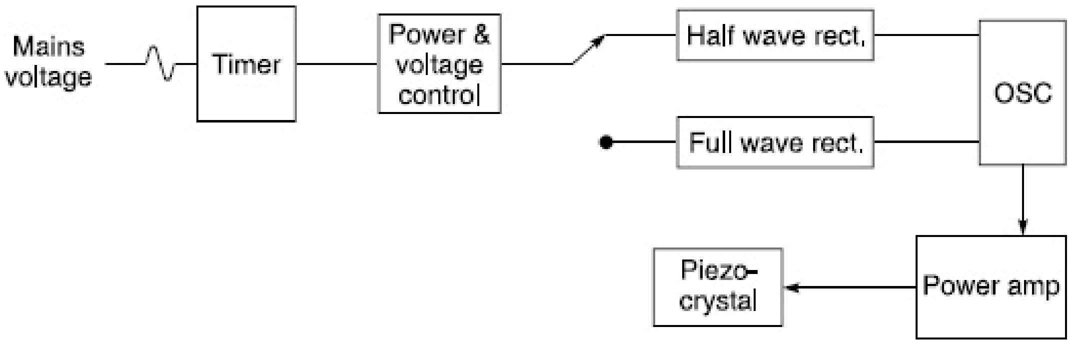


Figure 29.8. Block diagram of an ultrasonic therapy unit

The delivery of ultrasound power to the patient is to be done for a given time. This is controlled by incorporating a timer to switch on the circuit. The timer can be a mechanical spring-loaded type or an electronic one, allowing time settings from 0 to 30 minutes.

The output of the oscillator can be controlled by either of the following two methods:

- Using a transformer with a primary winding having multi-tapped windings and switching the same as per requirement;
- Controlling the firing angle of a triac placed in the primary circuit of the transformer, and thereby varying the output of the transformer.

The machine can be operated in either continuous or pulsed mode. A full-wave rectifier comes in the circuit for continuous operation. The mains supply is given to the oscillator without any filtering. The supply voltage is therefore at 100 Hz which causes the output 1 MHz to be amplitude modulated by this 100 Hz. In pulsed mode, the oscillator supply is provided by the half-wave rectifier and the oscillator gets the supply only for a half cycle. Thus the output 1 MHz is produced only for one half of the cycle and is pulsed.

The transducer is a lead zirconate titanate crystal, having 5-6 cm^2 effective radiating area. The length of the cable connecting the transducer with the oscillator is of critical dimension and should not be altered. In front of the crystal lies a metal face plate which is made to vibrate by the oscillations of the crystal. Ultrasonic waves are emitted from this plate. The crystal has a metal electrode pressed against its back surface by a coiled spring. Voltage is applied to the crystal via this electrode. The front diaphragm is grounded and provides a return path for the excitation voltage.

Dosage Control: The dosage can be controlled by varying any of the following variables.

- Frequency of ultrasound;
- Intensity of ultrasound; or
- Duration of the exposure.

The frequency is involved because the absorption of ultrasonics by the tissues is a frequency- dependent phenomenon. The question as to which ultrasonic frequency to use has been the subject of much investigation and thought but it has been established that a frequency of approximately 1 MHz is the most useful. The amount of energy absorption in the human tissue has been measured experimentally and in soft tissue, a reduction of 50% occurs with a 1 MHz ultrasonic transmission at a depth of 5 cm. The higher the frequency the quicker the energy loss and thus with a transmission of 3 MHz, this reduction of 50% occurs at a depth of only 1.5 cm. Below a frequency of 1 MHz, the beam of ultrasonic energy tends to diffuse and no efficient treatment can be expected. A frequency in the range of 800 kHz to 1 MHz is, therefore, most widely adopted.

Unlike the operation of a short-wave therapy unit, no tuning is necessary while the treatment is in progress. The operating frequency is also not very critical and may vary to the extent ± l0%.

The output power of an ultrasonic therapy unit can be varied continuously between 0 and 3 W/cm^2. The calibrated positions are marked in steps. The steps indicate the average value of intensity monitored in terms of electric power converted into acoustic energy.

Standard values concerning dosing in ultrasonic therapy have been established on the basis of experimental studies. In order to achieve maximum therapeutic efficiency, it is necessary to ascertain the correct ultrasonic intensity and duration of application for a given indication. To make matters simpler, some instruments are equipped with a 'dose tabulator' from which the data concerning dosing can be taken at a glance. In this table, a dose mark is given for every indication (disease) and all that is required is to set a pointer appropriately to ensure that the apparatus is providing the correct output intensity.

Apart from continuous and mains frequency modulated modes, ultrasonic output can also be modulated by any other frequency. The idea behind a pulsed operation is that the predominant effect of ultrasound is not the heating effect but the direct mechanical effect (micro-massage). The thermal effect is reduced by repeatedly interrupting the supply of energy through brief pauses.

Application Technique: There are several ways for applying ultrasonics to the body. The probe can be put in direct contact with the body (Fig. 29.9) through a couplant provided the part to be treated is sufficiently smooth and uninjured. In case a long area is to be treated, the probe is moved up and down, and for small areas it is given a circular motion to obtain a uniform distribution of ultrasonic energy. If there is a wound or an uneven part (joints etc.), the treatment may be carried out in a water bath. This is to avoid mechanical contact with the tissues which may damage an already injured surface. It should be ensured that air bubbles are not present either on the probe or the skin.

Figure 29.9. Ultrasonic therapy in use (Courtesy: M/s Chattanooga, U.S.A.)

29.5. ELECTRODIAGNOSTIC/THERAPEUTIC APPARATUS

29.5.1. Electrodiagnosis

If a normal muscle or motor nerve is stimulated with a current of adequate intensity, it results in its contraction. When there is disease or injury of a motor nerve or muscle, alterations are liable to occur in their response to electrical stimulation. The changed electrical response may be of considerable help in the diagnosis of certain diseases affecting them. Quantitatively, these changes manifest themselves in that a higher or lower current intensity than normal is required to bring about a muscle contraction. It is, therefore, possible to determine the degeneration and regeneration processes in nerves and the muscle system by the use of the stimulation current technique.

Intensity-Time Curve **(i-t Curves)**: In order to examine the conditions of excitability and to obtain a good picture of the degeneration and regeneration process of neuro-muscular units, modern stimulation current diagnosis plots the so called i-t curves based on the intensity of the stimulus and its duration. These curves are determined by means of rectangular and triangular pulses in such a manner that the threshold values are measured at progressively decreasing stimulation durations. The i-t curves have characteristic shapes and deviations from the standard form which lead to an indication of the state of the tissues.

In order to plot such curves, the tissue (muscle, nerve) to be examined is first stimulated with long impulses (usually of 1 s pulse duration and then with shorter and shorter impulses, (down to say, 0.05 ms). For each impulse duration, the current intensity is adjusted until the stimulation threshold has been exceeded and the effect of the stimulation detected. Obviously, the current intensity has to be increased. The impulse duration is usually varied in stages such as 1000–300–l00–10–3–1–0.05 ms and the control of current is affected by a continuously adjustable resistance.

Fig. 29.10 shows typical shapes of i-t curves for an intact neuro-muscular unit of normal excitability when rectangular impulses are used. It also shows the shape of the curve for a totally denervated muscle having an advanced state of degeneration and required excitability.

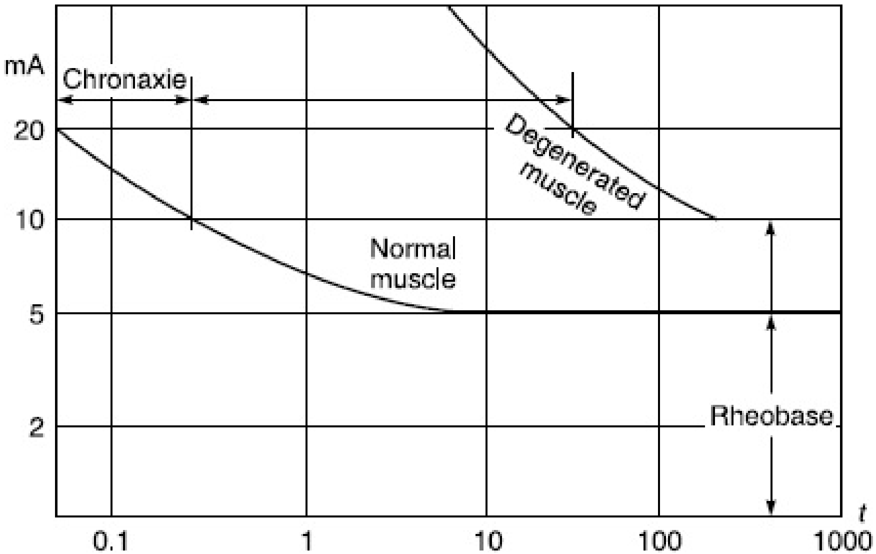


Figure 29.10. Typical intensity time curves of a normal muscle and degenerated muscle. The curve shows that decreasing excitability with progressive degeneration requires extended stimulation times and increased current strength for achieving successful stimulation

With degenerated muscle, the curve obtained is shifted to the right and upwards. The intermediate stages of degeneration and regeneration are characterized by curves lying in between these two limits.

The *chronaxie* and *rheobase* can be easily read from the i-t curves. The rheobase is the minimum intensity of current that will produce a response if the stimulus is of infinite duration, in practice an impulse of 100 ms being adequate for estimating this. The chronaxie is the minimum duration of impulse that will produce a response with a current of double the rheobase. For example if the rheobase is 6 mA, the chronaxie is the duration of the shortest impulse that will produce a muscle contraction with a current of 12 mA.

i-t curves with exponentially progressive current impulses can be drawn in the same way as rectangular impulses. The two curves differ considerably. A typical characteristic of these curves is that the stimulation threshold first decreases when the pulse duration is reduced and the rheobase is also missing. This is due to the phenomenon of the accommodability of the neuro-muscular units.

Accommodation: Accommodation is the property of a neuro-muscular unit of being able to respond less strongly to a slowly increasing current impulse. In other words, the units exhibit a lower excitability and a higher stimulation threshold. The importance of accommodation from the diagnostic point of view lies in the effect that it gives an indication of the presence or alteration of a state of degeneration.

In the representation of i-t curves, the determination of the accommodation consists of the comparison between the 100 ms points of the rectangular i-t curves and of the triangular i-t curves and is, in a way, analogous to the determination of the chronaxie, which is essentially a comparison of the two points of the rectangular i-t curves.

The types of waveforms required for electrodiagnosis are:

- *Galvanic current* for qualitative and quantitative determination of the galvanic excitability (rheobase and chronaxie);
- *Rectangular pulses* for checking nervous conduction as a control of functioning, also of prognostic importance;
- *Exponentially progressive current* for checking the accommodability or its

loss as a symptom of the degree of degeneration and for prognosis of the re-innervation of totally denervated muscles; and

- *Faradic current* for qualitative and quantitative determination of the faradic excitability.

29.5.2. Electrotherapy

Electrotherapy, employing low-volt, low-frequency impulse currents, has become an accepted practice in the physiotherapy departments. The biological reactions produced by low-volt currents have resulted in the adoption of this therapy in the management of many diseases affecting muscles and nerves. The technique is used for the treatment of paralysis with totally or partially degenerated muscles, for the treatment of pain, muscular spasm and peripheral circulatory disturbances, and for several other applications.

Although some of the principles upon which low-volt therapy depends have been known since the end of the last century, it is only in recent years that it has started being widely used with the availability of safe and simplified apparatus required for the purpose.

Different types of waveforms are used for carrying out specific treatments. The most commonly used pulse waveforms are discussed below.

Galvanic Current: When a steady flow of direct current is passed through a tissue, its effect is primarily chemical. It causes the movement of ions and their collection at the skin areas lying immediately beneath the electrodes. The effect is manifested most clearly in a bright red coloration which is an expression of hyperaemia (increased blood flow). Galvanic current is also called direct current, galvanism, continuous current or constant current.

Galvanic current may be used for the preliminary treatment of atonic paralysis and for the treatment of disturbance in the blood flow. It is also used for iontophoresis, which means the introduction of drugs into the body through the skin by electrolytic means. In general, the intensity of the current passed through any part of the body does not exceed 0.3 to 0.5 ma/sq cm of electrode surface. The duration of the treatment is generally 10 –20 minutes.

Faradic Current: Faradic current is a sequence of pulses with a defined shape and current intensity. The pulse duration is about 1 minute with a triangular waveform and an interval duration of about 20 minutes. Faradic current acts upon muscle tissue and upon the motor nerves to produce muscle contractions. There is no ion transfer and consequently, no chemical effect. This may be used for the treatment of muscle weakness after lengthy immobilization and of disuse atrophy.

Surging Current: If the peak current intensity applied to the patient increases and decreases rhythmically, and the rate of increase and decrease of the peak amplitude is slow, the resulting shape of the current waveform is called a surging current.

The main field of application of the Faradic surge current is in the treatment of functional paralysis. The surge rate is usually from 6-60 surges per minute in most of the instruments. The ratio of interval to the duration of the surging is also adjustable so that graded exercise may be administered. This type of current is usually required for the treatment of spasm and pain.

Exponentially Progressive Current: This current is useful for the treatment of severe paralysis. The main advantage of this method lies in the possibility of providing selective stimulation (Fig. 29.11) for the treatment of the paralysed muscles. This means that the surrounding healthy tissues even in the immediate neighbourhood of the diseased muscles are not stimulated. The slope of the exponential pulse is kept variable.

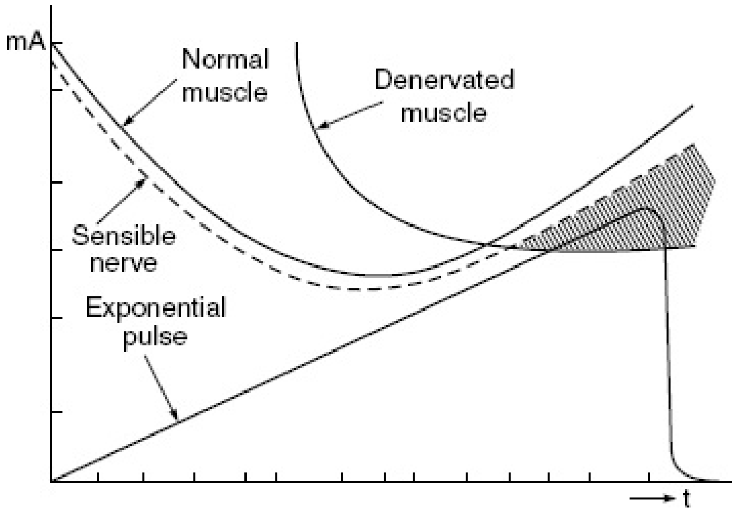


Figure 29.11. Principle of selective stimulation of the denervated musculature. Selective stimulation of the denervated muscle without irritation of the sensible receptors is possible in the shaded area of the graph

Biphasic Stimulation: The cell recovery from the effect of a stimulus current can be hastened by the passage of a lower intensity current of opposing polarity over a longer period so that the net quantity of electricity is zero. Such type of combination of positive and negative pulses is called biphasic stimulation. In a typical case, the stimulating pulse may be followed by a pulse of opposite polarity of one-tenth the amplitude and 10 times the width. Biphasic stimulation also helps to neutralize the polarization of the recording electrodes in case silver-silver chloride electrodes are not used. This means that there are no electrolytic effects, nor are any macroscopic changes affecting either the skin or the electrodes observed. Also, there is reduced muscle fatigue, since each current pulse is immediately followed by an opposite current phase of the same magnitude. The stimulation current intensity required during treatment is less as compared with monophasic currents. Monophasic current forms, however, retain their importance in electro-diagnostic evaluation since the necessary pulse shapes are defined monophasically.

29.5.3. Electrodiagnosis and Electrotherapy Apparatus

Several types of commercial units are available which give specific output waveforms for specific applications. However, the trend is in favour of having a versatile apparatus which gives output current waveforms to cover the whole range of electrodiagnostic and therapeutic possibilities. The output waveforms generally required are shown in Fig. 29.12.

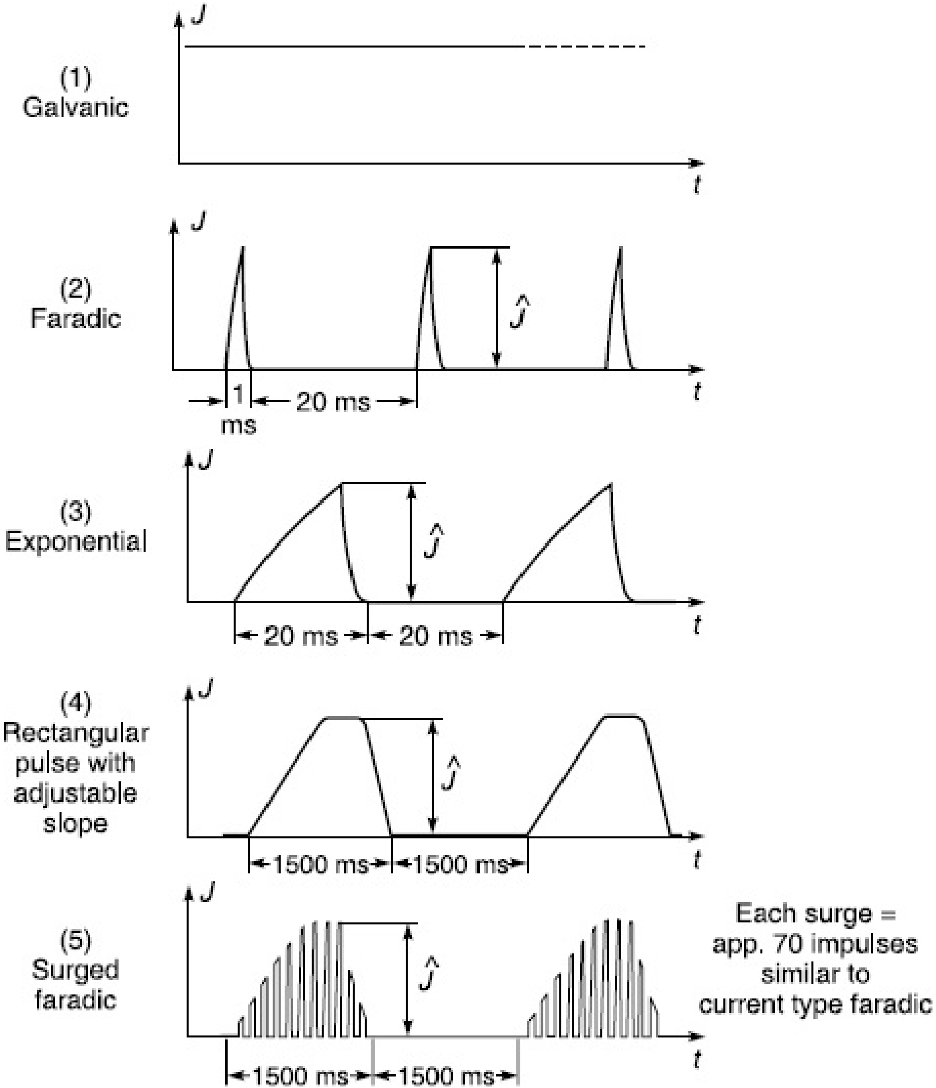


Figure 29.12. Current waveforms normally employed in electrodiagnosis and electrotherapy: (1) galvanic (2) Faradic (3) exponential (4) rectangular pulse with adjustable slope (5) surged Faradic.

Another important consideration is that the apparatus must be either of constant voltage or constant current type. Moreover, the apparatus must give reproducible and well-defined impulses that must correspond to the value set on the dials. For clinical practice, maximum tolerance permitted in the pulse parameters is 15%. The instrument generally has a floating output and incorporates an isolation transformer in the output.

The typical specifications of an electro-diagnostic therapy unit are as follows:

- Galvanic current up to 80 mA, ripple less than 0.5% as constant current or surging current with adjustable surge frequency from 6 to 30 surges per minute
- Exponentially progressive current pulse sequences with continuously

variable pulse duration from 0.01 to 1000 ms and independently adjustable interval duration of 1 to 10,000 ms. The pulse form can be set continuously between triangular and rectangular forms;

- Faradic surging current with 25 surges per minute, up to 80 mA. Precision and constancy of the values set better than ±10%; peak current measurement facility. Constant current circuit, both poles earth-free.

29.5.4. Functional Block Diagram

Fig. 29.13 shows the block diagram of a versatile electro-diagnostic therapeutic stimulator. It makes use of a variable rate multi-vibrator (M1) to set the basic stimulus frequency. The output from the free running multi-vibrator triggers a monostable multi-vibrator (M2) circuit which sets the pulse width. The output pulse from the monostable provides an interrupted galvanic output whose rate as well as duration can be independently controlled. Another astable multi-vibrator produces short duration pulses called faradic currents. Faradic currents are usually modulated at the frequency set by the multi-vibrator Ml, in a mixer circuit (M4). Since the modulation of Faradic pulses takes place with a slow rate of increase and decrease, the output of M4 is surged Faradic currents. By integrating the output of M2, the interrupted galvanic pulses can be modified to have an exponential rise and fall. The shape of these pulses is similar to a triangular waveform. Galvanic current is also made available by suitably tapping the DC supply.

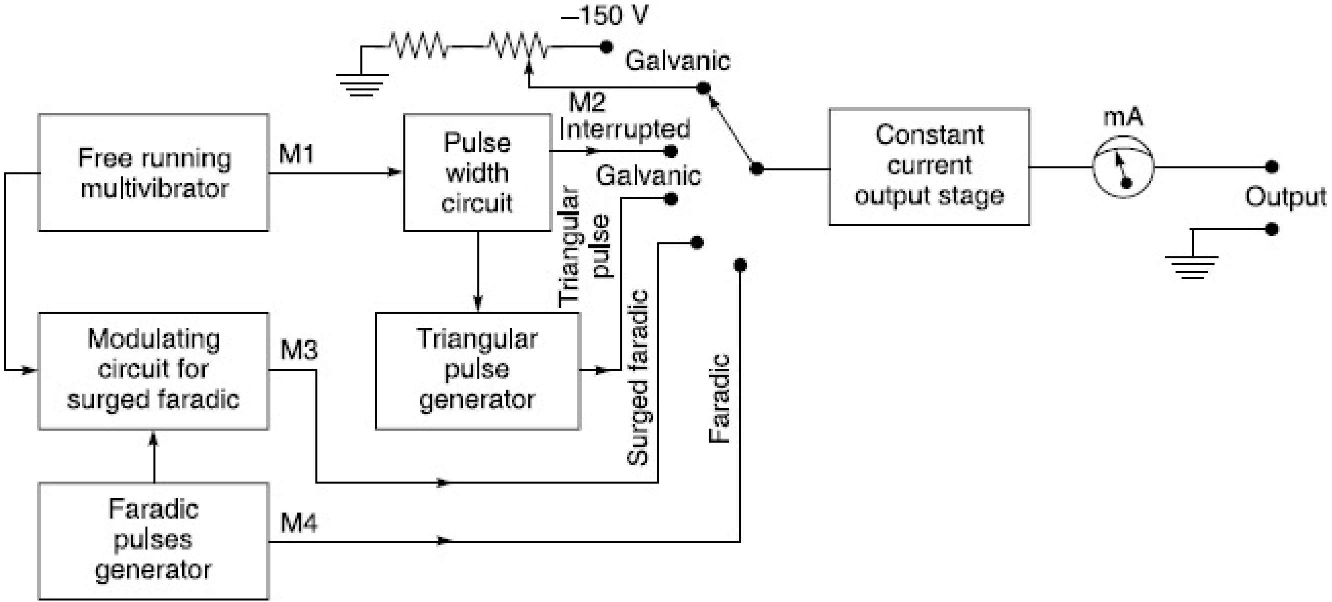


Figure 29.13. Schematic diagram of a diagnostic/therapeutic stimulating unit

Finally, any one of the waveforms can be selected through a selector switch and fed either to an emitter-follower stage in order to provide a low output impedance constant voltage output or to a high output impedance constant current stage. Usually the output impedance of a constant voltage stimulator is of the order of 100 Ω and that of a constant current type is greater than 100 kΩ.

The output of a diagnostic/therapeutic stimulator is kept floating, i.e. it is isolated from earth. The usual method is to have an isolation transformer at the output of the stimulator. This transformer has floating terminals and is fitted with an electrostatic shield to reduce capacitive coupling with the earth. Another method of isolation of the output from earth is by the use of a radio- frequency output stage.

The two methods have been widely used for providing isolation of the stimulator output, but they have some drawbacks. The simple transformer cannot transmit square waves without distorting the waveform and the method of radio-frequency is rather complex. Isolation can also be provided through the opto-isolation technique.

The question as to which type of stimulation impulses, whether constant voltage or constant current type, should be preferred in carrying out electro-diagnostic studies is still a matter of choice. However, most of the present-day instruments are of the constant current type because for a given electrode geometry, constant current stimulation will provide better reproducibility for a wide variation in preparation impedance. The advantages of constant current therapy are detailed below:

- The current flow is largely constant irrespective of the patient's resistance. The selected current intensity remains constant, even if the resistance in the tissue between the electrodes should vary, as a result of, say, changes in the blood circulation during treatment, or after previous therapy.
- The current waveform when applied is distortion-free, since micro-voltages between the electrode and the skin have no influence.
- Current therapy avoids accompanying symptoms such as irritating stimulatory sensations between electrodes by applying electrodes firmly to

the skin and keeping them in one position.

In case of constant voltage, the current flow is dependent on the resistance of the patient, that is, if the electrical resistance of the tissue increases, less current will flow, and vice versa. Irritating stimulatory sensations do not occur, even beneath electrodes that are not firmly applied or are moved over the skin, for example, during the search for a trigger point. This operating mode is recommended for the combined use of stimulation current and ultrasound.

Modern electro-diagnosis/therapy units are microprocessor-controlled which make possible a number of automatic sequences in selecting the type and quality of waveform. Also, the facility for automatic self-test is followed by the automatic setting of the basic program. Acoustic and visual signals provide information on the various operating situations. Operating errors are indicated on visual displays. A built-in service advice helps identify faults. All this intelligent information reduces the demands made on the therapist, who can then devote more time to the patient.

29.5.5. Interferential Current Therapy

Interferential electrical stimulation is a unique way of effectively delivering therapeutic currents to tissue. Conventional TENS (Transcutaneous Electrical Nerve Stimulator) and neuro-muscular stimulators use discrete electrical pulses delivered at low frequencies of 2–200 Hz. However, interferential stimulators use a fixed carrier frequency of 4,000 Hz and also a second adjustable frequency of 4,001–4,400 Hz. When the fixed and adjustable frequencies combine (heterodyne), they produce the desired beat frequency or interference frequency (Fig. 29.14). Interferential stimulation is concentrated at the point of intersection between the electrodes. This concentration occurs deep in the tissues as well as at the surface of the skin. Conventional TENS and neuro- muscular stimulators deliver most of the stimulation directly under electrodes. Thus, with interferential stimulators, the current perfuses to greater depths and over a larger volume of tissue than other forms of electrical therapy. When current is applied to the skin, the capacitive skin resistance decreases as pulse frequency increases. For example, at a frequency of 4,000 Hz (interferential range), the capacitive skin resistance is 80 times lower than with a frequency of 50 Hz (in the TENS range). Thus, interferential current crosses the skin with greater ease and with less stimulation of cutaneous nociceptors allowing greater patient comfort during electrical stimulation. In addition, because medium-frequency (Interferential) current is tolerated better by the skin, the dosage can be increased, thus improving the ability of the interferential current to permeate tissues and allowing easier access to deep structures. This explains why interferential current may be most suitable for treating patients with deep pain.

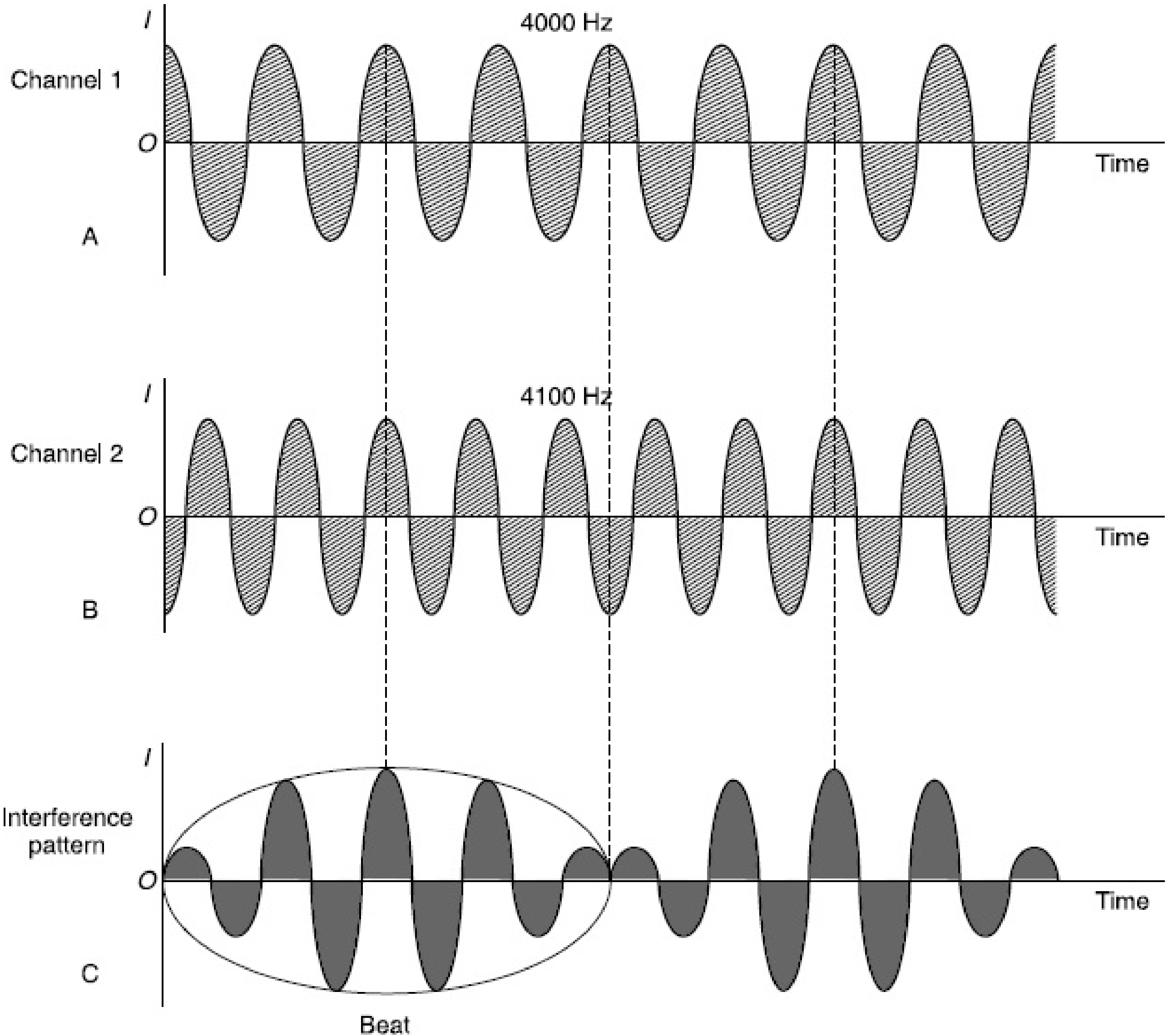


Figure 29.14. Principle of generation of interference currents

Interferential currents are produced by using two-channel stimulators and four electrodes. Each channel produces a sinusoidal, symmetrical alternating current at a high frequency (2000–5000 Hz). The electrodes are used in a quad-polar arrangement and the AC frequencies are set at slightly different frequencies but at similar amplitudes. The currents from the two waveforms interface with each other in the tissue, giving constructive (when the two waveforms add to each other) or destructive (when the circuits tend to cancel each other) interference.

The therapeutic current is the beat frequency. Neither the carrier frequency nor the variable frequency alone has any therapeutic value. The major benefit of interferential currents is that the therapeutic current is generated within the tissue, and therefore the treatment is possible at deeper structures. In addition, it is possible to increase the amplitude of the stimulus that can be tolerated and increase the comfort of the pulse as it passes through the skin. Joshi (2012) describes a microcontroller based design of an Interferential Therapy (IFT) system.

29.5.6. Diadynamic Current Therapy

The term 'diadynamic current' refers to a monophase (MF) or double-phase (DF) rectified alternating current, with a frequency which is derived directly from the mains supply, resulting in sinusoidal pulses with a duration of 10 ms. The wave form is shown in Fig. 29.15. The diadynamic current therapy is popular in Europe and have been found to have quite specific effects when used for pain reduction or improvement of tissue metabolism.

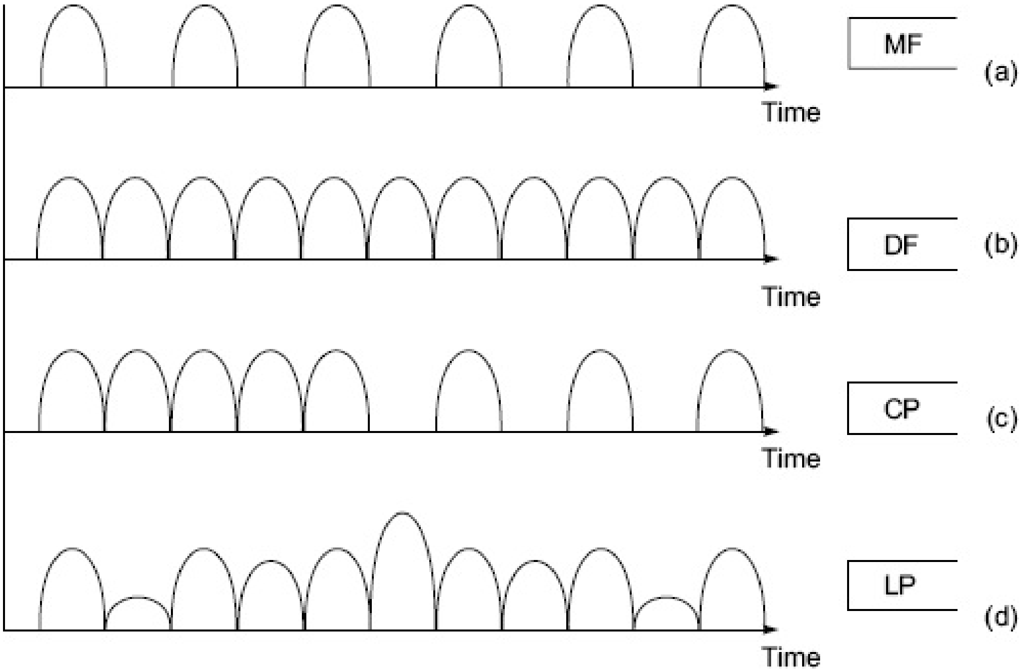


Figure 29.15. Diadynamic current waveforms (a) MF monophase rectified alternating current. (b) DF double-phase rectified alternating current. (c) CP rapid alternation between DF and MF. (d) LP slow alternation between DF and MF

The diadynamic currents are of the following types:

- Monophase (MF) frequency 50 Hz
- Double phase (DF) frequency 100 Hz
- Combined (CP) rapid alternation between one second of MF current and one second of DF current
- Long Phase (LP) slow alternation between six seconds of MF current and a six-second DF phase.

In the DF phase, the intervals between the MF pulses are filled with additional pulses which gradually increase in amplitude to that of the MF pulses, resulting in a DF current, after which the amplitude of the additional pulses decreases again to zero and the MF current continues for a further six seconds. The whole duration of the DF phase, including increase and decrease is six seconds. The CP and LP dynamic current types are used to prevent accommodation. CP is more aggressive than LP, as the changes are quite abrupt. Diadynamic current is particularly suitable for treating pain in small joints.

29.5.7. Types of Electrodes for Electro-diagnostic/Therapeutic Applications

Two methods of electrode systems are in common use. The mono-polar technique makes use of small active stimulation electrode. The indifferent or dispersive electrode is of larger area and is placed near to the active electrode. This technique is used for testing of the galvanic and Faradic excitability and for determining the chronaxie.

For diagnostic purposes, a ball or plate electrode which is provided with a small thick muslin strip is mounted on a special handle. The handle carries a finger-tip switch to facilitate convenient control of output. Similarly, a small metal electrode can be secured on the motor point, particularly for therapeutic applications.

For recording i-t curves, the bi-polar electrode technique is usually preferred. Both the electrodes are fixed to the body, so that the hands of the operator are free to operate the apparatus. The active electrode in this method need not be a small as we deal with higher current intensities and small area electrode may cause unpleasant heat sensations. Suitably sized metal sheets are used as electrodes in this system. The electrodes are fastened to a moistened pad of about 1 cm thickness and 1 cm wider than the electrode sheet on all sides. The material used for pads is of good absorbancy and ordinary water can be used to moisten the electrodes. The electrodes are held in position by rubber straps.

Standard texts on muscle stimulation emphasize that successful muscle stimulation can only be achieved if the activating currents are properly applied. Physiotherapists are trained to understand all about motor points and how to apply stimulation through these points.

29.6. PAIN RELIEF THROUGH ELECTRICAL STIMULATION

29.6.1. Transcutaneous Electrical Nerve Stimulator (TENS)

Pain is man's oldest enemy and for centuries, medicine has searched for an innocuous, non- destructive, non-invasive, well-tolerated and effective way of relieving pain that is both efficient and practical. In the past few years, several workers have reported their success in using electrical impulses to block the pathways of the transmission of pain. The impulses are produced in a battery- powered pulse-generator to which a pair of electrode-tipped wires can be attached. Applied to the skin overlying any painful area of the body, these electrodes provide continuous, mild electrical stimulation. These signals seem to jam the pain signals travelling along the nerve pathways before they can reach the brain. The result is analgesia, often for hours after stimulation ends. The pain control is explained by:

The ***Gate Control Theory*** which suggests that by electrically stimulating sensory nerve receptors, a gate mechanism is closed in a segment of the spinal cord, preventing pain- carrying messages from reaching the brain and blocking the perception of pain; and

The ***Endorsphin Release Theory*** which suggests that electrical impulses stimulate the production of endorphin and enkaphalins in the body. These natural, morphine-like substances block pain messages from reaching the brain, in a similar fashion to conventional drug therapy, but without the danger of dependence or other side-effects.

The electrical impulses required for electrotherapy to treat the pain are provided by an instrument called TENS (Transcutaneous Electrical Nerve Stimulator). Investigations on a great variety of electrical impulse parameters have indicated that two waveforms, the square wave and the spike wave are optimally and equally effective in relieving pain. Most stimulators feature adjustable settings to control the amplitude (intensity) of stimulation by controlling voltage, current and the width (duration) of each pulse. Electrodes are placed at specific sites on the body for treatment of pain. The current travels through the electrodes and into the skin stimulating specific nerve pathways to produce a tingling or massaging sensation that reduces the perception of pain.

Typically, the stimulator is based around a 500 ms spike pulse, having an adjustable amplitude of 0 to 75 mA and an adjustable frequency of 12 to 100 pulses per second. Instruments having similar specifications except that they produce square waveform, have a pulse frequency range of 20–200 Hz, pulse width from 0.1 to 1.0 ms and pulse amplitude of 0–120 V with maximum output current as 25 mA. The instrument powered by three standard flashlight batteries of 1.5 V each gives about 100 hours of continuous operation. Transcutaneous or skin surface application of electrical stimulus is accomplished by application of the conducting pads to various trigger-zone areas, acupuncture sites or even peripheral nerves. Skin irritation at the site of electrode application is diminished by the use of carbonized rubber electrodes applied with a tincture of Benzoin interface.

The skin electrode system must be designed so as to minimize impedance variations with motion, to conform to the body surface to provide a uniform impedance across the surface of the electrode and to have an adequate surface area. The adequate surface area can be determined keeping in view the peak square-wave current at the threshold of thermal damage as a function of the electrode surface area. The thermal damage threshold varies widely with skin impedance, which is a function of skin preparation.

Transcutaneous electrical nerve stimulation (TENS) electrodes are commonly moulded from an elastomer such as silicon rubber, loaded with carbon particles to provide conductance. Conformability is achieved by making the electrode thin. Useful carbon-loaded silicon rubbers have a minimum resistivity near 10 Ω cm. A thin electrode may exhibit an impedance which is not negligible as compared to the impedance of the interface and tissue under it. Thus, the design of an electrode with the required conformability and current distributing properties becomes a compromise in electrode geometry and material properties. The frequency-dependence of the electrode performance also has to be considered since the impedance between the electrode and subcutaneous contains capacitance.

29.6.2. Spinal Cord Stimulator

Spinal cord stimulation is a term relating to the use of electrical stimulation of the human spinal cord for the relief of pain. This is accomplished through the surgical placement of electrodes close to the spinal cord, either with leads extending through the skin, or chronically, with the leads connected to an implanted source of electrical current. The applied electrical impulses develop an electrical field in and around the spinal cord, which then causes depolarization or activation of a portion of the neural system resulting in physiological changes.

To diminish the chances of electrode dislocation or suboptimal initial electrode positioning, multipolar electrodes are used. At first they included four contacts. Modern electrodes have even more contacts, at present up to twenty, and with elaborate configurations for plate electrodes.

The stimulus source provides stimulation pulses at frequencies ranging from 10 to 1500 Hz, with pulse widths from 100 to 600 µs and controllable amplitude from 1 to 15 mA delivered into a load from 300 to 1500 Ω. These parameters can be controlled when one is using an implant that derives power and control through RF coupling from an externally power unit. Fig. 29.16 shows the Medtronic Spinal Cord stimulation system, which has an implantable pulse generator and a hand-held programmer.

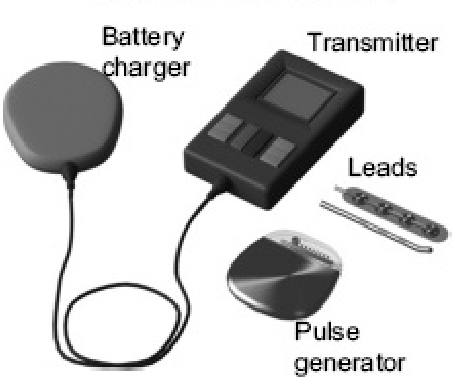


Figure 29.16. Spinal cord stimulation system with programmer (Transmitter) (Courtesy: M/s Medtronic, U.S.A.)

Modern stimulators also allow for modification of frequency, pulse-width and amplitude yielding square wave pulses either with constant voltage or constant current. Settings are individually tried out to result in minimizing the pain.

Since a spinal cord stimulator is not a life-support system, there is no hazard associated with a stimulator failing to provide an output. However, patients using ventricular inhibited or triggered pacemakers should not be exposed to nerve stimulation. Also, a patient entering a pulsed radio frequency field of the frequency to which the receiver is tuned would be in danger of having his stimulator activated by the field. Spinal cord stimulation has been shown to be of great benefit to some patients with multiple sclerosis and other neurological diseases; it is expected that the technique would be applied more and more in the near future.

The treatment of idiopathic scoliosis (lateral curvature of the spine) by electrical stimulation is described by Leonard (1980). The apparatus used for this purpose consists of an implanted radio receiver [Fig. 29.17(a)] and an external transmitter with an appropriate antenna [Fig. 29.17(b)]. The transmitter is designed to generate pulses for muscle contraction lasting 1.6 seconds with a rest period of 9 seconds between contractions. The actual stimulation is not a single pulse but rather a burst of pulses consisting of individual pulses 220 ms wide, repeated 33 times every second. For transmission through the skin, the pulse bursts are modulated with a carrier frequency of 460 kHz. The receiver is a passive device designed to receive only signals from the transmitter. It demodulates the signals and conducts them through the leads into the appropriate muscles to produce stimulation. The receiver circuit is embedded in an epoxy disc coated with silicon rubber for tissue compatibility. The receiver is attached to three leads of platinum-iridium wire terminating in platinum corkscrew electrodes. The electrodes are placed over appropriate para-spinal muscles during surgery. The receiver is placed in a subcutaneous pocket on the convex side of the curve. The transmitting antenna is a flat disc which is taped on the skin over the subcutaneous receiver by disposable adhesive.

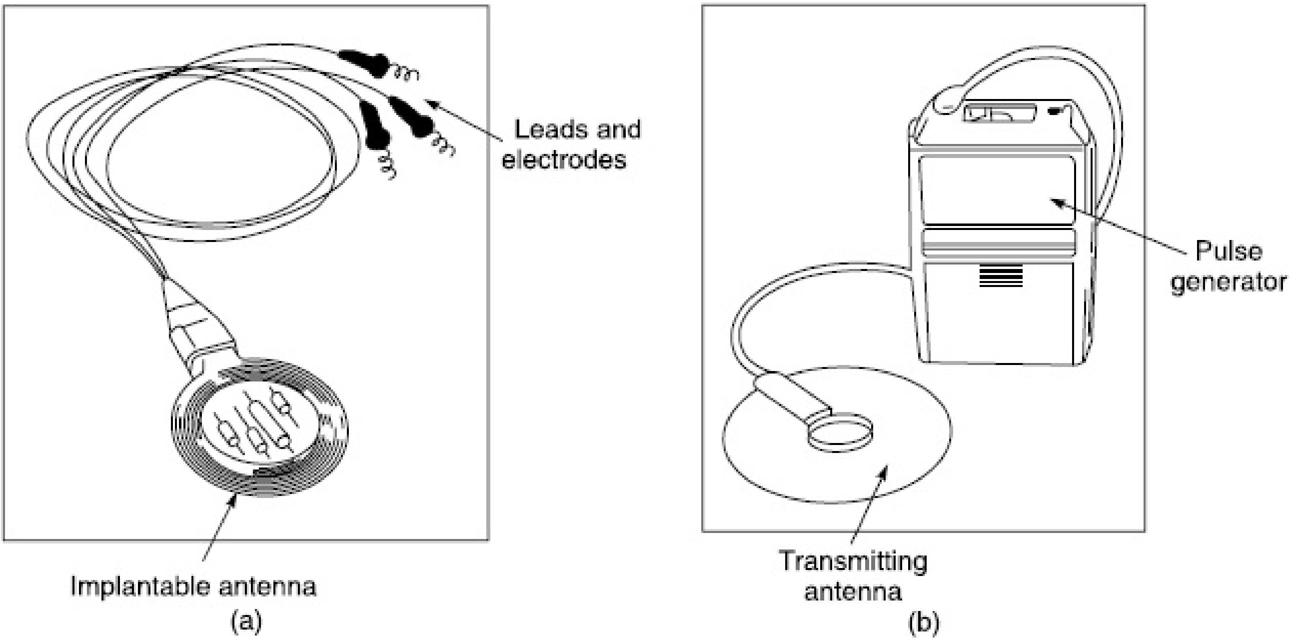


Figure 29.17. (a) Implanted radio receiver with leads (b) External transmitting unit with an antenna

This technique is considered as an exciting development in the field of scoliosis management, particularly of young children. For a given geometry, the effect of electrical stimulation on nerve tissue is determined by the charge per stimulus. Thus, in order to maintain a certain stimulus level despite a possibly varying electrode impedance the amount of charge per pulse delivered to the electrode must be kept constant. This can be achieved either by discharging a capacitor which has been charged to a given voltage or by driving the electrode by a current source thus supplying a constant current for a certain amount of time.

Algora and Pena (2009) describe a new powering system for implantable medical devices that could significantly increase their lifetime. The idea is based on the rechargeable battery, which is fed by the electric power generated by a photovoltaic converter inside the implantable device. Light impinges on the photovoltaic device through an optical fibre going from the photovoltaic device to just beneath the patient's epidermis. Light can enter the optical fibre by passing through the skin. A complete power-by-light system has been developed and tested by the authors with a real implantable pulse generator for spinal cord stimulation.

29.6.3. Magnetic Stimulation

A problem with electric stimulation is that it is painful (Hallett and Leonardo, 1990). The pain is not very different from that induced by the stimulation of peripheral nerves, but it is sufficient to limit its clinical acceptability. It has been shown by Barker *et al.* (1985) that it is possible to stimulate both the nerve and brain magnetically. A magnetic pulse is generated by passing a brief, high- current pulse through a coil of wire. The technique has an advantage in that the stimulation is almost painless. Although a large number of studies have been carried out to study the effectiveness and safety of magnetic stimulation, the technique is still experimental and regulated in countries like the USA.

29.7. DIAPHRAGM PACING BY RADIO-FREQUENCY FOR THE TREATMENT OF CHRONIC VENTILATORY INSUFFICIENCY

Sarnoff *et al.* (1948) introduced the term electro-phrenic respiration to describe the contraction of the diaphragm following electrical stimulation of the phrenic nerve. He experimented extensively with electrical stimulation of the phrenic nerve (Fig. 29.18) and demonstrated that subaximal electrical stimulation of only one phrenic nerve could affect normal oxygen and carbon dioxide exchange. The technique is now well-developed and radio frequency phrenic nerve pacemakers are commercially available.

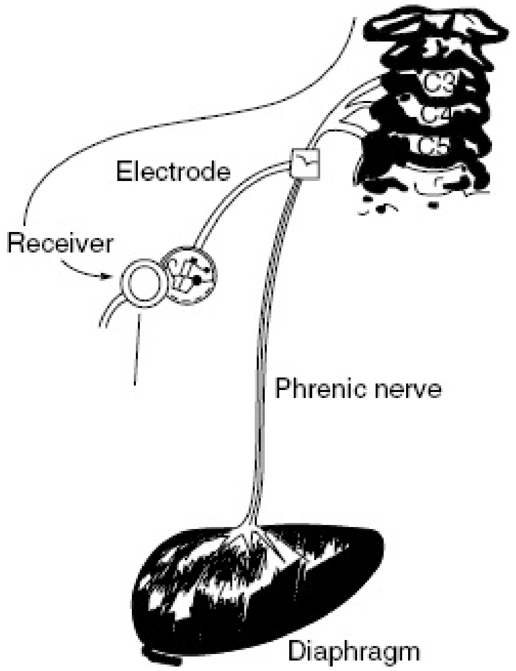


Figure 29.18. The diagram shows placement of receiver and electrode for phrenic nerve stimulation

The apparatus is a radio-frequency-coupled stimulator composed of a small external transmitter and a passive receiver capsule implanted subcutaneously in the patient. The energy required for stimulation is transmitted via the external battery-operated transmitter through the closed skin to the internally implanted receiver capsule. Multi-strand stainless steel wires covered with silicon rubber deliver the stimulus from the implant to the nerve-cuff placed around the phrenic nerve. A small antenna composed of several loops of wire taped to the patient's skin over the receiver capsule provides the electromagnetic coupling that is necessary for the operation. In order to eliminate the problem of antenna motion with respect to the implant's causing changes in the amplitude of the current stimulus applied to the nerve, a pulse width telemetry system is used. The current stimulus supplied to the nerve is 150 ms in duration. The amplitude of the pulse applied to the nerve is a function of the duration of the applied radio-frequency carrier, not of the amplitude of the carrier.

Noshiro and Suzuki (1978) stress the importance of synchronization of respiratory rhythm with electrical stimulation of the phrenic nerve. Synchronization is of clinical importance because ventilation cannot be fully performed if the remaining spontaneous breathing in assisted respiration is asynchronous with a respirator. It was observed by these workers that synchronization occurs only within the limited range of a stimulation period. Talonen *et al.* (1990) illustrate neuro-physiological and technical considerations for the design of an implantable phrenic nerve stimulator.

29.8. BLADDER STIMULATORS

The micturition reflex controls emptying of the bladder and guards against urinary tract infection and possible kidney malfunction. When it is faulty, as it often is in paraplegia, chronic infection can occur which may be life-threatening. Such patients mostly require a catheter either constantly or intermittently to maintain an infection-free state. Electronic devices have been used for direct electrical stimulation of the detrusor muscle of the bladder but it produced undesirable side-effects because of the necessarily high current sent to the surrounding pelvic structure. A technique has been developed to activate the micturition reflex by remote electronic stimulation of a permanently implanted spinal electrode, with which the paraplegic is able to empty the bladder completely without the use of a catheter.

The stimulating device is similar to that used in phrenic nerve stimulation. However, the stimulus provided is in the form of a biphasic pulse with a preset pulse width of 0.2 ms, a pulse intensity of 0.5 to 25 V and a pulse rate of 10 to 50 Hz. The sacral cord electrode consists of two insulated platinum wires, 2.5 mm in length, with 1.5 mm bared conical tips, mounted 2.5 mm apart on an epoxy strip. The two lead out wires are flexible, silastic-coated and are made of stainless steel and connect to a receiver with a circumference of 3 cm. The receiver is placed in the subcutaneous tissue on the left or right side of the patient's waist. Voiding usually begins 10 to 15 seconds after the onset of stimulation.

29.9. DEEP BRAIN STIMULATION (DBS)

The deep brain stimulation (DBS) therapy is a new treatment technique for a number of neurologic disorders. The technique in select brain regions has provided remarkable therapeutic benefits for otherwise treatment-resistant movement disorders such as Parkinson's disease, tremor and dystonia.

The system consists of three components: the implanted pulse generator (neurostimulator), the electrode and the extension. The arrangement is shown in Fig. 29.19. The electrode or lead is a thin, insulated wire which is inserted through a small opening in the skull and implanted in the brain. The tip of the electrode is positioned within the targeted brain area. The extension is an insulated wire that is passed under the skin of the head, neck, and shoulder, connecting the lead to the neurostimulator which is usually implanted under the skin near the collarbone. The stimulator delivers a constant fast-frequency stimulus which interrupts a specific circuit in the brain that is overactive in the disease state. This interruption of the diseased overactive circuit can significantly improve the symptoms of the disease.

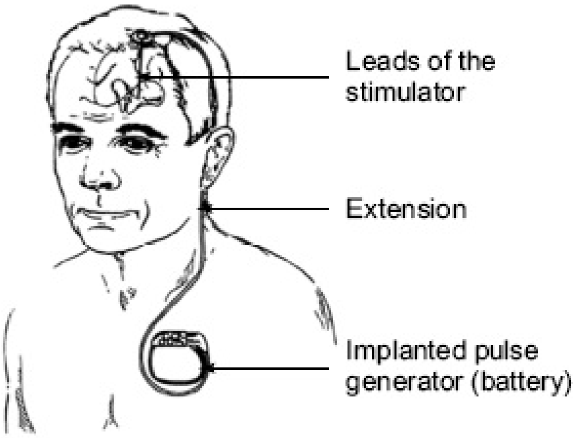


Figure 29.19. Arrangement for deep brain stimulation for Parkinson's disease

Fig. 29.20 is a typical neurostimulator from M/s Medtronic which is a dual channel device capable of delivering bilateral stimulation. It has two modes of operation. In the voltage mode, it delivers pulses with a rate of 2 to 250 Hz and voltage level of 0 to 10.5 volts. In the current mode, the pulse frequency is 30 to 250 Hz and current range of 0 to 25.5 mA. In both the modes, the pulse width is kept between 60 to 450 µs. Each lead carries upto 4 electrodes. The device contains a non-rechargeable battery and microelectronic circuitry to deliver a controlled electrical pulse to precisely targeted areas of the brain. The device is typically implanted subcutaneously near the clavicle.

Figure 29.20. Neuro stimulator (Courtesy: M/s Medtronic)

29.10. MODEL QUESTIONS

1. What is the principle of high frequency heat therapy? Explain the operation of a short-wave diathermy machine with the help of a block diagram. Why do we require automatic tuning in these machines?

2. What are the application techniques in short-wave diathermy machines? Why the pulsed therapy is preferred?

3. Explain the principle of heating using microwaves. Describe the working of microwave diathermy machine with the help of a block diagram.

4. What are the advantages of using ultrasonic for therapeutic purposes? Explain the working of an ultrasonic therapy unit with the help of a block diagram.

5. Explain the application technique of ultrasound therapy. How do we control the dosage in ultrasonic therapy units?

6. Draw a typical intensity-time curve of a normal and degenerated muscle and explain the following terms:
    - Chronaxie
    - Rheobase
    - Accommodation
7. Draw the various types of waveforms used for electro-diagnosis and electro-therapeutic applications. Explain with the help of a schematic diagram of a diagnostic/therapeutic stimulating unit.
8. Distinguish between interferential and diadynamic currents used in electro-therapy. Draw the diagrams of the two current waveforms.
9. Write short notes on the following:
    - Transcutaneous electrical nerve stimulator
    - Spinal cord stimulator
    - Deep brain stimulator

Citation

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Dr R.S. Khandpur: HANDBOOK OF BIOMEDICAL INSTRUMENTATION, THIRD EDITION. Physiotherapy and Electrotherapy Equipment, Chapter (McGraw-Hill Professional, 2014), AccessEngineering