ABSTRACT: A portable and relatively inconspicuous device for monitoring one's heart rate which is adapted for use by healthy persons engaged in an exercise program as well as by those who have suffered some form of heart disease is disclosed. The device is set to produce an audio null at a particular heart beat rate. The user is notified by the device when his actual heart rate is either greater or less than the set rate. The signals used for this purpose are audio signals, one type indicating that the actual heart rate is lower than it should be and another type signal indicating that it is higher. A null indicates that the actual and set rates coincide.
HEART RATE SENSOR DEVICE

The present invention relates in general to the medical instrument field and more particularly relates to an electronic device for continuously monitoring the heart.

Because heart disease is today the chief killer among adults, much has been written and said concerning cardiovascular health and physical fitness, and the literature contains innumerable references to the virtues and value of a regular exercise program for all classes of people and ages. See, for example, the May 14, 1968 issue of LOOK Magazine, pages 87—93 therein, wherein can be found the article entitled “How Much Jogging Is Good For Your Heart?” Thus, there is a growing body of evidence which indicates that if exercise is carefully regulated and controlled within the capability of the individual, a regular daily period of physical activity can produce a steady improvement in the capacity for work, even in a person who, at the start, is barely able to shuffle along at slow speed without encountering angina pain. The most dramatic work of this kind has been done with people who are recovering from an initial heart attack (coronary occlusion or infarct) and with patients suffering from coro.

At the present time, when an exercise program is prescribed for a typical cardiac patient, the doctor is forced to emphasize caution at the expense of effectiveness of the exercise because the patient will most likely be unsupervised during his exercise period and medical assistance may not readily be available to him should he need it at that time. Accordingly, primarily for these reasons, the most common form of exercise that is prescribed for such patients is “walking” or some light jogging. A further problem that is encountered is that many cardiologists see their rehabilitating patients at relatively infrequent intervals, so that the opportunity to reassess the capacity for work of these individuals and to change their prescription for exercise may present itself only after some weeks or even months. Thus, if the patient is making progress, the exercise that was close to the safety limit and therefore maximally effective in stimulating physiological recovery on the day after the patient’s visit to the doctor becomes progressively less effective with each passing day in that the effort actually expended becomes a smaller and smaller fraction of the maximum obtainable effort short of cardiac pain or damage. If the physician could be assured of his patient’s fitness and safety, he would certainly prefer to have each day’s activity adjusted to that day’s capacity. Stated differently, as the patient’s condition improved, it would be desirable to increase the level of the effort expended by him during the exercise period so that the relative workload would be constant, relative workload being defined as a percentage of the maximum tolerable workload.

On this subject, it is well established that heart rate is a linear function of workload under most ordinary circumstances, with the result that the most common index of effort or cardiovascular strain is the heart rate itself. In this regard, it has recently been confirmed that healthy individuals of very different characteristics relative to fitness for exercise attain the same heart rate at the same proportion of their maximum capacity, and there is no reason to suppose that cardiac patients are substantially different in this respect from healthy men. Thus, a particular workload, such as walking at a fixed speed up a fixed grade, would produce a much higher heart rate in an unfit patient who is suffering from cardiovascular disease or recovering from a heart attack than it would produce in a fit and healthy individual. Similarly, a young athlete would show a much lower heart rate when performing the same work than would the average healthy male or female. At the present time, if one wishes to control the severity of the load imposed by exercise, one may either specify in detail the nature of the activity and the pace at which it is to be carried out, all of which requires a thorough knowledge of the relationship between work and heart rate for various types of activities for each particular individual, or one can specify the heart rate that is to be maintained irrespective of the type of activity. This latter way is the preferred way.

In making a determination of this heart rate so that it can be prescribed for the patient, whether it be in the hospital laboratory or in the doctor’s office, the heart rate is continuously monitored while the workload is increased in small stepwise increments until the level is found where the desired heart rate is obtained. However, if a doctor wishes his patient to have information about his heart rate outside the laboratory or examination room, he must either teach the patient to take his own pulse, which is rather difficult to do even under the best of conditions while working or exercising, or provide him with a cardiotachometer or pulse meter whose meter dial would provide an indication of the heart rate. The basic difficulty with both these approaches is that they demand constant conscious attention and they are awkward to use, thereby making these instruments impractical for “field” use by the patient. It is hard to see, for example, how one can safely ride a bicycle while counting one’s own pulse or while looking at a pulse rate meter.

From what has been said above, it can be seen that a long-felt need has existed for a device that would provide heart rate information in a practical manner. The present invention overcomes the many limitations and problems, some of which have been mentioned herein, associated with these prior art devices and instruments, and, in so doing, it has thereby satisfied this long-felt need. Stated differently, an embodiment of the present invention for the first time provides the doctor and patient with an inconspicuous miniature device that continuously monitors heart rate for the user, and announces or provides a signal only when the rate measured differs from the one that the physician has preselected as the operating level. Embodiments of the present invention can also be used beneficially by healthy persons in their fitness development programs and, in such cases, the trainer or the user himself can select the heart rate level that is to be maintained.

According to the basic idea of the present invention, the EKG wave produced by the heart beat is picked up by a pair of electrodes, usually located on the chest. As is well known, this EKG wave is of a complex nature and includes as a component thereof what is known as the R wave or pulse. In the present invention, this R wave is selectively amplified to a predetermined level, the amplifier R wave then being used to trigger a monostable multivibrator that produces a square wave of a known and fixed duration for each beat of the heart. The duration of the square wave is set equal to the R to R intervals of the prescribed or specified heart rate and what is detected is the interval from the end of one square wave to the onset of the next. This is done by feeding the square wave through a one-way diode to a parallel resistor-capacitor circuit with a short time constant. The capacitor almost immediately discharges to nearly the full value of the square wave and holds this value until the end of the wave. It then starts to discharge through the resistor. But if the next square wave comes along within a short period of time (5 to 10 milliseconds), very little of its charge will have dissipated so that a basically DC voltage equal to the peak amplitude of the multivibrator square wave is developed.

This DC voltage is fed through a high resistance to one side of the diode, the other side being connected to the output of an audio oscillator whose base to peak amplitude just equals this DC voltage. If an earphone is placed on the DC side of the diode, no sound will be heard because even at the peak of the audio signal the amplitude just equals the DC back bias and thus no current can flow. If, now, the heart rate decreases, thereby increasing the time between the end of one square wave and the onset of the next, the above-said storage capacitor discharges further, thereby lowering the DC back bias to momentarily allow some audio signal through the diode. This results in a short “beeping” sound in the earphone at the heart rate. The slower the heart rate, the longer and more pronounced this “beep” becomes. On the other hand, as the heart rate increases toward the set point, the sound again dis-
appears until the rate has increased to the point where the R to R interval is just less than the square wave duration. When this occurs, the second R wave arrives while the multivibrator is still in its transient state and is therefore incapable of being refractored. Accordingly, every other R wave is ignored and a square wave is therefore generated only for every other heart beat. Within just a few heart beats, then, the embodiment goes from the state where the diode bias voltage is an almost pure DC above the audio cutoff level to a point where it drops almost to zero every other heart beat, thereby resulting in a full volume repetitive warning signal. This ability to so sharply discriminate between the selected heart rate and a rate that is either just slightly higher or lower is one of the key features of this invention.

It is, therefore, an object of the present invention to provide a heart rate sensor device that informs the user whenever his heart rate differs from a preselected value.

It is another object of the present invention to provide a heart rate monitoring device that uses an audio signal rather than visual means to indicate heart rate.

It is a further object of the present invention to provide a heart rate measuring device that produces a null (zero output) at the desired heart rate so that the user is not distracted when the heart rate is at the selected value.

It is an additional object of the present invention to provide a detection system wherein the signal of interest is converted to a nearly pure DC voltage only when the signal is at some preselected value and otherwise has a large AC component or falls to zero when the signal characteristics have changed from said value.

It is still another object of the present invention to provide a heart rate measuring device wherein, for each heart beat, a square wave is generated whose duration is set equal to the interval between preselected and desired heart rate and, wherein the interval between successive square waves is used to indicate the deviation of the actual heart beat rate from the preselected rate.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which an embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only and is not intended as a definition of the limits of the invention.

FIG. 1 illustrates the wave produced by a beat of the heart, known in the medical field as the EKG wave; and FIG. 2 is a schematic circuit of a preferred embodiment of the present invention.

For a more detailed understanding of the invention, reference is now made to the drawing and to FIG. 2 therein wherein a circuit diagram of a preferred embodiment of the invention is shown. However, although the overall device is illustrated in schematic circuit form for the purpose of indicating a reduction to practice, a block diagram has been superimposed over the schematics in order to facilitate and expedite the description. More particularly, the FIG. 2 embodiment includes a three-stage RC coupled amplifier 10 whose preferred design is such that it is sharply tuned at 12 c.p.s., nulled at 60 c.p.s., and has an overall gain of 2,000. Amplifier 10 is coupled at its output end to the input of a one-shot multivibrator 11 capable of producing a square wave of variable pulse width. Also included is an RC coupled audio oscillator 12 that is preferably designed to produce a signal of from 1 to 3 kilocycles. Finally, located and coupled between multivibrator 11 and audio oscillator 12 is an annunciator circuit 13 whose function is to let the user of the device audibly know that his heart rate, as detected by the device, differs from that for which the device has been set. Amplifier 10, multivibrator 11, and oscillator 12 are standard-type networks and, therefore, it is not deemed necessary to describe them in any detail. An annunciator circuit 13, on the other hand, does require detailed discussion and this will be provided below. The device is powered by a source of electrical power, such as a battery 14, through a switch 15.

Considering now the annunciator circuit with greater particularity, it includes a resistor 16 and a potentiometer 17 connected in series, this series combination of resistor and potentiometer being connected in parallel with a capacitor 18. One function of this parallel combination of elements is connected to ground, the other junction thereof being connected both to the output of multivibrator 11 and through a fixed resistor 20 to the cathode side of a diode that is generally designated as 21. The anode side of this diode 21 is connected both to the output of audio oscillator 12 and through a fixed resistor 22 to ground, as shown in the figure. As is also shown in the figure, the junction between resistor 20 and diode 21, designated 23, is coupled through a bypass capacitor 24 to one terminal of a pair of terminals 25, the other terminal of the pair being connected directly to ground. In the present invention, an earphone is plugged into terminals 25 so that any audio signals produced by the device may readily be heard by the user. However, since the earphone is not a part of the invention and, furthermore, since it is a standard device that is well known and available in the market place, it is not shown in the drawing.

In operation, the EKG wave produced by the heart is picked up by a pair of body electrodes that are usually located on the chest. As is well known, this EKG wave is of a complex nature and includes a component "spike" or pulse that has come to be designated technically as the "R" wave or pulse. A typical EKG wave is illustrated in FIG. 1 and the R pulse therein, designated 26, is clearly shown. As for the body electrodes, an electrode of the kind that can be used herein is shown and described in the patent issued to R. M. Berman, et al., on Apr. 16, 1963, U.S. Pat. No. 3,085,577, entitled "Body Electrode."

By means of the aforesaid electrodes, each EKG wave produced by the heart is fed to amplifier network 10 wherein the R wave portion thereof is selectively amplified, for example, to a level of 1-3 volts, before being applied to one-shot multivibrator 11. Accordingly, over a period of time, a train of voltage spikes or pulses of suitable magnitude is applied to the multivibrator which, in response thereto, produces or attempts to produce a corresponding train of square wave pulses. These square wave pulses are applied in succession to the parallel resistor-capacitor combination comprising resistor 16, potentiometer 17 and capacitor 18, the result being that the train of square wave pulses is thereby impressed across capacitor 18, the voltage across the capacitor during each pulse being substantially equal to the amplitude of these pulses. As is well known by those skilled in the electronic arts, the capacitor discharges between pulses at a rate determined by the value of fixed resistor 16 and the value of resistance selected for potentiometer 17. In this regard, the potentiometer is adjusted to provide a relatively short time constant, for example about 47 or so milliseconds, so that the voltage across the capacitor might normally decay with some degree of rapidity following each pulse.

It will also be recognized by those skilled in the electronic arts that whatever voltage appears across capacitor 18 is applied through resistor 20 to the cathode of diode 21 so that the diode is biased in reverse voltage. At this point it would be well to mention once again that multivibrator 11 is of the kind whose pulse durations can be manually varied or adjusted. Accordingly, in the present invention, the duration of the square waves are set equal to the R to R interval of the preferred heart rate, that is to say, the heart rate specified or prescribed by the doctor to be attained. When this is done and when the user's heart is actually beating at the specified rate, the end of each square wave pulse is followed by the onset of the next, with the result that the interval between pulses is very short indeed. What this means is that, under such circumstances, capacitor 18 has very little opportunity to discharge between...
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5 pulses. Basically, therefore, a DC voltage substantially equal to the peak amplitude of the multivibrator square waves is applied to the cathode of diode 21 to back bias it.

At the same time, the audio signal output of oscillator 12 is applied to the anode of diode 21. However, if the base to peak amplitude of the oscillator signal is made to just equal this DC voltage on the cathode, and this is what is done, no portion of the audio signal gets through to terminals 25. Consequently, when the actual heart rate equals the prescribed heart rate, no sound is heard by any earphone that may be plugged into terminals 25 and a sound null is obtained. If, now, the user's heart rate should decrease for some reason, thereby increasing the time between the heart's EKG waves and, in turn, increasing the time between the end of one square wave and the onset of the next, capacitor 18 will have time to discharge much further during the interval between pulses. As a consequence, the DC back bias on diode 21 is sufficiently lowered between pulses to momentarily allow some audio signal through the diode during each such interval to produce a series of short "beeping" sounds in the earphone at the user's actual heart rate. The slower the heart rate, the longer and more pronounced this beeping sound becomes, as may be expected.

On the other hand, should the user's heart rate be increased towards the set point, that is to say, toward the prescribed heart rate, the sounds will gradually disappear until the heart rate has once again increased to the point where the R to R interval is just about equal to the square wave duration. At this point, we again have a sound null. If, now, for some reason, the heart rate should increase or rise above the rate for which the device is set, the R to R interval will be less than the duration of a square wave out of the multivibrator. When this situation occurs, the second R wave arrives while the multivibrator is still in its transient state and, therefore, is incapable of being retriggered at that time. As a result, every other R wave is "ignored" and a square wave is generated only with every other heart beat. As a further result, capacitor 18 now has a chance to almost fully discharge between pulses, which means that the audio cutoff level or back bias on diode 31 practically drops to zero during these intervals. Accordingly, when the actual heart rate goes above the prescribed heart rate, a full-volume repetitive warning signal is suddenly produced in the earphone.

It is thus seen that a device according to the present invention has the ability to sharply discriminate between the selected heart rate and a rate that is either slightly lower or higher than it. More particularly, whenever the measured heart rate is slower than the preset rate, a "blip" sound is heard in the earphone that is synchronized with the user's heart beat. When the heart rate is equal to the presel ected value, the earphone is silent. Finally, when the target heart rate is exceeded, an insistent repetitive warning tone is heard in the earphone. This is one of the key features of this invention.

Although a particular arrangement of the invention has been illustrated above by way of example, it is not intended that the invention be limited thereto. Accordingly, the invention should be considered to include any and all modifications, alterations, or equivalent arrangements falling within the scope of the annexed claims.

Having thus described the invention, what we claim is:
1. A heart rate indicating device having a pair of output terminals adapted to provide prescribed audio signals at the pair of output terminals in response to the application of heart pulse signals corresponding to the heart beat rate of a user 65 thereof whenever said heart beat rate differs from a preselected rate, said device comprising:
   a. pulsing means operable in response to heart pulse signals to produce corresponding square wave pulses, said means including variable means for adjusting the duration of said square wave pulses until it is substantially equal to the interval between heart beats at the preselected heart rate;
   an oscillator that continuously generates an audio signal; and
   an annunciator means, coupled between said pulsing means and said oscillator, for respectively receiving the square wave pulses and audio signal therefrom, said annunciator means including means for applying said audio signal to said output terminals during periods intermediate successive square wave pulses whereby a sound null is produced when the user's heart beat rate is substantially equal to the preselected rate, a first distinctive audio signal is produced indicating that the user's heart beat rate is nominally above the preselected rate, and a second distinctive audio signal is produced indicating that the user's heart beat rate is nominally above the preselected rate.
2. The heart rate indicating device defined in claim 1 wherein said pulsing means includes amplifier means adapted to amplify only a selected portion of said heart pulse signals; and a monostable multivibrator coupled to said amplifier means to produce said square wave pulses in response to the amplified heart pulse signals, said variable means being adapted to permit manual variation of the width of said square wave pulses.
3. The heart rate indicating device defined in claim 1 wherein said annunciator means includes a diode having anode and cathode elements, and a biasing circuit that produces a direct-current voltage in response to said square wave pulses, said anode element being connected to said audio oscillator to receive the audio signal therefrom and said cathode element being connected to said biasing circuit to receive the direct-current voltage therefrom, a first of said pair of output terminals being operatively connected between said biasing circuit and said cathode element, a second of said pair of output terminals being maintained at a ground potential.
4. The heart rate indicating device defined in claim 1 wherein said pulsing means includes amplifier means adapted to amplify only a selected portion of said heart pulse signals, and a monostable multivibrator coupled to said amplifier means to produce said square wave pulses in response to the amplified heart pulse signals, said variable means being adapted to permit manual variation of the width of said square wave pulses; and wherein said annunciator means includes a diode having anode and cathode elements, and a biasing circuit that produces a direct-current voltage in response to said train of square wave pulses, said anode element being connected to said audio oscillator to receive the audio signal therefrom and said cathode element being connected to said biasing circuit to receive the direct-current voltage therefrom, a first of said pair of output terminals being operatively connected between said biasing circuit and said diode, a second of said pair of output terminals being adapted to be maintained at a ground potential.
5. The heart rate indicating device defined in claim 3 wherein said biasing circuit includes a resistor and a capacitor connected to smooth the square wave pulses applied to said annunciator means.
6. The heart rate indicating device defined in claim 2 wherein said annunciator means includes a diode having anode and cathode elements, said anode element being connected to said audio oscillator, said pair of output terminals being adapted to be coupled to an audio transducer, one of said pair of output terminals being connected to a ground lead; a capacitor connected between said cathode element and the other of said pair of output terminals; a smoothing network connected between said pulsing means and ground; and a resistor connected between said pulsing means and said cathode element.
7. The heart rate indicating device defined in claim 5 wherein said pulsing means includes amplifier means adapted to amplify only a selected portion of the heart pulse signals produced in response to the heart beat; and a monostable multivibrator coupled between said amplifier means and said annunciator means.