SPECIFICATION

Pulse rate measurement system

The present invention relates to a pulse rate measurement system and to such a system which finds particular application to a pace timing device for providing audible timing information to enable steps or actions in physical exercises to be performed at a suitable predetermined rate.

At present, there is widespread interest in the use of regular physical exercise as a means of promoting and maintaining bodily and psycological health. Various medical authorities have recommended such exercise as running and jogging, and these have become extremely popular in various countries. Medical science has also discovered in recent years that even persons suffering from cardiac problems can achieve a measure of improvement of the heart functioning, by undertaking such exercise as jogging, if this is done in a carefully predetermined manner. Excessive levels of exercise, however, can have adverse effects upon the body in some cases, particularly in the case of elderly persons. In the case of cardiac sufferers, of course, an excessive level of physical exertion can have dangerous or even fatal results. An excessive level of exercise can consist of, for example, running or jogging at an unsuitably high rate, or of running at a suitable rate but for an excessive period of time, which can also be considered as running for an excessive distance. It has therefore become very desirable to provide some means whereby a person undertaking exercise, or a physician or other person supervising such exercise, can measure the level of exercise, i.e. the rate at which it is performed and the time or distance over which it is performed. Such means should preferably be completely portable, simple to operate, and should provide clear and unambiguous indications. It is clearly desirable, particularly in the case of elderly persons or cardiac patients, to provide some means whereby the pulse rate of the person exercising can be measured during or immediately after the completion of the exercise. It is generally recognized that if the pulse rate remains above a certain level following the completion of exercise, this is an indication that the level of exertion is excessively high for that particular individual.

The present invention provides a pulse rate measurement system which is particularly suitable for use with pace timing devices such as those described in copending application number 7918583, Ser No. 2025093 from which application the present application has been divided. However, the present invention is not restricted to use with such pace timing devices.

According to the present invention, there is provided a pulse rate measurement system comprising:

a light emitting element disposed adjacent to the skin of a user;

circuit means for producing an activation signal comprising a pulse train, for periodically activating said light emitting element, the frequency of said periodic activation being high relative to the average pulse rate of the user;

a photoelectric detection element disposed adjacent to the skin of the user, and adjacent to said light emitting element;

screening means disposed between said light emitting element and said photoelectric detection element for preventing transmission of light between said photoelectric detection element and said light emitting element other than by a path which passes through a part of the body of the user;

circuit means for producing a detection monitor signal for periodically detecting a photoelectric voltage produced as a result of light impinging upon said photo-electric element, said detection monitor signal comprising a train of pulses synchronized with said activation signal in phase and frequency; and

an amplifier circuit periodically activated by said detection monitor signal to detect and amplify said photoelectric voltage, and comprising averaging circuit means for producing an output signal synchronized with the pulse rate of the user.

An embodiment of the present invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Fig. 1 is a block diagram illustrating the basic principles of a pace timing device;

Fig. 2 is a block diagram illustrating the essential sections of a pace timing device;

Fig. 3 is a circuit diagram of a pace timing device based on the block diagram of Fig. 2;

Fig. 4 is a circuit diagram of a pulse rate detection and amplifier system;

Fig. 5 shows a cross-sectional view of a housing incorporating the transmission and reception components of Fig. 4;

Fig. 6 shows the external appearance of a pace timing device which is equipped with the pulse rate measurement system of Figs. 1 and 5; and

Figs. 7 and 8 show the pace timing device of Fig. 6 attached to a user's hand.

Referring now to the drawings, Fig. 1 is a basic block diagram to illustrate the fundamental principles of a pace timing device. Numeral 10 denotes the basic system of the pace timing device, which performs timing, measurement, or other functions. Information for setting various parameters of the system can be entered through some input means 12, by an operator 14. Information which is processed by, or originated by, the basic system 10 is output by some output means 16 to the user of the device 18. Such output can be in the form of audible or visible signals directed to the user. As indicated by the broken lines, the user and the operator can be different, or can be the same person. For example, the operator can be a physician who is supervising physical exercise which is being undertaken by the user 18, or the user 18 can monitor the exercise process by himself. In any

case, a closed-loop man-machine system is established. It is essential to ensure that information can flow freely around this loop, in order to ensure ease of use of the device.

Referring now to Fig. 2, a block diagram is shown of the basic features of a first embodiment of a pace timing device. Numeral 20 denotes setting means, whereby an operator can cause a pace signal generation circuit 22 to generate a periodically repeated pace signal at a desired repetition rate. The pace signal will in general comprise repetitive bursts of a square-wave or sinusoidal signal, having frequency components in the audible range. The pace signal is applied to a drive circuit 24, which provides output signals of suitable amplitude for actuating an acoustic device 26, which thereby generates an audible pace timing signal comprising periodic tone bursts. The user can thereby perform actions of a physical exercise, such as running, jogging, etc., at the rate which is specified by the repetitive tone bursts. Numeral 30 denotes a power source, which will normally be a battery, in the case of a portable pace timing device. An opto-electric display device 28 may also be incorporated, in order to provide a visible display of the frequency of pace signal repetition which has been set. Also required, in some cases, is some switch means whereby the power supply of the device can be cut off in order to reduce unnecessary drain of the battery current. Such switch means may be incorporated in the setting means 20. Setting means 20 also serves to perform such functions as starting and stopping operation of the device, enabling and inhibiting audible generation of a pace signal, setting the repetition rate of the pace signals, adjustment of the tone pitch and timbre of the pace signals, and various other functions.

A specific embodiment of an extremely simple pace setting device, conforming to the block diagram of Fig. 2, is shown in Fig. 3. The embodiment of Fig. 3 utilizes bipolar transistors, and is suitable for either discrete component type construction, or integrated circuit type construction. Numeral 29 denotes a first oscillator circuit, which produces a signal determining the repetition rate of the pace signal. The signal produced by first oscillator circuit 29 will be designated as the first frequency signal. First oscillator circuit 29 comprises a two-stage ring oscillator circuit, and the frequency of oscillation is controlled by means of a variable resistor 13. The first frequency signal is applied through a resistor 19 to the base of a transistor 23 in a second oscillator circuit 21. Power is applied from a battery 30 to the circuit through a switch 8, so that operation can be switched on and off as required. Acoustic device 26 comprises a miniature loudspeaker, which is coupled to the collector of a transistor 25 in second oscillator circuit 21.

The operation of this circuit is as follows. If the voltage applied to resistor 19 from first oscillator circuit 29 is at the low level potential of battery 30 (referred to hereinafter as the L level), then second oscillator circuit 21 oscillates to provide a carrier signal at a relatively high audible frequency, causing an audible tone to be generated by loudspeaker 26. When the voltage applied to resistor 19 from first oscillator circuit 29 is at the high potential of battery 30 (referred to hereinafter as the H level), then a current is passed into the base of transistor 23, causing this transistor to become saturated, thereby inhibiting oscillation by second oscillator circuit 21. Thus, as first oscillator circuit 29 oscillates, operation of second oscillator circuit 21 is periodically enabled and inhibited, so that bursts of tone are generated by miniature loudspeaker 30 with the repetition rate of these tone bursts (i.e. of the pace signal) being determined by the oscillation frequency of first oscillator 29. Resistor 19 coupled to the base of transistor 23 thus serves as a means of modulating the signal produced by second oscillator 21 by the first frequency signal produced by first oscillator 29. The frequency of oscillation of first oscillator 29 can be, for example, of the order of 2 to 3 Hz, while that of second oscillator 21 can be of the order of 4 KHz.

A pace timing device of the form shown in Fig. 3 can be manufactured at very low cost. Discrete components can be utilized throughout if desired. It is also possible to provide all components other than variable resistor 13, loudspeaker 30 and capacitors 15 and 17 of first oscillator 29, on an integrated circuit. Due to the low frequency of operation of first oscillator 29, capacitors 15 and 17 would be too high in value to be accommodated on an integrated circuit chip. However, it is possible to utilize an oscillator circuit of relatively high frequency for first oscillator circuit 29, followed by several stages of frequency division, to provide a suitably low frequency for the first frequency signal. If this is done, then a pace timing device of very low cost can be provided, in which all circuitry is integrated.

A disadvantage of the arrangement shown in Fig. 3 is that the frequency of oscillation of first oscillator circuit 29 varies with changes in supply voltage and in operating temperature, due to changes in the base-emitter forward voltage (V_{be}) of the transistors with temperature. A suitable stabilized power supply for overcoming this problem is described in copending application number 7918583, Ser No. 2025093.

With the embodiment of Fig. 3, information concerning the pace signal repetition frequency can be fed back to the operator or user by means of a graduated dial coupled to variable resistor 13, suitably calibrated to indicate the pace frequency.

Fig. 4 shows the circuit of an embodiment of a pulse rate measurement system which is suitable for use with a pace time setting device. In this system the variation in light transmission through the flesh of the user due to changes in the blood vessels caused by the user's pulse are measured. These changes in the blood vessels cause the amount of light dispersed in passing through the flesh to be varied at a frequency which is identical

to the pulse rate of the user. In order to minimize power consumption by the pulse rate measurement system, measurement is performed on a periodic basis, as will be described. Numeral 640 denoted a light emitting element, consisting of a junction semiconductor device such as a gallium arsenic, gallium phosphor or gallium aluminum diode, which emits light in the range between the visible and the infrared wavelengths. This light emitting element is connected in series with a transistor 660, to the gate of which is applied an activation signal, comprising a train of clock pulses Ck. Each time a positive-going clock pulse Ck is applied to the gate, transistor 660 conducts, causing light to be emitted by element 640. This light passes through a part of the user's flesh or skin, as indicated by numeral 641, and that part of the light which is not dispersed or reflected thereby falls on a photoelectric detection element 642, which is a semiconductor element such as a silicon, germanium or lead sulphid diode, is reverse biased by means of a resistor 644. Changes in the voltage across resistor 644 due to light falling upon detection element 642 are applied through a DC blocking capacitor 646 to the first stage of an amplifier circuit. This is designed such as to be only operative for a short time interval while an activation pulse is being applied to the gate of transistor 660, so that light is being emitted by element 640. It has been found that the duration of the activation pulses which drive transistor 660 should be of the order of 30 microseconds, with a repetition frequency which is substantially higher than the maximum pulse rate to be measured, say, above 10 Hz. Pulses of a detection monitor signal, comprising a train of pulses synchronized with the activation signal pulses, switch the amplifier circuit into an operative condition. These consist of the clock pulses CK, and the inverse, $\overline{Ck}$, which is produced by means of an inverter 647. The first stage of the amplifier is controlled by switching transistors 664 and 648, which are set into the conducting condition when signals Ck and $\overline{Ck}$ to the H level and L level, respectively. The next stage of the amplifier is controlled by switching transistors 650 and 651, which are switched into conduction when signals $\overline{Ck}$ and CK go to the H and L levels respectively. When the second stage is switched off (i.e. transistors 650 and 651 become non-conducting), the output voltage of the second stage is stored as a charge on a small-value capacitor 652. The switching transistors 653 and 654 which control the third stage of the amplifier become conducting when signals go to the L and H levels respectively, and the amplified output from the third stage is stored in capacitor 655 when this stage becomes inoperative. The fourth stage of the amplifier is switched into operation when signals Ck and $\overline{Ck}$ go to the H and L levels respectively. In this way, successive amplifier stages are switched into operation in alternate phases of clock signal Ck, and each amplifier amplifies the voltage of the storage capacitor of the preceding stage. In this way, a very high level of amplification can be obtained with stability and simplicity of design. The outputs of the various stages are summed by means of transistors 658, 659, etc, each of which is connected through a resistor to an averaging amplifier.

The output of the averaging amplifier appears across capacitor 661, as a voltage which varies in synchronism with the pulse rate of the user, and this voltage is taken out through an output amplifier 662. The pulse rate signal thus produced can be measured and displayed in digital form or in analog form, and can also be used to cause an alarm warning to be sounded when a predetermined maximum pulse rate is exceeded, or to cause the user to be warned in some fashion that the rate of exercise is unsuitable.

In particular the pulse rate measurement system can incorporate a circuit for measuring the frequency of the output signal from the summing and averaging amplifier circuit together with an opto-electric display means for displaying the frequency as a pulse rate measurement. Further discussion concerning display of the pulse rate is given in copending application number 7918583.

In order to obtain maximum signal/noise ratio in the circuit of Fig. 4, it is preferable to cause each of the stages of the amplifier to be made operative immediately after light emission by element 640 has begun, and to be cut off before the light emission has ceased. For simplicity of description, means for achieving this are not shown in Fig. 4. The duration for which light emitting element 640 is driven by the clock pulses will depend upon the rise and fall times of the particular type of element employed, and may also depend upon the frequency response of transistor 660 which drives the element. A laser diode, which as a high efficiency, may be used as light emitting element 640.

The range of wavelengths to which the photoelectric detection element 642 is sensitive should be made as close as possible to the range of wavelengths of light emitted by element 640. It is also possible to modulate the light produced by element 640, and to perform demodulation of the received electrical signals in synchronism with this modulation.

To improve the signal/noise ratio by reducing the effects of ambient light changes, an optical filter may be inserted in the light path between elements 640 and 642. Also, either electrical connection (between element 642 and the amplifier circuit) or optical connection by optical fiber (between the user's skin and photoelectric detection element 642) may be employed.

A photoelectric detection element of high response speed is obtained by using a silicon PIN diode, however ordinary silicon or germanium diodes offer the advantage of lower cost. Cadmium sulfide or lead sulfide elements offer high sensitivity, and in the case of lead sulfide this is particularly true at the longer wavelengths of light.

Fig. 5 shows a cross-sectional view of a rate

detection unit 670 for use with a circuit such as that of Fig. 4 to form a pulse rate detection system. A case 671 is provided with openings 682 and 684 in which are fixed light emitting element 640 and photoelectric detection element 642, which are separated by a non-transparent bridge portion 672. Electrical connections to elements 640 and 642 are provided by leads 686 and 688. In use, the top portion of the unit is pressed into the user's skin, so that light can reach photoelectric detection element 642 from light emitting element 640 only by passing through the skin of the user. The degree of light transmission varies periodically, in synchronism with the pulse rate of the user, due to changes in the various blood vessels situated between the light emitting and receiving elements 604 and 642.

Fig. 6 shows the external appearance of a pace timing device which is equipped with a pulse rate measurement system. The circuitry, battery, etc, are contained in a case 678 which contains a display area 674 in which the pulse rate or pace timing frequency is displayed. The case is mounted on the user's wrist by means of a strap 676, which has an extension 672 carrying a ring 671 upon which is mounted the pulse rate detection unit 670 shown in Fig. 5. The device is attached to the user's hand as shown in Fig. 7. In order to bring the pulse rate detection unit 670 fully into contact with the user's skin, the fist is clenched as shown in Fig. 8.

Openings 682 and 684 in pulse rate detection unit 670 may be filled with a transparent substance. Alternatively, either or both of elements 640 and 642 may be accommodated within the body of the pace timing device 674, and connected to the pulse rate detection unit 670 by means of optical fiber.

It has been found that the user can adjust the force applied between the pulse rate detection unit 670 and the skin by the degree of force employed in making a fist, such as to ensure reliable detection of the pulse rate irrespective of the particular bodily characteristics of the user. When this is done, also, external light is shielded from the photoelectric detection element 642, by the construction of case 671 of the pulse rate detection unit.

Claims

1. A pulse rate measurement system comprising:

a light emitting element disposed adjacent to the skin of a user;

circuit means for producing an activation signal comprising a pulse train, for periodically activating said light emitting element, the frequency of said periodic activation being high relative to the average pulse rate of the user;

a photoelectric detection element disposed adjacent to the skin of the user, and adjacent to said light emitting element;

screening means disposed between said light emitting element and said photoelectric detection element for preventing transmission of light between said photoelectric detection element and said light emitting element other than by a path which passes through a part of the body of the user;

circuit means for producing a detection monitor signal for periodically detecting a photoelectric voltage produced as a result of light impinging upon said photo-electric element, said detection monitor signal comprising a train of pulses synchronized with said activation signal in phase and frequency; and

an amplifier circuit periodically activated by said detection monitor signal to detect and amplify said photoelectric voltage, and comprising averaging circuit means for producing an output signal synchronized with the pulse rate of the user.

2. A pulse rate measurement system as claimed in claim 1, wherein said amplifier circuit comprises a plurality of complementary field effect transistor stages, and wherein alternate ones of said transistor stages are activated by detection monitor signals of opposite phase, and further comprising a capacitor equipped at the output of each of said stages for storing a charge while the corresponding stage is in a deactivated condition.

3. A pulse rate measurement system as claimed in claim 2, wherein said amplifier circuit further comprises a summing and averaging amplifier for summing the signals produced by said plurality of complementary field effect transistor stages, and producing a signal comprising a time average of this summed signal.

4. A pulse rate measurement system as claimed in claim 1, wherein each of said activation signal and said detection monitor signals comprises a train of pulses, and wherein the pulse width of said detection monitor signal pulses is less than that of said activation signal pulses.

5. A pulse rate measurement system as claimed in claim 1, wherein said light emitting element and said photoelectric element are mounted upon a ring for fitting around a finger of the user, and wherein said amplifier is wrist-mounted.

6. A pulse rate measurement system as claimed in claim 5, wherein connection between said light emitting element, photo-electric element and said amplifier is performed by means of electric wire leads.

7. A pulse rate measurement system as claimed in claim 5, wherein connection between said amplifier and at least one of said light emitting element and said photoelectric element is performed by means of a flexible optical fiber lead.

8. A pulse rate measurement system as claimed in claim 1, and further comprising circuit means for measuring the frequency of the output signal from said summing and averaging amplifier circuit means, and opto-electric display means for

detection unit 670 for use with a circuit such as that of Fig. 4 to form a pulse rate detection system. A case 671 is provided with openings 682 and 684 in which are fixed light emitting element 640 and photoelectric detection element 642, which are separated by a non-transparent bridge portion 672. Electrical connections to elements 640 and 642 are provided by leads 686 and 688. In use, the top portion of the unit is pressed into the user's skin, so that light can reach photoelectric detection element 642 from light emitting element 640 only by passing through the skin of the user. The degree of light transmission varies periodically, in synchronism with the pulse rate of the user, due to changes in the various blood vessels situated between the light emitting and receiving elements 604 and 642.

Fig. 6 shows the external appearance of a pace timing device which is equipped with a pulse rate measurement system. The circuitry, battery, etc, are contained in a case 678 which contains a display area 674 in which the pulse rate or pace timing frequency is displayed. The case is mounted on the user's wrist by means of a strap 676, which has an extension 672 carrying a ring 671 upon which is mounted the pulse rate detection unit 670 shown in Fig. 5. The device is attached to the user's hand as shown in Fig. 7. In order to bring the pulse rate detection unit 670 fully into contact with the user's skin, the fist is clenched as shown in Fig. 8.

Openings 682 and 684 in pulse rate detection unit 670 may be filled with a transparent substance. Alternatively, either or both of elements 640 and 642 may be accommodated within the body of the pace timing device 674, and connected to the pulse rate detection unit 670 by means of optical fiber.

It has been found that the user can adjust the force applied between the pulse rate detection unit 670 and the skin by the degree of force employed in making a fist, such as to ensure reliable detection of the pulse rate irrespective of the particular bodily characteristics of the user. When this is done, also, external light is shielded from the photoelectric detection element 642, by the construction of case 671 of the pulse rate detection unit.

Claims

1. A pulse rate measurement system comprising:

a light emitting element disposed adjacent to the skin of a user;

circuit means for producing an activation signal comprising a pulse train, for periodically activating said light emitting element, the frequency of said periodic activation being high relative to the average pulse rate of the user;

a photoelectric detection element disposed adjacent to the skin of the user, and adjacent to said light emitting element;

screening means disposed between said light emitting element and said photoelectric detection element for preventing transmission of light between said photoelectric detection element and said light emitting element other than by a path which passes through a part of the body of the user;

circuit means for producing a detection monitor signal for periodically detecting a photoelectric voltage produced as a result of light impinging upon said photo-electric element, said detection monitor signal comprising a train of pulses synchronized with said activation signal in phase and frequency; and

an amplifier circuit periodically activated by said detection monitor signal to detect and amplify said photoelectric voltage, and comprising averaging circuit means for producing an output signal synchronized with the pulse rate of the user.

2. A pulse rate measurement system as claimed in claim 1, wherein said amplifier circuit comprises a plurality of complementary field effect transistor stages, and wherein alternate ones of said transistor stages are activated by detection monitor signals of opposite phase, and further comprising a capacitor equipped at the output of each of said stages for storing a charge while the corresponding stage is in a deactivated condition.

3. A pulse rate measurement system as claimed in claim 2, wherein said amplifier circuit further comprises a summing and averaging amplifier for summing the signals produced by said plurality of complementary field effect transistor stages, and producing a signal comprising a time average of this summed signal.

4. A pulse rate measurement system as claimed in claim 1, wherein each of said activation signal and said detection monitor signals comprises a train of pulses, and wherein the pulse width of said detection monitor signal pulses is less than that of said activation signal pulses.

5. A pulse rate measurement system as claimed in claim 1, wherein said light emitting element and said photoelectric element are mounted upon a ring for fitting around a finger of the user, and wherein said amplifier is wrist-mounted.

6. A pulse rate measurement system as claimed in claim 5, wherein connection between said light emitting element, photo-electric element and said amplifier is performed by means of electric wire leads.

7. A pulse rate measurement system as claimed in claim 5, wherein connection between said amplifier and at least one of said light emitting element and said photoelectric element is performed by means of a flexible optical fiber lead.

8. A pulse rate measurement system as claimed in claim 1, and further comprising circuit means for measuring the frequency of the output signal from said summing and averaging amplifier circuit means, and opto-electric display means for

displaying said frequency as a pulse rate measurement.

9. A pulse rate measurement system substantially as hereinbefore described and as illustrated in the accompanying drawings.

10. A pace timing device having a pulse rate measurement system as claimed in any preceding claim.

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